

Automotive Technology

Fourth Edition

Principles, Diagnosis, and Service

NATEF

James D. Halderman

AUTOMOTIVE TECHNOLOGY

Principles, Diagnosis, and Service

FOURTH EDITION

James D. Halderman

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PREFACE

UPDATES TO THE FOURTH EDITION

- Number of chapters increased from 103 to 130.
- Many long chapters were split and content was reorganized to make teaching and learning easier.
- New chapters include:

  Chapter 17 – Preventive Maintenance and Service Procedures

  Chapter 19 – Diesel Engine Operation and Diagnosis

  Chapter 20 – Coolant

  Chapter 22 – Engine Oil

  Chapter 27 – In-Vehicle Engine Service

  Chapter 36 – Gaskets and Sealants

  Chapter 37 – Engine Assembly and Dynamometer Testing

  Chapter 49 – CAN and Network Communications

  Chapter 66 – Gasoline

  Chapter 67 – Alternative Fuels

  Chapter 68 – Diesel and Biodiesel Fuels

  Chapter 79 – Gasoline Direct Injection Systems

  Chapter 80 – Electronic Throttle Control Systems

  Chapter 108 – Electronic Stability Control Systems

  Chapter 110 – Tire Pressure Monitoring Systems

  Chapter 115 – Electronic Suspension Systems

  Chapter 127 – Automatic Transmission/Transaxle Principles

  Chapter 128 – Hydraulic Components and Control Systems

  Chapter 129 – Automatic Transmission/Transaxle Diagnosis and In-Vehicle Service

  Chapter 130 – Automatic Transmission/Transaxle Unit Repair
- Over 300 new color photos and line drawings.
- New design, showing major and minor headings, is clearer and makes it easier to grasp important information.

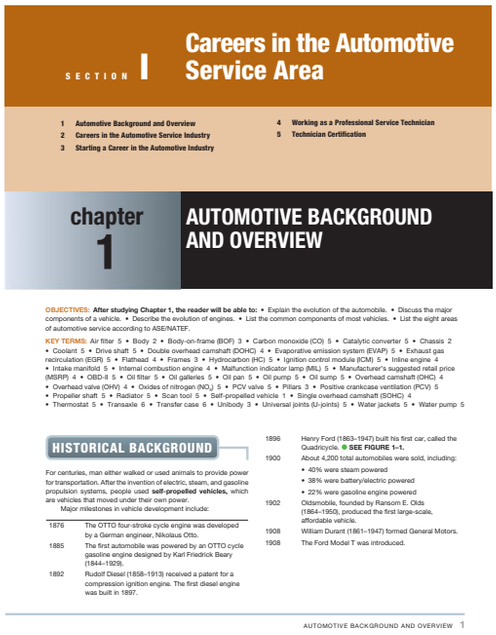
ASE AND NATEF CORRELATED This comprehensive textbook is divided into sections that correspond to the eight areas of certifications as specified by the National Institute for Automotive Service Excellence (ASE) and the National Automotive Technicians Education Foundation (NATEF). The areas of the ASE material certification test are listed in the objectives at the beginning of each chapter, and all laboratory worksheets are correlated to the NATEF Task List.

A COMPLETE INSTRUCTOR AND STUDENT SUPPLEMENT PACKAGE This book is accompanied by a full set of instructor and student supplements. Please see page v for a detailed list of supplements.

A FOCUS ON DIAGNOSIS AND PROBLEM SOLVING The primary focus of this textbook is to satisfy the need for problem diagnosis. Time and again, the author has heard that technicians need more training in diagnostic procedures and skill development. To meet this need and to help illustrate how real problems are solved, diagnostic stories are included throughout. Each new topic covers the parts involved as well as their purpose, function, and operation, and how to test and diagnose each system.

The following pages highlight the unique core features that set this book apart from other automotive textbooks.

IN-TEXT FEATURES



SECTION 1 Careers in the Automotive Service Area

1 Automotive Background and Overview
2 Careers in the Automotive Service Industry
3 Starting a Career in the Automotive Industry
4 Working as a Professional Service Technician
5 Technician Certification

chapter 1 AUTOMOTIVE BACKGROUND AND OVERVIEW

OBJECTIVES: After studying Chapter 1, the reader will be able to: • Explain the evolution of the automobile. • Discuss the major components of a vehicle. • Describe the evolution of engines. • List the common components of most vehicles. • List the eight areas of automotive service according to ASE/NATEF.

KEY TERMS: Air filter 5 • Body 2 • Body-on-frame (BOF) 3 • Carbon monoxide (CO) 5 • Catalytic converter 5 • Chassis 2 • Coolant 5 • Drive shaft 5 • Double overhead camshaft (DOHC) 4 • Evaporative emission system (EVAP) 5 • Exhaust gas recirculation (EGR) 5 • Flathead 4 • Frames 3 • Hydrocarbon (HC) 5 • Ignition control module (ICM) 5 • Inline engine 4 • Intake manifold 5 • Internal combustion engine 4 • Malfunction indicator lamp (MIL) 5 • Manufacturer's suggested retail price (MSRP) 4 • OBD-II 5 • Oil filter 5 • Oil galleries 5 • Oil pan 5 • Oil pump 5 • Oil sump 5 • Overhead camshaft (OHC) 4 • Overhead valve (OHV) 4 • Oxides of nitrogen (NO_x) 5 • PCV valve 5 • Pillars 3 • Positive crankcase ventilation (PCV) 5 • Propeller shaft 5 • Radiator 5 • Scan tool 5 • Self-propelled vehicle 1 • Single overhead camshaft (SOHC) 4 • Thermostat 5 • Transaxle 6 • Transfer case 6 • Unibody 3 • Universal joints (U-joints) 5 • Water jackets 5 • Water pump 5

HISTORICAL BACKGROUND

For centuries, man either walked or used animals to provide power for transportation. After the invention of electric, steam, and gasoline propulsion systems, people used **self-propelled vehicles,** which are vehicles that moved under their own power.

Major milestones in vehicle development include:

1876 The OTTO four-stroke cycle engine was developed by a German engineer, Nikolaus Otto.
1885 The first automobile was powered by an OTTO cycle gasoline engine designed by Karl Friedrick Beary (1844–1929).
1892 Rudolf Diesel (1858–1913) received a patent for a compression ignition engine. The first diesel engine was built in 1897.
1896 Henry Ford (1863–1947) built his first car, called the Quadricycle. SEE FIGURE 1-1.
1900 About 4,200 total automobiles were sold, including:
• 40% were steam powered
• 38% were battery/electric powered
• 22% were gasoline engine powered
1902 Oldsmobile, founded by Ransom E. Olds (1864–1950), produced the first large-scale, affordable vehicle.
1908 William Durant (1861–1947) formed General Motors.
1908 The Ford Model T was introduced.

AUTOMOTIVE BACKGROUND AND OVERVIEW 1

OBJECTIVES AND KEY TERMS appear at the beginning of each chapter to help students and instructors focus on the most important material in each chapter. The chapter objectives are based on specific ASE and NATEF tasks.

TECH TIP

Right to TIghten

Whenever removing any automotive component, it is wise to screw the bolts back into the holes a couple of threads by hand. This ensures that the right bolt will be used in its original location.

TECH TIP feature real-world advice and "tricks of the trade" from ASE-certified master technicians.

SAFETY TIP

Shop Cloth Disposal

Always dispose of oily shop cloths in an enclosed container to prevent a fire. SEE FIGURE 1–69. Whenever oily cloths are thrown together on the floor or workbench, a chemical reaction can occur, which can ignite the cloth even without an open flame. This process of ignition without an open flame is called **spontaneous combustion**.

SAFETY TIPS alert students to possible hazards on the job and how to avoid them.

REAL WORLD FIX

Lightning Damage

A radio failed to work in a vehicle that was outside during a thunderstorm. The technician checked the fuses and verified that power was reaching the radio. Then the technician noticed the antenna. It had been struck by lightning. Obviously, the high voltage from the lightning strike traveled to the radio receiver and damaged the circuits. Both the radio and the antenna were replaced to correct the problem. SEE FIGURE 26–26.

REAL WORLD FIXES present students with actual automotive service scenarios and show how these common (and sometimes uncommon) problems were diagnosed and repaired.

FREQUENTLY ASKED QUESTION

What Is an "SST?"

Vehicle manufacturers often specify a **special service tool (SST)** to properly disassemble and assemble components, such as transmissions and other components. These tools are also called special tools and are available from the vehicle manufacturer or their tool supplier, such as Kent-Moore and Miller tools.

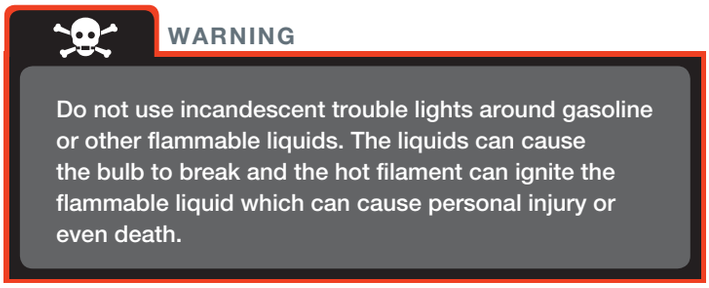
FREQUENTLY ASKED QUESTIONS are based on the author's own experience and provide answers to many of the most common questions asked by students and beginning service technicians.

NOTE: Most of these "locking nuts" are grouped together and are commonly referred to as *revailing torque nuts.* This means that the nut will hold its tightness or torque and not loosen with movement or vibration.

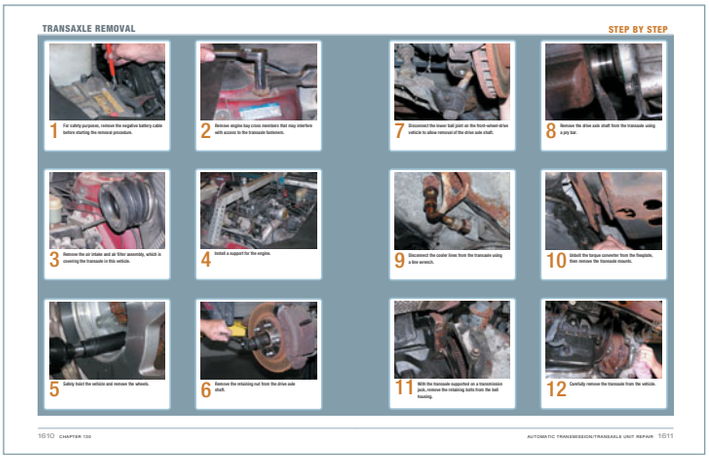
NOTES provide students with additional technical information to give them a greater understanding of a specific task or procedure.

CAUTION: Never use hardware store (nongraded) bolts, studs, or nuts on any vehicle steering, suspension, or brake component. Always use the exact size and grade of hardware that is specified and used by the vehicle manufacturer.

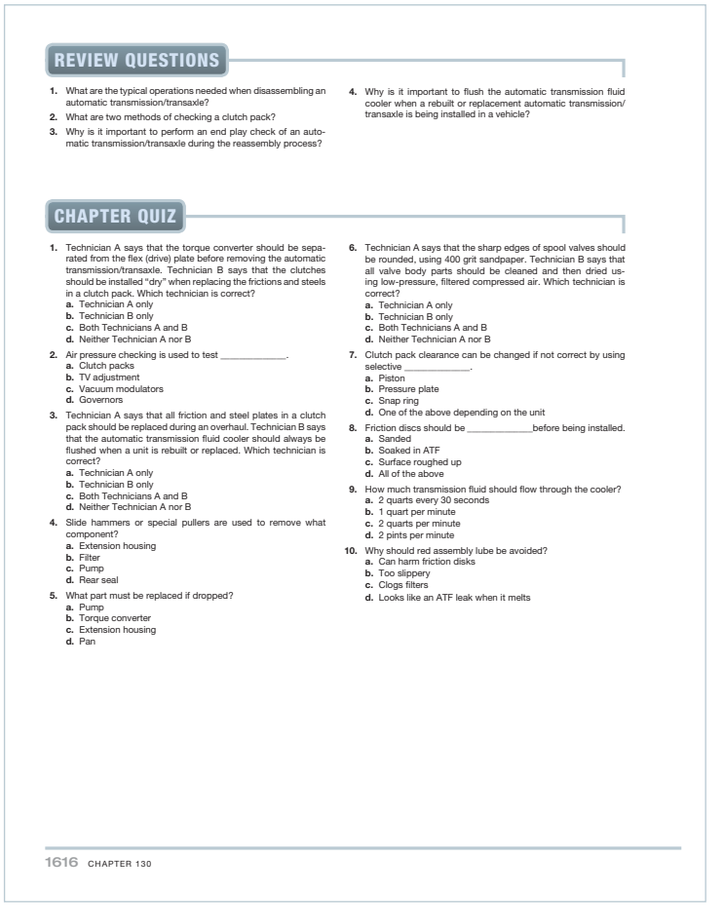
CAUTIONS alert students about potential damage to the vehicle that can occur during a specific task or service procedure.



WARNINGS alert students to potential dangers to themselves during a specific task or service procedure.



STEP-BY-STEP photo sequences show in detail the steps involved in performing a specific task or service procedure.



THE REVIEW QUESTIONS AND CHAPTER QUIZ at the end of each chapter help students review the material presented in the chapter and test themselves to see how much they've learned.

SUPPLEMENTS

INSTRUCTOR SUPPLEMENTS The instructor supplement package has been completely revamped to reflect the needs of today's instructors. The **Annotated Instructor's Guide (ISBN: 0-13-255157-8)** is the cornerstone of the package and includes:

- Chapter openers that list:
  - — NATEF/ASE tasks covered in the chapter
  - — All key terms
  - — All chapter objectives
- The entire text (matching page numbers with student edition) with margin notes. These notes include:
  - — Tips for in-class demonstrations
  - — Suggested hands-on activities
  - — Cross-curricular activities
  - — Internet search tips
  - — Assessments
  - — Safety Tips
  - — Classroom discussion questions
- A guide to using MyAutomotiveLab in the course

Also included in the instructor supplement package are:

- PowerPoint presentations
- Image Library containing every image in the book for use in class or customized PowerPoints
- TestGen software and test bank
- Chapter Quizzes
- Chapter Review Questions
- English and Spanish glossary
- NATEF Correlated Task Sheets
- NATEF/ASE Correlation Charts

To access supplementary materials online, instructors need to request an instructor access code. Go to www.pearsonhighered.com/irc to register for an instructor access code. Within 48 hours of registering, you will receive a confirming e-mail including an instructor access code. Once you have received your code, locate your text in the online catalog and click on the Instructor Resources button on the left side of the catalog product page. Select a supplement, and a login page will appear. Once you have logged in, you can access instructor material for all Prentice Hall textbooks. If you have any difficulties accessing the site or downloading a supplement, please contact Customer Service at http://247.prenhall.com.

STUDENT SUPPLEMENTS Today's student has more access to the Internet than ever, so all supplemental materials are downloadable at the following site for no additional charge: www.pearsoned.com/autostudent

On the site, students will find:

- PowerPoint presentations
- Chapter review questions and quizzes
- English and Spanish glossary
- A full Spanish translation of the text

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—James D. Halderman

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Jim is the author of many automotive textbooks all published by Pearson Prentice Hall Publishing Company.

Jim has presented numerous technical seminars to national audiences including the California Automotive Teachers (CAT) and the Illinois College Automotive Instructor Association (ICAIA) as well as a member and presenter at the North American Council of Automotive Teachers (NACAT). Jim was also named Regional Teacher of the Year by General Motors Corporation and outstanding alumni of Ohio Northern University.

Jim and his wife, Michelle, live in Dayton, Ohio. They have two children.

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BRIEF CONTENTS

SECTION I Careers in the Automotive Service Area 1

chapter 1 Automotive Background and Overview 1

chapter 2 Careers in the Automotive Service Industry 8

chapter 3 Starting a Career in the Automotive Industry 16

chapter 4 Working as a Professional Service Technician 24

chapter 5 Technician Certification 34

SECTION II Safety, Environmental, and Health Concerns 41

chapter 6 Shop Safety 41

chapter 7 Environmental and Hazardous Materials 48

SECTION III Tools, Shop Equipment, and Measuring 57

chapter 8 Fasteners and Thread Repair 57

chapter 9 Hand Tools 68

chapter 10 Power Tools and Shop Equipment 82

chapter 11 Vehicle Lifting and Hoisting 91

chapter 12 Measuring Systems and Tools 97

SECTION IV Principles, Math, and Calculations 105

chapter 13 Scientific Principles and Materials 105

chapter 14 Math, Charts, and Calculations 114

SECTION V Vehicle Service Information, Identification, and Routine Maintenance 119

chapter 15 Service Information 119

chapter 16 Vehicle Identification and Emission Ratings 125

chapter 17 Preventative Maintenance and Service Procedures 130

SECTION VI Engine Repair 146

chapter 18 Gasoline Engine Operation, Parts, and Specifications 146

chapter 19 Diesel Engine Operation and Diagnosis 158

chapter 20 Coolant 175

chapter 21 Cooling System Operation and Diagnosis 182

chapter 22 Engine Oil 198

chapter 23 Lubrication System Operation and Diagnosis 210

chapter 24 Intake and Exhaust Systems 219

chapter 25 Turbocharging and Supercharging 227

chapter 26 Engine Condition Diagnosis 237

chapter 27 In-Vehicle Engine Service 252

chapter 28 Engine Removal and Disassembly 261

chapter 29 Engine Cleaning and Crack Detection 272
chapter 30 Cylinder Head and Valve Guide Service 280
chapter 31 Valve and Seat Service 293
chapter 32 Camshafts and Valve Trains 314
chapter 33 Pistons, Rings, and Connecting Rods 336
chapter 34 Engine Blocks 351
chapter 35 Crankshafts, Balance Shafts, and Bearings 364
chapter 36 Gaskets and Sealants 381
chapter 37 Engine Assembly and Dynamometer Testing 388
chapter 38 Engine Installation and Break-in 415
SECTION VII Electrical and Electronic Systems 420
chapter 39 Electrical Fundamentals 420
chapter 40 Electrical Circuits and Ohm's Law 428
chapter 41 Series, Parallel, and Series-Parallel Circuits 434
chapter 42 Circuit Testers and Digital Meters 444
chapter 43 Oscilloscopes and Graphing Multimeters 460
chapter 44 Automotive Wiring and Wire Repair 467
chapter 45 Wiring Schematics and Circuit Testing 479
chapter 46 Capacitance and Capacitors 493
chapter 47 Magnetism and Electromagnetism 498
chapter 48 Electronic Fundamentals 509
chapter 49 CAN and Network Communications 524
chapter 50 Batteries 538
chapter 51 Battery Testing and Service 544
chapter 52 Cranking System 556
chapter 53 Cranking System Diagnosis and Service 566
chapter 54 Charging System 577
chapter 55 Charging System Diagnosis and Service 587
chapter 56 Lighting and Signaling Circuits 604
chapter 57 Driver Information and Navigation Systems 625
chapter 58 Horn, Wiper, and Blower Motor Circuits 646
chapter 59 Accessory Circuits 657
chapter 60 Airbags and Pretensioner Circuits 686
chapter 61 Audio System Operation and Diagnosis 698
SECTION VIII Heating and Air Conditioning 712
chapter 62 Heating and Air-Conditioning Components and Operation 712
chapter 63 Automatic Air-Conditioning System Operation 731

chapter 64 Heating and Air-Conditioning System Diagnosis 737
chapter 65 Heating and Air-Conditioning System Service 745
SECTION IX Engine Performance 754
chapter 66 Gasoline 754
chapter 67 Alternative Fuels 766
chapter 68 Diesel and Biodiesel Fuels 777
chapter 69 Ignition System Components and Operation 781
chapter 70 Ignition System Diagnosis and Service 794
chapter 71 Computer Fundamentals 812
chapter 72 Temperature Sensors 819
chapter 73 Throttle Position (TP) Sensors 828
chapter 74 MAP/BARO Sensors 832
chapter 75 Mass Air Flow Sensors 840
chapter 76 Oxygen Sensors 845
chapter 77 Fuel Pumps, Lines, and Filters 860
chapter 78 Fuel-Injection Components and Operation 875
chapter 79 Gasoline Direct-Injection Systems 887
chapter 80 Electronic Throttle Control System 892
chapter 81 Fuel-Injection System Diagnosis and Service 900
chapter 82 Vehicle Emission Standards and Testing 918
chapter 83 Evaporative Emission Control Systems 927
chapter 84 Exhaust Gas Recirculation Systems 935
chapter 85 Positive Crankcase Ventilation and Secondary Air-Injection Systems 942
chapter 86 Catalytic Converters 948
chapter 87 OnBoard Diagnosis 957
chapter 88 Scan Tools and Engine Performance Diagnosis 965
SECTION X Hybrid and Fuel Cell Vehicles 983
chapter 89 Introduction to Hybrid Vehicles 983
chapter 90 Hybrid Safety and Service Procedures 991
chapter 91 Fuel Cells and Advanced Technologies 1002
SECTION XI Brakes 1015
chapter 92 Braking System Components and Performance Standards 1015
chapter 93 Braking System Principles 1021
chapter 94 Brake Hydraulic Systems 1027
chapter 95 Hydraulic Valves and Switches 1040
chapter 96 Brake Fluid and Lines 1050
chapter 97 Brake Bleeding Methods and Procedures 1061

chapter 98 Wheel Bearings and Service 1070
chapter 99 Drum Brakes 1087
chapter 100 Drum Brake Diagnosis and Service 1101
chapter 101 Disc Brakes 1114
chapter 102 Disc Brakes Diagnosis and Service 1128
chapter 103 Parking Brake Operation, Diagnosis, and Service 1145
chapter 104 Machining Brake Drums and Rotors 1157
chapter 105 Power Brake Unit Operation, Diagnosis, and Service 1195
chapter 106 ABS Components and Operation 1208
chapter 107 ABS Diagnosis and Service 1220
chapter 108 Electronic Stability Control Systems 1232

SECTION XII Suspension and Steering 1239

chapter 109 Tires and Wheels 1239
chapter 110 Tire Pressure Monitoring Systems 1261
chapter 111 Tire and Wheel Service 1270
chapter 112 Suspension System Principles and Components 1288
chapter 113 Front Suspensions and Service 1311
chapter 114 Rear Suspensions and Service 1335
chapter 115 Electronic Suspension Systems 1343
chapter 116 Steering Columns and Gears 1358
chapter 117 Steering Linkage and Service 1372
chapter 118 Power-Assisted Steering Operation and Service 1388
chapter 119 Wheel Alignment Principles 1413
chapter 120 Alignment Diagnosis and Service 1427

SECTION XIII Manual Drive train and Axles 1454

chapter 121 Clutches 1454
chapter 122 Manual Transmissions/Transaxles 1471
chapter 123 Drive Axle Shafts and CV Joints 1494
chapter 124 Drive Axle Shafts and CV Joint Service 1503
chapter 125 Differentials 1516
chapter 126 Four-Wheel-Drive and All-Wheel Drive 1534

SECTION XIV Automatic Transmissions and Transaxles 1551

chapter 127 Automatic Transmission/Transaxle Principles 1551
chapter 128 Hydraulic Components and Control Systems 1567
chapter 129 Automatic Transmission/Transaxle Diagnosis and In-Vehicle Service 1586
chapter 130 Automatic Transmission/Transaxle Unit Repair 1598

Index 1617

SECTION I

Careers in the Automotive Service Area

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chapter 1

AUTOMOTIVE BACKGROUND AND OVERVIEW

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HISTORICAL BACKGROUND

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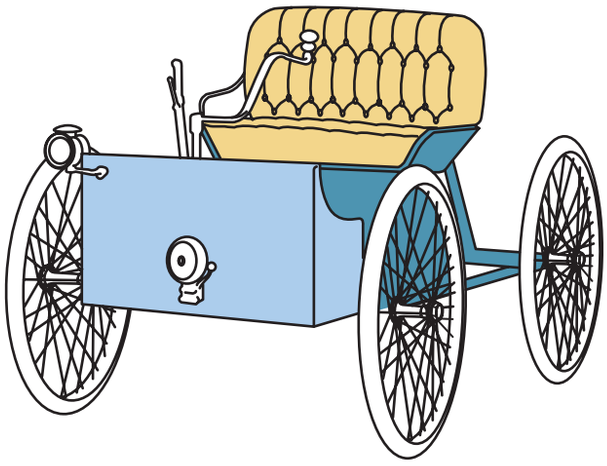


FIGURE 1–1 A Ford Quadricycle built by Henry Ford.



FIGURE 1–2 Most vehicle bodies were constructed with a wood framework until the 1920s.

1912	The electric starter was invented by Charles F. Kettering (1876–1958) of Dayton, Ohio, first used on a Cadillac. The starter was produced by a new company called Delco, which stood for Dayton Electric Laboratories Company.
1914	First car with a 100% steel body was made by the Budd Corporation for Dodge. Before 1914, all car bodies had wood components in them.
1922	The first vehicle to have four-wheel hydraulically operated brakes was a Duesenberg built in Indianapolis, Indiana.
1940	The first fully automatic transmission was introduced by Oldsmobile.
1973	Airbags were offered as an option on some General Motors vehicles.
1985	Lincoln offers the first four-wheel antilock braking system.
1997	The first vehicle with electronic stability control was offered by Cadillac.

BODIES

Early motor vehicles evolved from horse-drawn carriages. The engine and power train were attached to a modified carriage leading to the term "horseless carriage". ● **SEE FIGURE 1–2.**

The bodies evolved until in the 1930s, all-steel-enclosed bodies became the most used type. All bodies depended on a frame of wood or steel to support the chassis components.

CHASSIS SYSTEMS OVERVIEW

The **chassis** system of the vehicle includes the following components:

1. Frame or **body** of the vehicle, which is used to provide the support for the suspension and steering components as well as the powertrain.
2. The suspension system of the vehicle, which provides a smooth ride to the driver and passengers and helps the tires remain on the road even when the vehicle is traveling over rough roads. The suspension system includes springs and control arms which allow the wheel to move up and down and keep the tires on the road.



FIGURE 1–3 A chassis of a 1950s era vehicle showing the engine, drivetrain, frame, and suspension.

3. The braking system of the vehicle is used to slow and stop the rotation of the wheels, which in turn stops the vehicle. The braking system includes the brake pedal, master cylinder, plus wheel brakes to each wheel. Two types of wheel brakes are used. Disc brakes include a caliper, which applies force to brake pads on both sides of a rotating disc or rotor. Drum brakes use brake shoes which are applied by hydraulic pressure outward against a rotating brake drum. The brake drum is attached to and stops the rotation of the wheels. Drum brakes are often used on the rear of most vehicles.
4. Wheels and tires—The wheels are attached to the bearing hubs on the axles. The tires must provide traction for accelerating, braking, and cornering, as well as provide a comfortable ride. Wheels are constructed of steel or aluminum alloy and mount to the hubs of the vehicle using lug nuts, which must be tightened correctly to the proper torque.

The chassis components include:

- Front and rear suspension
- Axles and hubs (to support the wheels and tires)
- Steering mechanism
- Engine and transmission
- Final drive differential and axles

Often, these chassis were so complete that they could be driven without a body. ● **FIGURE 1–3.**

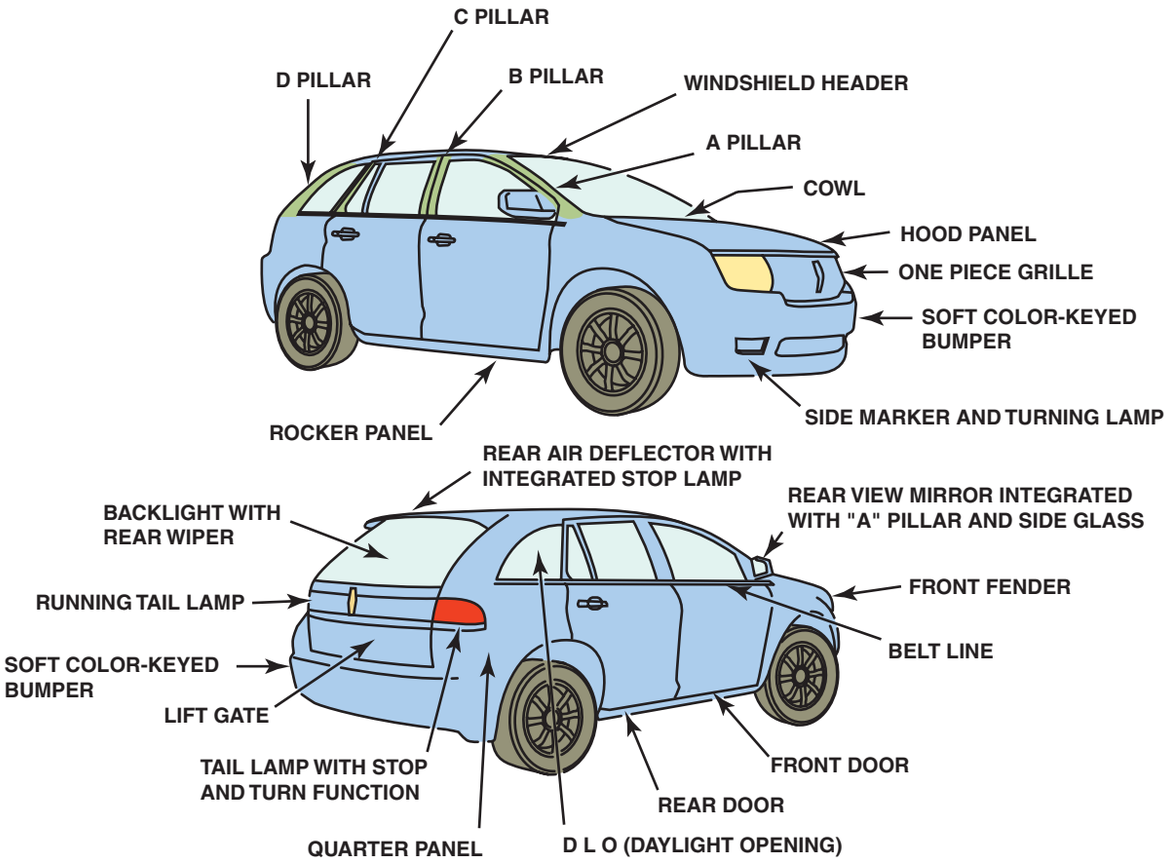


FIGURE 1–4 Body and terms.

Many of the expensive automakers in the 1920s and 1930s had bodies built by another company. Eventually, most bodies were constructed of steel and many without the need for a frame to support the drivetrain and suspension.

BODY TERMS The roof of a vehicle is supported by **pillars** and they are labeled A, B, C, and D from the front to the rear of the vehicle. All vehicles have an A pillar at the windshield but many, such as a hardtop, do not have a B pillar. Station wagons and sport utility vehicles (SUVs) often have a D pillar at the rear of the vehicle. ● **SEE FIGURE 1–4.**

FRAMES

Frame construction usually consists of channel-shaped steel beams welded and/or fastened together. Vehicles with a separate frame and body are usually called **body-on-frame** vehicles (**BOF**). Many terms are used to label or describe the frame of a vehicle including:

UNIT-BODY CONSTRUCTION Unit-body construction (sometimes called **unibody**) is a design that combines the body with the structure of the frame. The body is composed of many individual stamped-steel panels welded together. The strength of this type of construction lies in the *shape* of the assembly. The typical vehicle uses 300 separate stamped-steel panels that are spot-welded together to form a vehicle's body. ● **SEE FIGURE 1–5.**

NOTE: A typical vehicle contains about 10,000 separate individual parts.

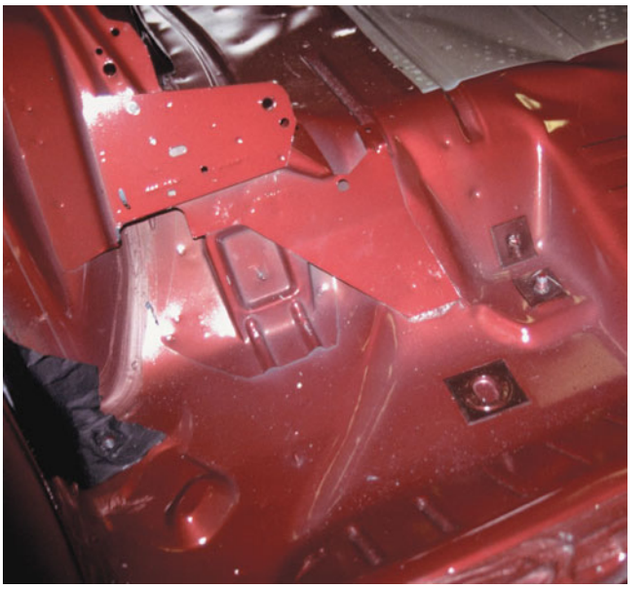


FIGURE 1–5 Note the ribbing and the many different pieces of sheet metal used in the construction of this body.

TECH TIP

Treat a Vehicle Body with Respect

Do not sit on a vehicle. The metal can easily be distorted, which could cost hundreds of dollars to repair. This includes sitting on the hood, roof, and deck (trunk) lid, as well as fenders. Also, do not hang on any opened door as this can distort the hinge area causing the door not to close properly.



FIGURE 1–6 A Corvette without the body. Notice that the vehicle is complete enough to be driven. This photo was taken at the Corvette Museum in Bowling Green, Kentucky.



FIGURE 1–7 A Ford flathead V-8 engine. This engine design was used by Ford Motor Company from 1932 through 1953. In a flathead design, the valves located next to (beside) the cylinders.

SPACE-FRAME CONSTRUCTION Space-frame construction consists of formed sheet steel used to construct a framework of the entire vehicle. The vehicle is drivable without the body, which uses plastic or steel panels to cover the steel framework. ● **SEE FIGURE 1–6.**

ENGINE DESIGN EVOLUTION

All gasoline and diesel engines are called **internal combustion engines** and were designed to compress an ignitable mixture. This mixture was ignited by using a spark (gasoline) or by heat of compression (diesel). Early engines used valves that were in the engine block, which also contained the round cylinders where pistons were fitted. The pistons are connected to a crankshaft, which converts the up and down motion of the pistons to a rotary force which is used to propel the vehicle.



FIGURE 1–8 A Monroney label as shown on the side window of a new vehicle.

? **FREQUENTLY ASKED QUESTION**

What Is the Monroney Label?

The Monroney label is the sticker on the vehicle that lists the **manufacturer's suggested retail price,** usually abbreviated **MSRP.** The law that requires this label on all vehicles is called the Monroney Law, named for the congressman who sponsored the bill, Almer S. Monroney (1902–1980), a U.S. farm representative from Oklahoma from 1939–1951 and a U.S. Senator from 1951 to 1969.

Before the Monroney label law was passed in 1958, the price of a vehicle was unknown to new vehicle buyers who had to rely on the dealer for pricing. Besides all of the standard and optional equipment on the vehicle, the Monroney label also includes fuel economy and exhaust emission information. ● **SEE FIGURE 1–8.**

INLINE VERSUS V-TYPE DESIGN Most early engines used four or six cylinders arranged inline. These were called **inline engines** and are still produced today. Some engines with 4, 6, 8, 10, 12, or 16 cylinders were arranged with half of the cylinders on each set of a "V" and connected to a common crankshaft in the bottom of the "V." The crankshaft changed the up-and-down motion of the piston to rotary motion, allowing the engine to power the drive wheels.

VALVE LOCATION DESIGN The design where the valves were located in the engine block is called **flathead** design because the cylinder head simply covered the combustion chamber and included a hole for the spark plug. The engine block contains passages for coolant as well as lubricating oil and is the support for all other engine systems. ● **SEE FIGURE 1–7.**

By the 1950s, most engine designs placed the valves in the cylinder head. This is called an **overhead valve** or **OHV** design.

Even newer engine designs feature **overhead camshafts (OHC),** called **single overhead camshaft (SOHC)** designs and engines that use two overhead camshafts per bank of cylinders called **double overhead camshaft (DOHC)** designs. The placement of the camshaft, which results in better flow of intake air into and exhaust out of the engine.

The need for reduced emissions and greater fuel economy led to advances in engine design. These changes included:

- Electronic ignition systems
- Electronic fuel injection
- Computerized engine controls
- Emission control devices, including the catalytic converter used in the exhaust system to reduce emissions
- Improved engine oils that help reduce friction and reduce emissions

ENGINE SYSTEMS OVERVIEW

Every engine requires many systems to function correctly.

COOLING SYSTEM While some older engines were air cooled, all engines currently in production are liquid cooled. Coolant is circulated by a **water pump** through passages in the cylinder block and head called **water jackets.** The **coolant** is a mixture of antifreeze and water to provide corrosion and freezing protection. After the coolant picks up the heat from the engine, it flows through a **radiator,** which cools the coolant by releasing the heat into the air. The temperature of the coolant is maintained by using a **thermostat** located in the coolant passage, which opens to allow coolant to flow to the radiator or closes until the coolant is hot enough to need cooling.

LUBRICATION SYSTEM All engines need a supply of lubricating oil to reduce friction and help to cool the engine. Most engines are equipped with an **oil pan,** also called an **oil sump,** containing 3 to 7 quarts (liters) of oil. An engine driven **oil pump** forces the oil under pressure through an **oil filter,** then to passages in the block and head called **oil galleries,** and then to all of the moving parts.

AIR INTAKE SYSTEM All engines, both gasoline and diesel engines, draw air from the atmosphere. It requires about 9,000 gallons of air for each gallon of gasoline used. The air must be drawn where deep water in the road cannot be drawn into the engine. The air is then filtered by a replaceable **air filter.** After the air is filtered, it passes through a throttle valve and then into the engine through an **intake manifold.**

FUEL SYSTEM The fuel system includes the following components and systems:

- Fuel tank
- Fuel lines and filter(s)
- Fuel injectors
- Electronic control of the fuel pump and fuel injection

The fuel injectors are designed to atomize the liquid gasoline into small droplets so they can be mixed with the air entering the engine. This mixture of fuel and air is then ignited by the spark plug.

STARTING AND CHARGING SYSTEM Engine starting and charging systems, which include the battery, starting (cranking) system and charging system components and circuits.

IGNITION SYSTEM The ignition system includes the ignition coil(s) which creates a high voltage spark by stepping up battery voltage using an **ignition control module (ICM).** The arc across the electrodes of the spark plug ignites the air-fuel mixture in the combustion chamber and the resulting pressure pushes the piston down on the power stroke.

EMISSION CONTROL SYSTEM The control of vehicle emissions includes controlling gasoline vapors from being released into the atmosphere in addition to reducing the emissions from the exhaust. Unburned gasoline emissions are called **hydrocarbon (HC)** emissions and exhaust gases that are controlled include **carbon monoxide (CO)** and **oxides of nitrogen (NO_X).** The **evaporative emission control system,** usually called the **EVAP system,** is designed to prevent gasoline fumes and vapors from being released. Other emission control systems include:

- **Positive crankcase ventilation (PCV).** This system uses a valve called a **PCV valve** to regulate the flow of gases created in the crankcase of a running engine, which are routed back into the intake manifold. The engine will then draw these gases into the combustion chamber where they are burned to help prevent the release of the gases into the atmosphere.
- **Exhaust gas recirculation (EGR).** The EGR system meters about 3% to 7% of the exhaust gases back into the intake where the gases reduce the peak combustion temperature and prevent the oxygen (O_2) and nitrogen (NO) from the air from combining to form oxides of nitrogen.
- **Catalytic converter.** The catalytic converter is a unit located in the exhaust system usually close to the engine, which causes chemical changes in the exhaust gases.
- On-board diagnostics means that the engine as well as the engine management systems can test itself for proper operation and alert the driver if a fault is detected. The warning lamp is called the **malfunction indicator light (MIL)** and is labeled “Check Engine” or “Service Engine Soon.” The on-board diagnostic system is currently in the second generation and is called **OBD-II.** Electronic hand-held testers, called **scan tools,** are needed to access (retrieve) stored diagnostic trouble codes (DTCs) and view sensor and system data.

POWERTRAIN OVERVIEW

The purpose of the powertrain is to transfer the torque output of the engine to the drive wheels.

REAR-WHEEL-DRIVE POWERTRAIN A rear-wheel-drive vehicle uses the following components to transfer engine torque to the rear drive wheels:

- **Transmission.** An automatic transmission usually uses planetary gearsets and electronic controls to change gear ratios. In a manually shifted transmission, the drivetrain contains a clutch assembly, which allows the driver to disengage engine torque from the transmission to allow the driver to shift from one gear ratio to another. The transmission contains gears and other assemblies that provide high torque output at low speeds for acceleration and lower torque output but at higher speeds for maximum fuel economy at highway speeds.
- **Drive Shaft.** A **drive shaft,** also called a **propeller shaft,** is used to connect and transmit engine torque from the transmission to the rear differential. **Universal joints (U-joints)** are used to allow the rear differential to move up and down on the rear suspension and still be able to transmit engine torque.



FIGURE 1–9 A dash control panel used by the driver to control the four-wheel-drive system.



FIGURE 1–10 The alternator is in the heart of the electrical system.

- **Differential.** A differential is used at the rear of the vehicle and performs three functions:
  - Allows different axle speeds for cornering.
  - The differential increases the torque applied to the rear drive wheels by reducing the speed.
  - The differential also changes the direction of the applied engine torque and uses axle shafts to transfer the torque to the drive wheels.

FRONT-WHEEL-DRIVE POWERTRAIN A front-wheel-drive vehicle uses a **transaxle,** which is a combination of a transmission and differential in one assembly. Drive axle shafts then transfer the engine torque to the front drive wheels from the output of the transaxle.

FOUR-WHEEL-DRIVE SYSTEM There are many types of methods of powering all four wheels. Many include a **transfer case** to split engine torque to both the front and the rear wheels. ● **SEE FIGURE 1–9.**

ELECTRICAL/ELECTRONIC SYSTEMS OVERVIEW

Early vehicles did not have an electrical system because even the ignition did not require a battery. Early engines used a magneto to create a spark instead of using electrical power from a battery as used today.

The first electrical components on vehicles were battery-powered lights, not only for the driver to see the road, but also so others could see an approaching vehicle at night.

Only after 1912 and the invention of the self-starter did the use of a battery become commonplace. Charles F. Kettering also invented the point-type ignition system about the same time as the self-starter. Therefore, the early batteries were often referred to as SLI batteries meaning starting, lighting, and ignition. From the 1920s into the 1950s other electrical components were added, such as radios, defroster fans, and horns. It was not until the 1960s that electrical accessories, such as air conditioning, power seats, and power windows, became common.

Today's vehicles require alternators that are capable of producing a higher amount of electricity than was needed in the past, and the number of electronic components has grown to include every system in the vehicle, including:

- A tire pressure monitoring system for the tires
- Heated and cooled seats
- Automatic climate control
- Power windows
- Security systems
- Electric power steering
- Electronic suspension

● **SEE FIGURE 1–10.**

HEATING, VENTILATION, AND AIR CONDITIONING OVERVIEW

Early model vehicles did not include any heaters or other methods to provide comfort for the driver and passengers. Most early vehicles were open with a simple removable top. Some had optional side curtains that provided all-weather protection. In the 1930s and 1940s when fully enclosed bodies became common, the vehicle manufacturers started to include heaters, which were small radiators with engine coolant flowing through them. About the same time and into the 1950s, about the only options that many vehicles had were a radio and heater, abbreviated R & H.

Today, air-conditioning systems are on most vehicles and incorporate defrosters and passenger compartment heating, often in two zones for maximum comfort of the driver and passenger. Additional related comfort options today include heated and cooled seats and heated steering wheels.

EIGHT AREAS OF AUTOMOTIVE SERVICE

In 1972, the National Institute for Automotive Service Excellence, a non-profit organization known as simply ASE, created a series of eight tests that cover the major vehicle systems. ● **SEE FIGURE 1–11.**

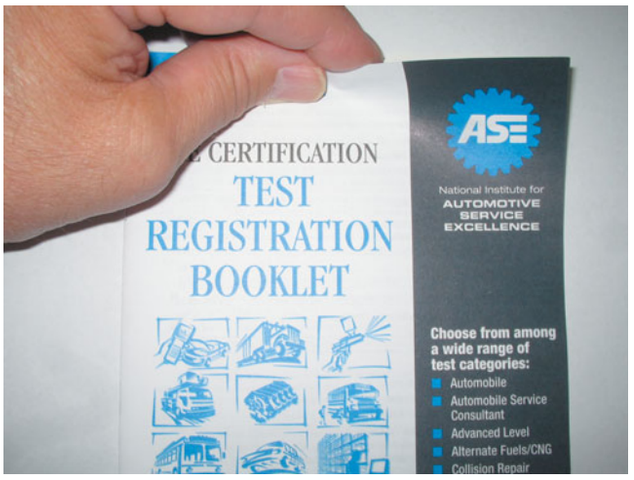


FIGURE 1–11 Test registration booklet that includes details on all vehicle-related certification tests given by ASE.

ENGINE REPAIR (A1) This content area includes questions related to engine block and cylinder head diagnosis and service, as well as the lubrication, cooling, fuel, ignition, and exhaust systems inspection and service.

AUTOMATIC TRANSMISSION (A2) This content area includes general automatic transmission/transaxle diagnosis, including hydraulic and electronic related systems.

MANUAL DRIVE TRAIN AND AXLES (A3) This content area includes clutch diagnosis and repair, manual transmission diagnosis and repair, as well as drive shaft, universal, and constant velocity joint diagnosis and service. Also included in this content area are rear differential diagnosis and repair plus four-wheel-drive component diagnosis and repair.

SUSPENSION AND STEERING (A4) This content area includes steering and suspension system diagnosis and repair, including wheel alignment diagnosis and adjustments, and wheel and tire diagnosis and repair procedures.

BRAKES (A5) The brake content area includes the diagnosis and repair of the hydraulic system, drum and disc brake systems, plus power assist units, antilock braking, and traction control systems.

ELECTRICAL/ELECTRONIC SYSTEMS (A6) This content area includes many systems, including the battery, starting, charging, lighting, gauges, and accessory circuit diagnosis and repair.

HEATING AND AIR CONDITIONING (A7) The heating and air-conditioning content area includes air-conditioning service, refrigeration systems, heating and engine cooling systems diagnosis and repair, as well as refrigerant recovery, recycling, handling, and retrofit.

ENGINE PERFORMANCE (A8) The engine performance content area includes diagnosis and testing of those systems responsible for the proper running and operation of the engine. Included in this area are general engine diagnosis, ignition and fuel systems, as well as emission control and computerized engine control diagnosis and repair.

This textbook covers the content of all eight ASE areas plus all of the background and fundamental information needed by technicians.

REVIEW QUESTIONS

1. In 1900, what was the most produced vehicle powered by?
2. What parts are included in the vehicle chassis?
3. Why were early engines called flat heads?
4. What is the difference between a unit-body and body-on-frame vehicle?
5. The powertrain consists of what components?
6. What are the eight automotive service content areas?

CHAPTER QUIZ

1. The first self-propelled vehicle that used an OTTO cycle four-stroke gasoline engine was produced in _____.
   a. 1885 **c.** 1902
   b. 1900 **d.** 1908
2. Early vehicles were constructed mostly of what material?
   a. Steel
   b. Cast iron
   c. Wood
   d. Tin
3. Which component is *not* part of the chassis system?
   a. Frame
   b. Electrical system
   c. Suspension
   d. Brakes
4. Early engines were called flat head design because they _____.
   a. Were only inline engines
   b. Did not include valves
   c. Used valves beside the cylinder
   d. Used spark plugs at the top of the cylinders
5. A V-type engine could have how many cylinders?
   a. 4 **c.** 8
   b. 6 **d.** All of the above
6. What component regulates the temperature of the coolant in an engine?
   a. Cooling (water) jackets **c.** Cooling fan(s)
   b. Thermostat **d.** Radiator

7. A malfunction indicator light (MIL) on the dash may be labeled _____.
   a. Check engine **c.** MIL
   b. Service vehicle soon **d.** MAL
8. To retrieve stored diagnostic trouble codes, a service technician needs a _____.
   a. Paper clip
   b. Desktop computer
   c. Wireless connection to an electronic tester
   d. Scan tool
9. A four-wheel drive vehicle often uses a _____ to transmit torque to all four wheels.
   a. Drive shaft **c.** Transaxle
   b. U-joint **d.** Transfer case
10. Automotive service systems are generally separated into how many content areas?
   a. 4 **c.** 8
   b. 6 **d.** 10

chapter 2 CAREERS IN THE AUTOMOTIVE SERVICE INDUSTRY

OBJECTIVES: **After studying Chapter 2, the reader will be able to:** • Describe automotive service-related positions. • Discuss the level of training and experience needed for each position. • Describe the technical skills needed for each position. • Explain the relationship of the service manager to others in a shop and company.

KEY TERMS: Entrepreneur 14 • On-the-job training (OJT) 10 • Parts counter person 13 • Service advisor 12 • Service consultant 12 • Service manager 12 • Service writer 12 • Shop foreman 12 • Team leader 12 • Technician (tech) 8 • VIN 11 • Work order 11

THE NEED FOR AUTOMOTIVE TECHNICIANS

The need for trained and skilled automotive **technicians** is greater than ever for several reasons, including:

- Vehicles are becoming more complex and require a higher level of knowledge and skills.
- Electrical and electronic components and sensors are included throughout the vehicle.
- Construction of parts and materials being used has changed over the last few years, meaning that all service work must be done to specified procedures to help avoid damage being done to the vehicle.
- Increasing numbers of different types of lubricants and coolants make even routine service challenging.

All of the above issues require proper training and the ability to follow factory specified procedures to ensure customer satisfaction. The number of service technicians needed is increasing due to more vehicles on the road. A good service technician can find work in almost any city or town in the country, making the career as a professional service technician an excellent choice.

THE NEED FOR CONTINUOUS VEHICLE SERVICE

Vehicles are lasting longer due to improved materials and more exacting tolerances. Every year, vehicles are being driven farther than ever before. It used to be (in the 1950s) that the life of a vehicle was considered to be 100,000 miles or 10 years. Now achieving 200,000 miles without a major repair is common with proper maintenance and routine service. However, even the amount of needed routine service has been reduced due to changes in the vehicles, such as radial tires that now last 40,000 miles instead of older tires which were worn out and needed to be replaced every 15,000 miles.

WARRANTIES A warranty is a guarantee to the purchaser of a vehicle that it will function as specified. The warranty covers the quality and performance of the product and states the conditions under which the warranty will be honored. Vehicle warranties vary but all warranties indicate a time and mileage restriction. The expressed warranties often include the following areas:

- New vehicle limited warranty that covers most components and is commonly called a bumper-to-bumper policy.

- Powertrain warranty covers the engine, transmission/transaxle, and final drive units. This coverage usually is longer than the bumper-to-bumper coverage.
- Sheet metal rust through warranty is usually longer than the bumper-to-bumper and powertrain warranty and covers rust if a hole occurs starting from inside the outer metal surface of the body.
- Emission control device warranties depend on the emission rating, the warranty coverage of the powertrain control module (PCM), and the catalytic converter and are covered for 8 years and 80,000 miles up to 10 years and 150,000 miles.

Vehicle warranties, unless an emergency repair, must be performed at a dealership, which is certified by the vehicle manufacturer to perform the repairs. At the dealership, the technician performing the repair must also be certified by the vehicle manufacturer.

All technicians should be familiar with what may be covered by the factory warranties to help ensure that the customer does not have to pay for a repair that may be covered. While warranties do cover many components of the vehicle, wear and service items are not covered by a warranty in most cases and therefore, offer excellent opportunity for additional service work for trained automotive technicians.

INCREASING AGE OF A VEHICLE The average age of a vehicle on the road today has increased to older than nine years. This trend means that more vehicles than ever are not covered by a factory warranty and are often in need of repair. Aftermarket warranties also can be used at most repair facilities, making it very convenient for vehicle owners.

TECHNICIAN WORK SITES

Service technician work takes place in a variety of work sites including:

NEW VEHICLE DEALERSHIPS Most dealerships handle one or more brands of vehicle, and the technician employed at dealerships usually has to meet minimum training standards. The training is usually provided at no cost online or at regional training centers. The dealer usually pays the service technician for the day(s) spent in training as well as provides or pays for transportation, meals, and lodging. Most dealerships offer in house on-line training with minimum off-site training. ● **SEE FIGURE 2–1.**

INDEPENDENT SERVICE FACILITIES These small- to medium-size repair facilities usually work on a variety of vehicles. Technicians employed at independent service facilities usually have to depend on aftermarket manufacturers' seminars or the local vocational school or college to keep technically up-to-date. ● **SEE FIGURE 2–2.**

MASS MERCHANDISER Large national chains of vehicle repair facilities are common in most medium- and large-size cities. Some examples of these chains include Sears, Goodyear, Firestone, and NAPA, as shown in ● **SEE FIGURE 2–3.** Technicians employed by these chains usually work on a wide variety of vehicles. Many of the companies have their own local or regional training sites designed to train beginning service technicians and to provide update training for existing technicians.



FIGURE 2–1 A service technician checking for a noise of a vehicle in a new-vehicle dealership service department.



FIGURE 2–2 A typical independent service facility. Independent garages often work on a variety of vehicles and perform many different types of vehicle repairs and service. Some independent garages specialize in just one or two areas of service work or in just one or two makes of vehicles.



FIGURE 2–3 This NAPA parts store also performs service work from the garage area on the side of the building.

SPECIALTY SERVICE FACILITIES Specialty service facilities usually limit their service work to selected systems or components of the vehicle and/or to a particular brand of vehicle. Examples of specialty service facilities include Midas, Speedy, and AAMCO Transmissions. Many of the franchised specialty facilities have their own technician training for both beginning and advanced technicians. ● **SEE FIGURE 2–4.**

FLEET FACILITIES Many city, county, and state governments have their own vehicle service facilities for the maintenance and

repair of their vehicles. Service technicians are usually employees of the city, county, or state and are usually paid by the hour rather than on a commission basis. ● **SEE FIGURE 2–5.**

TECHNICIAN JOB CLASSIFICATIONS

There are many positions and jobs in the vehicle service industry. In smaller service facilities (shops), the duties of many positions may be combined in one job. A large city dealership may have all of the following vehicle service positions. A technician is often referred to as a tech.



FIGURE 2–4 Midas is considered to be a specialty service shop.

LUBE TECH/QUICK SERVICE TECHNICIAN A lubrication technician should be trained in the proper use of hand tools and instructed how to properly service various types of vehicles. The training could be **on-the-job (OTJ)** or could be the result of high school or college automotive training. Some larger companies provide in-house training for new technicians and as a result they are trained to perform according to a specified standard. It is important that the lubrication technician double-check the work to be certain that the correct viscosity oil has been installed and to the specified level. The oil plug and oil filter must also be checked for leakage.

Lubrication technicians are trained to perform routine services including:

- Oil and oil filter change
- Chassis lubrication
- Fluids check and refill
- Tire inflation checks
- Accessory drive belt inspection
- Air filter check and replacement
- Cabin filter replacement
- Windshield wiper blade replacement

As a result of these tasks the lubrication technician should be skilled in hoisting the vehicle and able to handle the tasks efficiently and in minimum time.

NEW VEHICLE PREPARATION FOR DELIVERY A new entry-level position at a dealership often includes preparing new vehicles for delivery to the customer. This is often referred to as "new car prep." The duties performed for new vehicle preparation are generally learned on the job. The vehicle manufacturer publishes guidelines that should be followed and it is the responsibility of the



FIGURE 2–5 A school bus garage is a typical fleet operation shop that needs skilled service technicians.

new vehicle preparation person to see that all items are checked and serviced, and all associated paperwork is completed. The activities normally associated with preparing a new vehicle for delivery include:

- Installing wheel center caps or wheel covers (if used)
- Installing roof racks, running boards, and other dealer-installed options
- Checking and correcting tire pressures

NOTE: Many vehicle manufacturers ship the vehicles to the dealer with the tires overinflated to help prevent movement of the vehicle during shipping.

- Checking all fluids
- Checking that everything works including the remote key fob and all accessories
- Ordering any parts found to be broken, missing, and damaged in transit
- Removing all protective covering and plastic from the seats, carpet, and steering wheel
- Washing the vehicle

? FREQUENTLY ASKED QUESTION

Why Is the Work Order Important?

The **work order** is a legal document that includes the description of the vehicle and the work requested by the customer. The customer then signs the work order authorizing that the stated work be performed. If there are additional faults found then the shop must notify the customer and get permission to change the amount or extent of the work originally authorized. As work is performed on the vehicle, the parts used and the labor operation performed are added. This creates a complete file on the repair. This means that the vehicle has to be properly identified by including the **vehicle identification number (VIN)** on the work order. There is only one vehicle with that VIN, yet there may be many "white Chevrolet pickup trucks."

The work order is the paper trail that shows all operations, labor times, and parts used when the vehicle was in control of the shop. A work order is often required even when the technician is working on his or her own vehicle.

GENERAL SERVICE TECHNICIAN

A general service technician usually has training as an automotive technician either in one or more of the following:

- High school—Technical or vocational school or a comprehensive high school that has an Automotive Youth Education System (AYES) program or NATEF certification.
- College or technical school—Usually a two-year program that can earn the student an associate's degree.
- Career college or institute—Usually a 6-month to 12-month program earning the graduate a certificate.

Automotive service technicians perform preventative maintenance, diagnose faults, and repair automotive vehicles and light trucks.

Automotive service technicians adjust, test, and repair engines, steering systems, braking systems, drivetrains, vehicle suspensions, electrical systems and air-conditioning systems, and perform wheel alignments. In large shops, some technicians specialize in repairing, rebuilding, and servicing specific parts, such as braking systems, suspension, and steering systems. In smaller shops, automotive service technicians may work on a wider variety of repair jobs.

Automotive service technicians begin by reading the work order and examining the vehicle. To locate the cause of faulty operation and repair it, a technician will:

- Verify customer concern
- Use testing equipment, take the vehicle for a test-drive, and/or refer to manufacturer's specifications and manuals
- Dismantle faulty assemblies, repair, or replace worn or damaged parts
- Reassemble, adjust, and test the repaired mechanism

Automotive service technicians also may:

- Perform scheduled maintenance services, such as oil changes, lubrications, and filter replacement
- Advise customers on work performed, general vehicle conditions, and future repair requirements

WORKING CONDITIONS Most automotive service technicians work a 40-hour, five-day week. Some evening, weekend, or holiday work may be required. The work is sometimes noisy and dirty. There is some risk of injury involved in working with power tools and near exhaust gases.

SKILLS AND ABILITIES The work is most rewarding for those who enjoy doing precise work that is varied and challenging. Also, technicians usually achieve job security and a feeling of independence.

To be successful in the trade, automotive service technicians need:

- Good hearing, eyesight, and manual dexterity (ability to work with hands)
- Mechanical aptitude and interest
- The ability to lift between 25 and 50 pounds (11 and 25 kilograms)
- The willingness to keep up-to-date with changing technology

A working knowledge of electricity, electronics, and computers is also required for many service procedures.

EMPLOYMENT AND ADVANCEMENT. Automotive service technicians are employed by automotive repair shops, specialty repair shops, service facilities, car and truck dealerships, and by large organizations that own fleets of vehicles.

Experienced automotive service technicians may advance to service manager or shop foreman. Some automotive service technicians open their own repair facilities.

Many technicians can also start work in a shop or dealership and learn on the job. Most technicians keep up-to-date by attending update seminars or training classes on specific topics throughout the year.

Specific tasks performed by a general service technician can include the following:

- All of the tasks performed by the lubrication technician.
- Engine repairs including intake manifold gasket replacement; cylinder head replacement; and oil and water pump replacement plus other engine-related tasks.
- Brake system service and repair including disc brakes; drum brakes; parking brake; and antilock brake (ABS) diagnosis and service.

- Suspension-related service including tire inspection and replacement; shock and strut replacement; servicing or replacing wheel bearings; performing steering component inspection and parts replacement; and performing wheel alignment and vibration diagnosis.
- Electrical-related diagnosis and repair including starting and charging problems; correcting lighting and accessory faults; and general service such as light bulb replacement and key fob reprogramming.
- Heating, ventilation and air conditioning work usually involves the use of diagnostic and service equipment that requires special training and certification if working with refrigerants.
- Engine performance-related diagnosis and repair including replacing fuel pumps and filters; cleaning or replacing fuel injectors; service ignition system components; solving emissions-related failures; and determining the cause and correcting "Check Engine" lights.
- Manual transmission service and repairs including replacing clutches; adjusting, or replacing clutch linkage; and performing four-wheel-drive diagnosis and service procedures.
- Automatic transmission service and repairs including performing routine automatic transmission service; removing and replacing automatic transmissions; servicing differentials, transmissions/transaxles and performing diagnosis and service checks including fluid pressure and scan tool diagnosis.

The vehicle is then driven by the service technician to verify the repair.

TECHNICIAN TEAM LEADER A **team leader** is an experienced service technician who is capable of performing most if not all of the work that the shop normally handles. The team leader then assigns work to others in the group based on the experience or competency of the technician. The team leader then checks the work after it has been completed to be sure that it has been correctly performed. The number of hours of labor for each member of the team is totaled each pay period. Each member of the team is paid an equal share of the time but at different rates. The team leader gets a higher per hour rate than the others on the team. The rate of pay per hour is based on the level of training and experience. A beginning technician may or may not be paid as part of the total team hours depending on how the team system is organized. While some shops do not use teams, many large shops or dealerships have two or more teams. The advantage of a team-type organization is that everyone on the team looks out and helps each other if needed because they are all paid based on the number of hours the team generates. The team leader performs the duties of a shop foreman but only for those members on the team and not the entire shop. The team leader is under the direction and control of the service manager.

SHOP FOREMAN A **shop foreman** (usually employed in larger dealerships and vehicle repair facilities) is an experienced service technician who is usually paid a salary (so much a week, month, or year). A shop foreman is a knowledgeable and experienced service technician who keeps up-to-date with the latest vehicle systems, tools, and equipment. Typical shop foreman's duties include:

- Test-driving the customer's vehicle to verify the customer concern (complaint)
- Assigning work to the service technicians
- Assisting the service technicians
- Helps maintain the shop and shop equipment
- Assisting the service manager
- Verifying that the repair is completed satisfactorily

The shop foreman is under the direction and control of the service manager.

SERVICE ADVISOR A **service advisor,** also called a **service writer** or **service consultant,** is the person at the dealership or shop designated to communicate the needs of the customer and accurately complete a work order.

A service advisor should:

- Have a professional appearance
- Be able to speak clearly
- Be able to listen carefully to the customer
- Write neatly and/or type accurately
- Be familiar with industry and shop standards and procedures

Most service advisors would benefit from taking a short course on service advising skill development and interpersonal relationship building. A service advisor should be familiar with the operation of the vehicle, but not to the same level as a service technician. A service advisor should not diagnose the problem, but rather state clearly on the work order what, when, and where the problem occurs so that the service technician has all the needed information to make an accurate diagnosis. ● **SEE FIGURE 2–6** for an example of a typical work order.

The service advisor's duties include:

1. Recording the vehicle identification number (VIN) of the vehicle on the work order
2. Recording the make, model, year, and mileage on the work order
3. Carefully recording what the customer's complaint (concern) is so that the service technician can verify the complaint and make the proper repair
4. Reviewing the customer's vehicle history file and identifying additional required service
5. Keeping the customer informed as to the progress of the service work

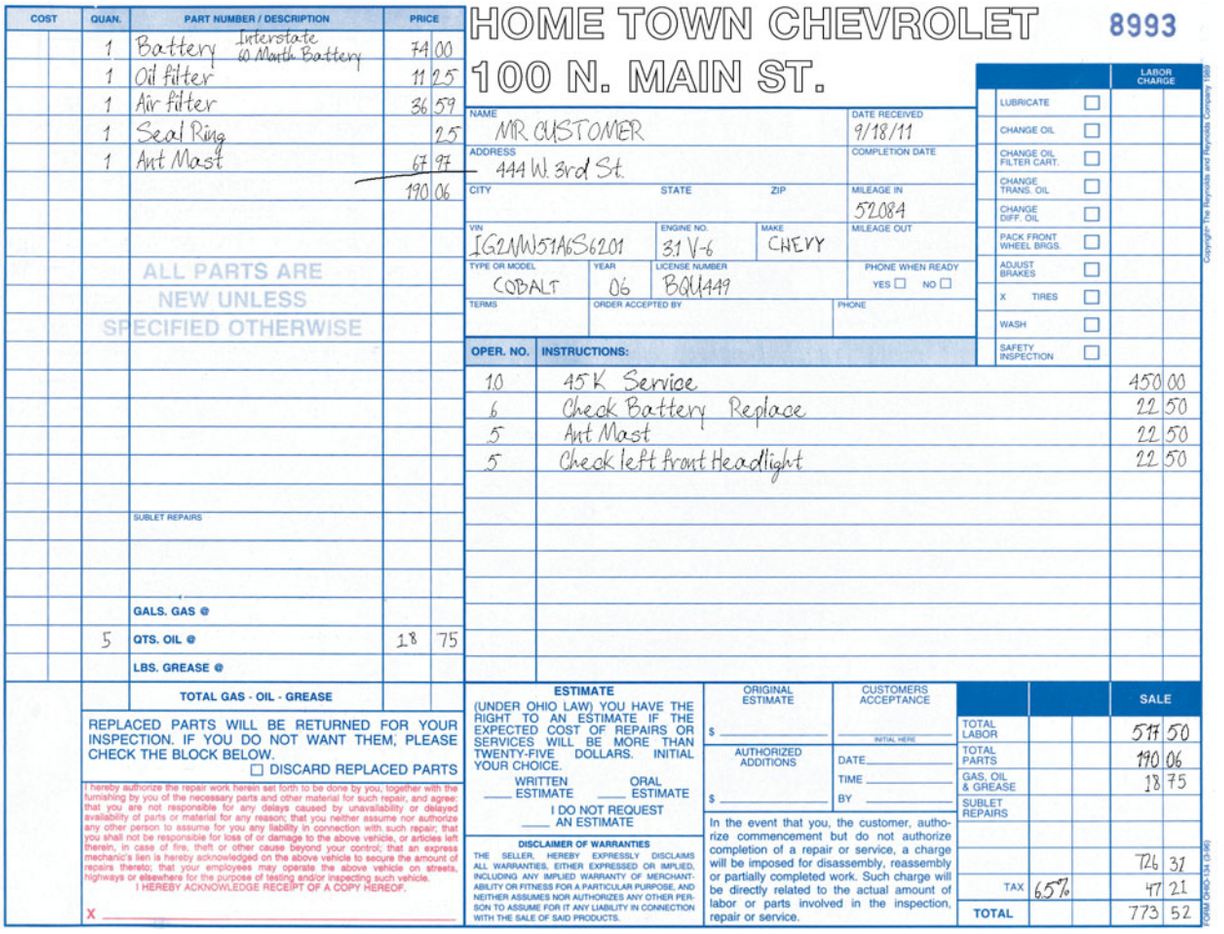
A service advisor must be at the shop early in the morning to greet the customers and often needs to stay after the shop closes for business to be available when the customer returns at the end of the day.

SERVICE MANAGER The **service manager** rarely works on a vehicle but instead organizes the service facility and keeps it operating smoothly. A service manager can be a former service technician or in many larger dealerships, a business major graduate who is skilled at organization and record keeping. The service manager typically handles all of the paperwork associated with operating a service department.

NOTE: In a small shop, the shop owner usually performs all of the duties of a shop foreman and service manager, as well as the lead technician in many cases.

Typical duties of a service manager include:

- Establishing guidelines to determine the technicians' efficiency
- Supervising any warranty claims submitted to the vehicle manufacturer or independent insurer
- Evaluating and budgeting for shop tools and equipment
- Establishing service department hours of operation and employee schedules



HOME TOWN CHEVROLET 8993
100 N. MAIN ST.

COST	QUAN.	PART NUMBER / DESCRIPTION	PRICE
	1	Battery Interstate 60 Month Battery	74 00
	1	Oil filter	11 25
	1	Air filter	36 59
	1	Seal Ring	2 5
	1	Ant Mast	67 97
			190 06
		ALL PARTS ARE NEW UNLESS SPECIFIED OTHERWISE	
		SUBLET REPAIRS	
		GALS. GAS @	
	5	QTS. OIL @	18 75
		LBS. GREASE @	
		TOTAL GAS - OIL - GREASE	

NAME: MR CUSTOMER — DATE RECEIVED: 9/18/11
ADDRESS: 444 W. 3rd St. — COMPLETION DATE:
CITY — STATE — ZIP — MILEAGE IN: 52084
VIN: 1G2AW51A6S6201 — ENGINE NO.: 3.1 V-6 — MAKE: CHEVY — MILEAGE OUT:
TYPE OR MODEL: COBALT — YEAR: 06 — LICENSE NUMBER: BQU449 — PHONE WHEN READY: YES ☐ NO ☐
TERMS — ORDER ACCEPTED BY — PHONE

LABOR CHARGE	
LUBRICATE ☐	
CHANGE OIL ☐	
CHANGE OIL FILTER CART. ☐	
CHANGE TRANS. OIL ☐	
CHANGE DIFF. OIL ☐	
PACK FRONT WHEEL BRGS. ☐	
ADJUST BRAKES ☐	
X TIRES ☐	
WASH ☐	
SAFETY INSPECTION ☐	

OPER. NO.	INSTRUCTIONS:	
10	45K Service	450 00
6	Check Battery Replace	22 50
5	Ant Mast	22 50
5	Check left front Headlight	22 50

REPLACED PARTS WILL BE RETURNED FOR YOUR INSPECTION. IF YOU DO NOT WANT THEM, PLEASE CHECK THE BLOCK BELOW.
☐ DISCARD REPLACED PARTS

I hereby authorize the repair work herein set forth to be done by you; together with the furnishing by you of the necessary parts and other material for such repair, and agree: that you are not responsible for any delays caused by unavailability or delayed availability of parts or material for any reason; that you neither assume nor authorize any other person to assume for you any liability in connection with such repair; that you shall not be responsible for loss of or damage to the above vehicle, or articles left therein, in case of fire, theft or other cause beyond your control; that an express mechanic's lien is hereby acknowledged on the above vehicle to secure the amount of repairs thereto; that your employees may operate the above vehicle on streets, highways or elsewhere for the purpose of testing and/or inspecting such vehicle.
I HEREBY ACKNOWLEDGE RECEIPT OF A COPY HEREOF.
X _____

ESTIMATE
(UNDER OHIO LAW) YOU HAVE THE RIGHT TO AN ESTIMATE IF THE EXPECTED COST OF REPAIRS OR SERVICES WILL BE MORE THAN TWENTY-FIVE DOLLARS. INITIAL YOUR CHOICE.
___ WRITTEN ESTIMATE ___ ORAL ESTIMATE
___ I DO NOT REQUEST AN ESTIMATE

DISCLAIMER OF WARRANTIES
THE SELLER HEREBY EXPRESSLY DISCLAIMS ALL WARRANTIES, EITHER EXPRESSED OR IMPLIED, INCLUDING ANY IMPLIED WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE, AND NEITHER ASSUMES NOR AUTHORIZES ANY OTHER PERSON TO ASSUME FOR IT ANY LIABILITY IN CONNECTION WITH THE SALE OF SAID PRODUCTS.

ORIGINAL ESTIMATE: $ _____ — CUSTOMERS ACCEPTANCE: _____ INITIAL HERE
AUTHORIZED ADDITIONS: $ _____ — DATE _____ TIME _____ BY _____

In the event that you, the customer, authorize commencement but do not authorize completion of a repair or service, a charge will be imposed for disassembly, reassembly or partially completed work. Such charge will be directly related to the actual amount of labor or parts involved in the inspection, repair or service.

		SALE
TOTAL LABOR		577 50
TOTAL PARTS		190 06
GAS, OIL & GREASE		18 75
SUBLET REPAIRS		
		726 31
TAX	6.5%	47 21
TOTAL		773 52

Copyright The Reynolds and Reynolds Company 1988
FORM OR&O-134 (3-96)

FIGURE 2–6 Typical work order. *(Courtesy of Reynolds and Reynolds Company)*

TECH TIP

Check the Vehicle before Work Is Started

As part of the work order writing process, the service advisor should look over the vehicle and make a written note of any body damage that may already exist. If any damage is noted it should be mentioned to the customer and noted on the work order. Often the customer is not aware of any damage especially on the passenger side and thus would blame the shop for the damage after the service work was performed.

- Assigning working hours and pay for technicians and others in the service department
- Establishing procedures and policies to keep the service area clean and properly maintained

PARTS-RELATED POSITIONS

The parts manager and other parts personnel such as the **parts counter person** are responsible for getting the correct part for the service technician.

PARTS COUNTER PERSON A parts counter person often learns job skills by on-the-job training. A good parts counter person must be able to greet and easily talk to customers and technicians. A parts counter person must also have computer skills and the willingness to help others.

The parts counter person usually has the following duties:

- Greet the customer or technician
- Locate the correct parts for the service technician or customer
- Suggest related parts (retail customers)
- Stock shelves
- Check in delivered parts
- Take inventory
- Keep the parts department clean
- Help the parts manager

● **SEE FIGURE 2–7.**

PARTS MANAGER The specific duties of a parts manager usually include:

- Ordering parts from the vehicle manufacturers and aftermarket companies
- Stocking parts
- Organizing the parts department in a clear and orderly fashion
- Locating parts quickly within the parts department
- Developing contacts with parts departments in other local dealerships so that parts that are not in stock can be purchased quickly and at a reasonable cost



FIGURE 2–7 Parts counter people need to know many aspects of automotive repair to be effective with customers.

SALES JOBS—USED VEHICLES; NEW VEHICLES

SALESPERSON When a vehicle is sold, it generates a potential customer for the service department. New and many used vehicle sales dealerships employ salespeople to help the customer select and purchase a vehicle. The salesperson should have excellent interpersonal skills, as well as be familiar with the local and regional laws and taxes to be able to complete all of the paperwork associated with the sale of a vehicle. The usual duties of a vehicle salesperson include:

- Greet the customer
- Introduce yourself and welcome the customer to the store
- Qualify the customer as to the ability to purchase a vehicle
- Demonstrate and ride with the customer on a test-drive
- Be able to find the answer to any question the customer may ask about the vehicle and/or financing
- Be able to complete the necessary paperwork
- Follow up the sale with a telephone call or card

SALES MANAGER A sales manager is an experienced salesperson who is able to organize and manage several individual salespeople. The duties of a sales manager include:

- Establish a schedule where salespeople will be available during all hours of operation
- Consult with salespeople as needed on individual sales
- Train new salespeople
- Conduct sales promotion activities
- Attend or assign someone to attend vehicle auctions to sell and/or purchase vehicles
- Keep up-to-date with the automotive market
- Purchase vehicles that sell well in the local market
- Answer to the general manager or dealership principal

? FREQUENTLY ASKED QUESTION

What Is an Entrepreneur?

An **entrepreneur** is a person who starts and operates a business. Many service technicians want to eventually own their own shop and become an entrepreneur. However, operating a shop involves many duties and responsibilities that many service technicians lack, including:

- Bookkeeping and accounting skills
- Tax preparation (local, state, and federal)
- Sales tax collection and payment
- Health insurance arrangements for employees
- Unemployment compensation payments
- Workers' compensation payments
- Uniform payment
- Real estate taxes
- Garage keepers liability insurance

While at first it may seem like owning your own shop would be great, a good technician can often make more money, and have fewer headaches, by simply working for someone else.

OTHER CAREERS IN THE AUTOMOTIVE INDUSTRY

Other careers in the automotive industry include:

- Sales representative for automotive tools and equipment
- Technical trainers
- Technical school instructors
- Wholesale parts warehouse management
- Insurance adjuster
- Automotive technical writer
- Warranty claim examiner

TYPICAL AUTOMOTIVE ORGANIZATION ARRANGEMENT

LARGE COMPREHENSIVE NEW VEHICLE DEALER A typical dealership includes many levels because there are many departments such as sales (new and used) as well as the service, parts and body shops to manage. ● **SEE FIGURE 2–8.**

INDEPENDENT SHOP. An independent shop may or may not have a shop foreman depending on the number of technicians and the volume of work. Larger independent shops have a shop foreman, whereas at smaller shops, the owner is the shop foreman. ● **SEE FIGURE 2–9.**

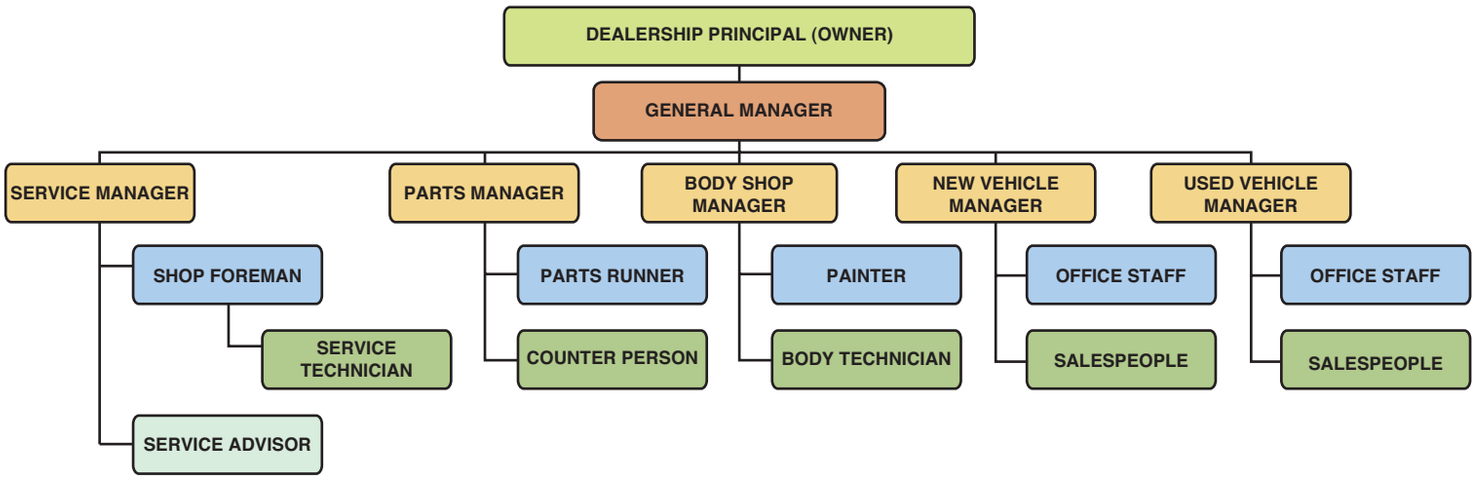


FIGURE 2–8 A typical large new vehicle dealership organizational chart.

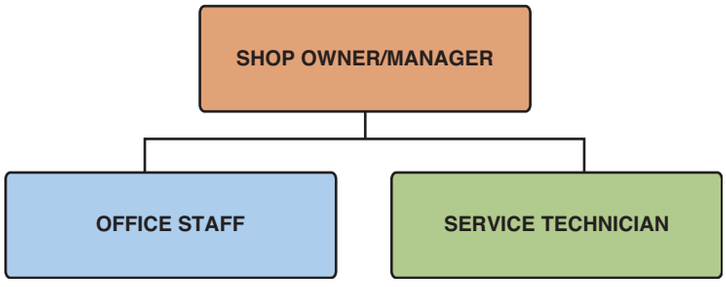


FIGURE 2–9 A typical independent shop organizational chart.

REVIEW QUESTIONS

1. What should be included on a work order?
2. Why should a vehicle be inspected when the work order is being written?
3. What tasks are usually performed by a general service technician?
4. What duties are performed by the shop foreman and service manager?
5. What duties are performed by a parts counter person?
6. What duties are performed by vehicle salespeople?

CHAPTER QUIZ

1. A service advisor is called a _____.
   a. Shop foreman **c.** Service writer
   b. Service manager **d.** Technician
2. What is *not* included on a work order?
   a. Customer's mother's maiden name
   b. VIN
   c. Mileage
   d. Description of work requested
3. All of the following are usual duties of a lube technician *except* _____.
   a. Oil change **c.** Water pump replacement
   b. Air filter replacement **d.** Accessory drive belt inspection
4. New vehicle preparation is usually an entry-level vehicle service position and usually involves what duties?
   a. Installing dealer-installed options
   b. Correcting tire pressures
   c. Removal of all protective coverings and plastic
   d. All of the above
5. What is *not* a duty of a general service technician?
   a. Have the customer sign the work order
   b. Order the parts needed
   c. Diagnose the customer's concern
   d. Perform vehicle repair procedures
6. Which description best fits the role of a service advisor?
   a. A skilled technician
   b. A beginning technician
   c. A customer service representative
   d. A money manager
7. Two technicians are discussing the duties of a shop foreman and a service manager. Technician A says that a shop foreman diagnoses vehicle problems. Technician B says that the service manager usually repairs vehicles. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
8. Who is the person that greets the service customer and completes the work order?
   a. Service manager **c.** Service writer
   b. Service advisor **d.** Either b or c
9. Which job would be concerned with the maintenance of the shop equipment?
   a. Service manager **c.** Shop owner
   b. Shop foreman **d.** Any ofw the above
10. Which job would be concerned with working hours and pay?
    a. Service manager **c.** Service advisor
    b. Shop foreman **d.** Service technician

chapter 3

STARTING A CAREER IN THE AUTOMOTIVE INDUSTRY

OBJECTIVES: **After studying Chapter 3, the reader will be able to:** • Explain the steps and processes for applying for a job. • Describe what the resume should include. • Explain why having a good driving record is important to a shop owner. • Discuss how to prepare for a career in the automotive industry.

KEY TERMS: Apprentice program 17 • Clock-in 20 • Clock time 20 • Commission pay 21 • Cooperative education 17 • Entrepreneur 23 • Federal tax 21 • FICA 21 • Flat-rate 21 • Gross 21 • Housing expense 22 • Incentive pay 21 • Job shadowing 16 • Net 21 • Part-time employment 17 • Reference 19 • Resume 18 • Soft skills 17 • State tax 21 • Straight time 20

PREPARING FOR AN AUTOMOTIVE SERVICE CAREER

DESIRE AND INTEREST

If a person has an interest in automobiles and trucks and likes computers, the automotive service field may be a good career choice. Computer skills are needed in addition to hands-on skills for several reasons, including:

- Service information, such as diagnostic procedures and specifications, is commonly available in electronic format.
- Work orders are commonly written and sent to the technician electronically. The technician therefore needs typing skills to type the steps taken during the service or repair procedures.
- Warranty claims are often submitted by the Internet and computer skills are needed to quickly and accurately submit claims and answer questions from the insurance company.

Interest in vehicles is also very important toward being successful as a professional service technician. Most technicians enjoy working on vehicles, not only professionally, but also during their spare time. Many technicians own a project vehicle, which could include:

- Drag race vehicle
- Race vehicle used in road racing
- A fun vehicle used on sunny weekend days and evenings
- Motorcycle
- Snowmobile or jet ski
- Truck for rock crawling

TECHNICAL KNOWLEDGE AND SKILLS

The enjoyment of being involved with vehicles is very important because the job of servicing and repairing automobiles and trucks can be hard and dirty work. Many men and women enjoy being around and learning about the details of vehicle operation. With these desires and interest, working in the automotive service field is a great career. Technical information, skills, and tools needed include:



TECH TIP

If in Doubt, Ask

No one expects a beginning service technician to know everything, but other technicians do not know what you do or do not know. It is usually assumed that the beginning technician will ask for help if they think they need the help. However, asking for help is very rare and requires the beginning technician to admit that they do not know something. Not asking for help can cause harm to the vehicle or the service technician. If in doubt—always ask. No one will be upset and learning the answer to your question will help in the learning experience.

- **Hand tools and tool usage.** Owning and experience using hand tools is important for a service technician. All service technicians are expected to be able to remove and replace parts and components as needed in a timely manner using proper tools and techniques.
- **Technical knowledge.** While knowing how all aspects of the vehicle works is not expected of a beginning service technician, it is important that the technician have a basic understanding of the parts and procedures needed at least for routine service procedures.

JOB SHADOWING

A great way to see what it is really like to work as a service technician is to follow a professional around for a day or more. **Job shadowing** is usually arranged through an automotive program, and the shop or dealership has agreed to allow someone into the shop area to observe.

While it does allow the student to observe, job shadowing does not allow the person to perform any work or help the technician in any way. During the day, the person who is job shadowing has to wear all personal protective equipment as required by the technician and must observe all safety regulations. The advantages of job shadowing include:

- Being able to observe a typical day in the life of an automotive technician

- Being able to talk to the working technician about what is being done and why
- Being able to observe other technicians and seeing the various skill levels that often exist in a shop

COOPERATIVE EDUCATION PROGRAMS **Cooperative education** programs are formal programs of study at a high school or college where the student attends classes at the school, and also works at a local shop or dealership.

If a cooperative education program is held at the high school level, the work at the shop or dealership occurs during the afternoon or evening and during the summer between the junior and senior year. The most common high school cooperative program is called AYES, which means Automotive Youth Education System (see www.ayes.org). The vehicle manufacturers involved in this program include:

- General Motors
- Chrysler
- Toyota
- Honda
- Nissan
- BMW
- Kia
- Subaru
- Hyundai

If the cooperative education program is held at a community college, the work at the dealership occurs around the training sessions, usually the first or second half of a semester or on alternative semesters. The most common college programs include:

- General Motors ASEP (Automotive Service Educational Program) (see *www.gmasepbsep.com*)
- Ford ASSET (Automotive Student Service Educational Program) (see *www.fordasset.com*)
- Chrysler CAP (College Automotive Program) (see *www.chryslercap.com*)
- Toyota T-TEN (Toyota Technician Education Network) (see *www.toyota.com/about/tten/index.html*)

Another factory sponsored program open to those who have already completed a postsecondary automotive program is BMW STEP (Service Technician Education Program) (see *www.bmwusa.com/about/techtraining.html*).

APPRENTICE PROGRAMS An **apprentice program** involves a beginning service technician working at a shop or dealership during the day and attending training classes in the evening. The key advantage to this type of program is that money is being earned due to full-time employment and getting on-the-job training (OJT) during the day. Often the shop or dealership will help pay for training. While this program usually takes more than two years to complete, the work performed at the shop or dealership usually becomes more technical as the apprentice becomes more knowledgeable and gets more experienced.

PART-TIME EMPLOYMENT Working part time in the automotive service industry is an excellent way to get hands-on experience, which makes it easier to relate classroom knowledge to everyday problems and service issues. Working part time gives the student technician some flexibility as to college schedules and provides an income needed for expenses. Often **part-time employment** becomes full-time employment so it is important to keep attending technical classes toward becoming an asset to the company.

DEVELOPING AN EMPLOYMENT PLAN

An employment plan is an evaluation of your skills, interest, and talents. Selecting a career is different than getting a job. A typical job, while it does involve some training, usually can be learned in a few days to several months. However, a career requires many years to achieve competence. Therefore, selecting a career should require a thorough self-examination to determine what your true interest is in a particular career field. Some items that you should enjoy or would be willing and able to learn include:

- Working with your hands, using tools and equipment
- Computer usage, including typing skills
- Working in an area where lifting is often required
- Being able to read, understand, and follow service information, technical service bulletins, and work orders
- Being able to perform diagnostic work and figure out the root cause of a problem

SOFT SKILLS In addition, any career, including being a service technician, requires many people skills, often called **soft skills.** These people-related skills include:

- Working cooperatively with other people
- Communicating effectively with others verbally (speech) and in writing
- Working as a member of a team for the benefit of all
- Being able to work by yourself to achieve a goal or complete a job assignment
- Being able to lead or supervise others
- Willingness to work with others with a different background or country of origin

While it is almost impossible to be able to answer all of these questions, just looking at these items and trying to identify your interests and talents will help in your selection of a career that gives you lifelong satisfaction.

LOCATING EMPLOYMENT POSSIBILITIES Locating where you wish to work is a very important part of your career. Of course, where you would like to work may not have an opening and you may have to work hard to locate a suitable employer. First, try to select a shop or dealership where you think you would like to work because of location, vehicles serviced, or other factors. Ask other technicians who have worked or are presently working there to be sure that the location would meet your needs.

If looking for employment through a want ad in a newspaper or employment Web site, check the following:

- **Job description.** Is this a position that could advance into a more technical position?
- **Tools needed.** Most professional service technician positions require that the technician provide their own tools. (The shop or dealership provides the shop equipment.) Do you have the tools needed to do the job?
- **Hours needed.** Are you available during the hours specified in the ad?
- **Drug testing.** Is a drug test needed for employment and are you prepared to pass?

PREPARING A RESUME

A **resume** is usually a one-page description of your skills, talents, and education. It is used by prospective employers to help narrow the field of applicants for a job or position. The number one purpose of a resume is to obtain a job interview. A good resume should include the following items:

Personal Information

- Full given name (avoid nicknames)
- Mailing address (do not use a post office [PO] box)
- Telephone and/or cell phone number
- E-mail address
- Avoid using dates which could indicate your age

Educational Information

- Highest education level achieved
- Major, if in a college or in a training program

Experience and Skills

- Work or volunteer experience that may be helpful or useful to an employer. For example, if you took a course in welding, this may be useful to a shop owner who is looking for a service technician who could do welding, even though this fact was not included in the job posting.
- A valid driver's license is a must for most professional service technicians.
- A good driving record. Often the shop insurance company will not allow a shop owner to hire a technician with a poor driving record.

Sample Resume

Personal Information:

James Hartman
301 Main Street
City, State 40005
Telephone: (555) 555-0170
Cell: (555) 555-1139

Career Goal:

To become a certified ASE master technician and work at a new vehicle dealership.

Experience:

2006 to the present—I work part time (20 hours per week) at Miller Service performing routine vehicle service, including oil changes, tire balancing, brake repairs, timing belt replacement, and intake manifold gasket replacement. I have assisted with suspension and air-conditioning repairs and own a basic set of hand tools.

Education:

High school diploma from Central High School, City, State 40010. I am finishing a two-year automotive technician training program at City College, City, State 40010 (to be completed May 15).

Additional Training and Certification:

ASE certified in Brakes and Engine Repair.
Attended a seminar on wide-band oxygen sensors and electronic throttle control at a local automotive service exposition.

Other Skills and Interests:

I am restoring a 1969 Chevrolet Camaro, including all mechanical repairs and upgraded suspension system.

References:

Available upon request.

REFERENCES A **reference** is someone who is willing to tell a possible employer about you, including your skills and talents, as well as your truthfulness and work habits.

Most employers would like to see someone who is familiar with you and your family, such as a priest, minister, or elder in your church. Some teachers or coaches also can be asked to be a reference. Always ask the person for approval before including the person on your list of references. Ask the reference to supply you with a written recommendation. Some references prefer to simply fill out a reference questionnaire sent by many companies. If a reference sends you a written recommendation, have copies made so they can be included with your resume.

PREPARING A COVER LETTER

When answering an advertisement in a newspaper or magazine, be sure to include the details of where you saw the ad in your cover letter to the employer. For example: "I am applying for the position as an entry-level service technician as published in the August 15 edition of the Daily News."

If the requirements for the position are listed, be sure to include that you do have the specified training and/or experience and the tools needed for the job.

If calling about a position, be sure to state that you are applying for the position posted and ask to speak to the correct person or to the person mentioned in the ad.

Sample Cover Letter

301 Main Street
City, State 40005
Telephone: (555) 555-0170
Cell: (555) 555-1139

Date

Mr. John Smith
Smith Dealership
800 North Street
City, State 40010

Dear Mr. Smith:

I am applying for the position of general service technician at your dealership as advertised in the Sunday, January 7, edition of the Daily News.

I am currently finishing my studies in Automotive Technology at City College and have worked part time at Miller Service for the past two years. I am ASE certified in Brakes and Engine Repair and plan to become certified in all eight areas. I have my own tools and currently can work in the afternoons and evenings. After May 15, I will be able to work full time after completing my automotive courses.

I look forward to the opportunity to discuss my skills and resume in an interview. Thank you for your consideration.

Sincerely,

James Hartman

Enclosure (1)

TECH TIP

Always Be Truthful

No one is smart enough to be a liar. If you say something that is not true, then you have to remember what was said forever or your lie will often be discovered. If asked about your experience or knowledge, try to be as truthful as possible. Facts and skills can be learned and not knowing how to do everything that a shop may be involved with is not an indication that you will be rejected from the job opening.

CONTACTING POTENTIAL EMPLOYERS

When a job opening is posted in a newspaper or it is mentioned by a friend, most experts recommend that you visit the shop or dealership in person to see where the job is located, the condition of the buildings, and the surrounding areas. This trip could also be used for you to submit your resume and cover letter in person unless the company indicates otherwise. Be prepared to be interviewed when submitting your resume. Even if the position has already been filled, the trip gives you experience in meeting people and seeing the shop, which helps increase your confidence during the job search. Searching for a job is a full-time job in itself. Be prepared every day to answer ads, search employment web sites and travel to shops or dealerships.

COMPLETING THE EMPLOYMENT APPLICATION

Most businesses require that an employment application be completed because it not only asks for all necessary personal information needed, but also references and emergency contacts. Most employment application forms ask for previous employers, the names and telephone numbers of contact people, and other information which you may not remember. It is wise to have all of the information written down ahead of time and take it with you for reference when completing the application. Always answer questions honestly and as thoroughly as possible. Never lie on an employment application.

THE INTERVIEW

When meeting for the job interview, be sure to dress appropriately for the position. For example, a suit and tie would not be appropriate for an interview for a service technician position. However, the following may be a helpful guide:

- Wear shoes that are not sneakers and be sure they are clean
- Wear slacks, not jeans
- Wear a shirt with a collar
- Do not wear a hat
- Be clean shaven or have beard/mustache neatly trimmed
- Have clean hair
- Avoid facial jewelry

During the interview, try to answer every question honestly. Emphasize what you are capable of providing to the shop including:

- Enthusiasm
- Experience
- Willingness to work
- Willingness to work long hours and/or long weeks

AFTER THE INTERVIEW

After the interview, follow up with a letter thanking the shop for the interview. In the letter include when the interview occurred and that from the information you received, that you are very interested in becoming a part of the organization (shop or dealership). Also include contact information such as your cell phone number and e-mail address so the service manager can easily get in contact with you. A quick review of your skills and talent will also be helpful to the shop owner or service manager.

ACCEPTING EMPLOYMENT

When a job is offered, there will likely be some paperwork that needs to be filled out and decisions made. Some of the requested information could include:

- Social security number (social insurance number in Canada)
- W-4 tax withholding form
- Emergency contact people
- Retirement plan selection (This is usually given to you to study and return at a later date.)
- Other information which may be unique to the shop or dealership

After accepting the employment position, be sure to determine exactly what day and time you should report to work and try to determine where your tools should be placed. Most places will show you around and introduce you to others you will work with.

TECHNICIAN PAY METHODS

STRAIGHT-TIME PAY METHODS

When the particular service or repair is not covered or mentioned in a flat-rate guide, it is common practice for the technician to **clock-in** and use the actual time spent on the repair as a basis for payment. The technician uses a flat-rate time ticket and a time clock to record the actual time. Being paid for the actual time spent is often called **straight time** or **clock time.** Difficult engine performance repairs are often calculated using the technician's straight time.

FLAT-RATE PAY METHODS

Beginning service technicians are usually paid by the hour. The hourly rate can vary greatly

depending on the experience of the technician and type of work being performed. Most experienced service technicians are paid by a method called **flat-rate.** The flat-rate method of pay is also called **incentive** or **commission pay.** "Flat-rate" means that the technician is paid a set amount of time (flat-rate) for every service operation. The amount of time allocated is published in a flat-rate manual. For example, if a bumper requires replacement, the flat-rate manual may call for 1.0 hour (time is always expressed in tenths of an hour). Each hour has 60 minutes. Each tenth of an hour is 1/10 of 60 or 6 minutes.

0.1 hour = 6 minutes
0.2 hour = 12 minutes
0.3 hour = 18 minutes
0.4 hour = 24 minutes
0.5 hour = 30 minutes
0.6 hour = 36 minutes
0.7 hour = 42 minutes
0.8 hour = 48 minutes
0.9 hour = 54 minutes
1.0 hour = 60 minutes

Many service operations are greater than 1 hour and are expressed as such:

2.4 hours = 2 hours and 24 minutes
3.6 hours = 3 hours and 36 minutes

The service technician would therefore get paid the flat-rate time regardless of how long it actually took to complete the job. Often, the technician can "beat flat-rate" by performing the operation in less time than the published time. It is therefore important that the technician not waste time and work efficiently to get paid the most for a day's work. The technician also has to be careful to perform the service procedure correctly because if the job needs to be done again due to an error, the technician does the repair at no pay. Therefore, the technician needs to be fast and careful at the same time.

The vehicle manufacturer determines the flat-rate for each labor operation by having a team of technicians perform the operation several times. The average of all of these times is often published as the allocated time. The flat-rate method was originally developed to determine a fair and equitable way to pay dealerships for covered warranty repairs. Because the labor rate differs throughout the country, a fixed dollar amount would not be fair compensation. However, if a time could be established for each operation, then the vehicle manufacturer could reimburse the dealership for the set number of hours multiplied by the labor rate approved for that dealership. For example, if the approved labor rate is $60.00 per hour and:

Technician A performed 6.2 hours × $60.00 = $372.00
Technician B performed 4.8 hours × $60.00 = $288.00
The total paid to the dealership by the manufacturer = $660.00

This does not mean that the service technician gets paid $60.00 per hour. Sorry, no! This means that the dealership gets reimbursed for labor at the $60.00 per hour rate. The service technician usually gets paid a lot less than half of the total labor charge.

Depending on the part of the country and the size of the dealership and community, the technician's flat-rate per hour income can vary from $7.00 to $20.00 or more per flat-rate hour. Remember, a high pay rate ($20 for example) does not necessarily mean that the service technician will be earning $800.00 per week (40 hours × $20.00 per hour = $800.00). If the dealership is not busy or it is a slow time of year, maybe the technician will only have the opportunity to "turn" 20 hours per week. So it is not really the pay rate that determines what a technician will earn but rather a combination of all of the following:

- Pay rate
- Number of service repairs performed
- Skill and speed of the service technician
- Type of service work (a routine brake service may be completed faster and easier than a difficult engine performance problem)

A service technician earns more at a busy dealership with a lower pay rate than at a smaller or less busy dealership with a higher pay rate.

PAYROLL DEDUCTIONS

GROSS VERSUS NET COMPENSATION

Most beginning technicians start by receiving a certain amount of money per hours worked. **Gross** earnings are the total amount you earned during the pay period. The paycheck you receive will be for an amount called **net** earnings. Taxes and deductions that are taken from your paycheck may include all or most of the following:

- **Federal** income **tax**
- **State** income **tax** (not all states)
- Social Security taxes (labeled **FICA,** which stands for Federal Insurance Contribution Act)
- Health/dental/eye insurance deductions

In addition to the above, uniform costs, savings plan deductions, parts account deductions, as well as weekly payments for tools, may also reduce the amount of your net or "take-home" pay.

RETIREMENT INFORMATION AND PAYMENTS

Some shops or dealerships offer some retirement savings plan but the most commonly used is an employer-sponsored 401(k) account named after a section of the U.S. Internal Revenue Code. A 401(k) account allows a worker to save for retirement while deferring taxes on the saved money and earnings until withdrawal. Most 401(k) plans allow the employer to select from stock mutual funds or other investments. A 401(k) retirement plan offers two advantages compared to a simple savings account.

- The contributions (money deposited into the account) are tax deferred. The amount will increase due to interest and no taxes are due until the money is withdrawn.
- Many employers provide matching contributions to your 401(k) account which can range from 0% (no matching contributions) to 100%.

The savings really add up over time. For example, if you start saving at age 25 and your income averages $3,000 per month ($36,000 per year) and you contribute 6% of your pay and the employer contributes 3%, after 40 years at age 65, the account will be worth $1,700,000 (one million, seven hundred thousand dollars) assuming a 10% average return.

In retirement, most experts agree that 4% of the total can be withdrawn each year and not reduce the capital investment. Four percent of $1,700,000 is $68,000 per year or over $5,600 per month every month for the rest of your life.

TECH TIP

Hourly Rate to Annual Income

To calculate the amount of income that will be earned using an hourly rate, do the following:

Multiply the hourly rate times 2 and then times 1000.
For example: $10 per hour × 2 × 1000 = $20,000 per year.
This easy-to-use formula assumes working eight hours an day, five days a week for 50 weeks (instead of 52 weeks in the year).

The reverse can also be easily calculated:

Divide the yearly income by 2 and then by 1000 = hourly rate
For example: $36,000 per year ÷ 2 = $18,000 ÷1000 = $18 per hour

ADDITIONAL SERVICE TECHNICIAN BENEFITS Many larger dealerships and service facilities often offer some or all of the following:

- Paid uniforms/cleaning
- Vacation time
- Update training (especially new vehicle dealerships)
- Some sort of retirement (usually a contributing 401(k)) program
- Health and dental insurance (usually not fully paid)
- Discounts on parts and vehicles purchased at the dealership or shop

Not all service facilities offer all of these additional benefits.

HOUSING AND LIVING EXPENSES

As a general guideline, **housing expenses** such as rent or a mortgage payment should not exceed 30% of the gross monthly income. For example,

Ten dollars per hour times 40 hours per week = $400 per week times 4 weeks in a month = $1600 per month. Thirty percent of $1600 is $480 per month for rent or a mortgage payment.

A vehicle payment should not exceed 25% of the gross earnings. In the example where the pay was $10 per hour, the maximum recommended vehicle payment should be $400 per month.

BECOMING A SHOP OWNER

Many service technicians want to start and operate their own shop. Becoming a shop owner results in handling many non-automotive-related duties that some technicians do not feel qualified to handle, including:

- Handling customers
- Ordering and paying for shop equipment and supplies

FREQUENTLY ASKED QUESTION

Where Does All the Money Go?

Money earned does seem to quickly disappear. For example, if a soft drink and a bag of chips were purchased every day at work for $2.50, this amounts to $12.50 per week or $50 per month, which is $600 per year. Use the following chart to see where the money goes.

Income

Labor rate per hour × number of hours worked = _____
Overtime pay, if applicable = _____
Part-time work on weekends = _____
TOTAL WEEKLY INCOME = _____
Multiply by 4.3 to get the **MONTHLY INCOME** = _____

Monthly Expenses

Car/truck payment = _____
Rent/mortgage = _____
Gasoline = _____
Food (groceries) = _____
Fast food or restaurants = _____
Heat and electric (heat/air conditioning) = _____
Water and sewer = _____
Telephone (cell) = _____
Cable TV/internet access = _____
Clothing (including cleaning) = _____
Credit card payment = _____
TOTAL MONTHLY EXPENSES = _____

Hopefully, the total income is more than the total expenses!

FREQUENTLY ASKED QUESTION

Employee or Contract Labor?

Most shops and dealerships hire service technicians as employees. However, some shops or businesses will pay a technician for services performed on a contract basis. This means that they are not hiring you as an employee, but simply paying for a service similar to having a plumber repair a toilet. The plumber is performing a service and is paid for the job rather than as an employee of the shop. An employer/employee relationship exists if the shop meets two factors:

1. **Direction**—This means that the employer can direct the technician to report to work to perform service work.
2. **Control**—This means that the employer can direct the hours and days when the work is to be performed and at the employer's location.

A contract labor association exists if the repairs are performed without both direction and control of the shop.

If a contract labor basis is established, then no taxes are withheld. It is then the responsibility of the technician to make the necessary and required general tax payments and pay all taxes on time.

- Bookkeeping, including payroll
- Budgeting for and paying for garage owner's insurance and workers' compensation
- Paying rent, as well as heat/air-conditioning bills
- Advertising expenses
- Hiring and firing employees

TECH TIP

Find Three Key People

An **entrepreneur** is a person who organizes and manages their own business assuming the risk for the sake of a profit. Many service technicians have the desire to own their own repair facility. The wise business owner (entrepreneur) seeks the advice of the following people when starting and operating their own business.

1. **Attorney (lawyer)** —This professional will help guide you to make sure that your employees and your customers are protected by the laws of your community, state, and federal regulations.
2. **Accountant** —This professional will help you with the journals and records that must be kept by all businesses and to help with elements such as payroll taxes, unemployment taxes, and workmen's compensation that all businesses have to pay.
3. **Insurance Agent** —This professional will help you select the coverage needed to protect you and your business from major losses.

REVIEW QUESTIONS

1. What facts should be included on the resume?
2. What are five interviewing tips?
3. What is the difference between gross pay and net pay?
4. What taxes are usually withheld from a paycheck?
5. What are five duties of a shop owner?

CHAPTER QUIZ

1. A resume should be how many pages long?
   a. 1
   b. 2
   c. 3
   d. 4 or more
2. What personal information should *not* be included on the resume?
   a. Address
   b. Cell or telephone number
   c. Age
   d. Work experience
3. Why is having a good driving record good for the shop?
   a. Allows the use of a company vehicle
   b. Lowers insurance costs
   c. Allows you to drive customers' vehicles
   d. Permits you to use your vehicle to get parts
4. Which is *not* recommended during an interview?
   a. Wear shoes that are not sneakers
   b. Wear a shirt with a collar
   c. Have clean hair
   d. Wear jeans
5. During an interview, try to _____.
   a. Show enthusiasm
   b. Explain your work experience
   c. State your willingness to work
   d. All of the above
6. Ten dollars per hour is about how much income per year?
   a. $20,000 **c.** $30,000
   b. $25,000 **d.** $35,000
7. One of the deductions from a paycheck is for Social Security. This item is usually shown on the pay stub as _____.
   a. Social Security
   b. SSA
   c. FICA
   d. U.S. government deduction
8. Technician A says that the net pay amount is usually higher than the gross pay amount. Technician B says that the gross pay amount is usually higher than the net pay. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. A beginning service technician earns $400 per week. How much should the technician spend on a vehicle payment?
   a. $400 per month **c.** $800 per month
   b. $500 per month **d.** $1000 per month
10. Which activity does not allow a person to perform any work while at the shop?
    a. Cooperative education program
    b. Apprenticeship program
    c. Job shadowing
    d. Part-time employment

chapter 4

WORKING AS A PROFESSIONAL SERVICE TECHNICIAN

OBJECTIVES: **After studying Chapter 4, the reader will be able to:** • Discuss how to start a new job. • Describe the advantages of having a mentor. • Explain how a mentor can improve on-the-job learning. • Discuss the role of the trainee with a mentor. • Explain formal and informal evaluations. • Describe the role of a service technician. • Explain how the flat-rate pay plan works. • Describe the type and pricing of parts.

KEY TERMS: Advisor 31 • Advocate 31 • Aftermarket parts 29 • Coach 30 • Core 29 • Core charge 29 • Counselor 30 • Critical thinking 31 • Customer pay (CP) 28 • Flagging 29 • Formal evaluation 32 • Informal evaluation 32 • Jobber 29 • Mentor 30 • Original equipment (OE) 29 • Rebuilt 30 • Remove and inspect (R & I) 29 • Remove and replace (R & R) 29 • Renewal parts 29 • Repair order (RO) 27 • Role model 31 • Service bay 27 • Stall 27 • Teacher 30 • Three Cs (concern, cause, correction) 27 • Trainee 30 • Warehouse distributor 29

PROFESSIONALISM

Professionalism and personal credibility are important and can determine success as a service technician or as a customer service provider. A true professional does the following on a regular basis.

1. **Practice consistency.** Be positive, professional, and warm at all times.
2. **Keep your word.** Follow through with the commitments that you make. People will not have faith in you if you break your promises.
3. **Develop technical expertise.** Become very knowledgeable about the vehicles being serviced. Attend regular update training classes to keep up with the latest technical information and equipment.
4. **Become a teammate with your co-workers.** Working successfully with others shows that you have common goals and can benefit from the specific skills of others.
5. **Be accountable.** Practice honesty all of the time, admit mistakes, and take responsibility for actions. Apologize if you are wrong.

ETHICS

Ethics are a set of principles that govern the conduct of an individual or group. Sometimes ethical decisions are easy to recognize and are perceived as popular choices of behavior by the people around us. At other times the spectrum of potential choices falls into gray areas in which the "right" or "wrong" course of action is difficult or nearly impossible to identify. When faced with an ethically challenging situation, ask yourself the following questions:

- Is it legal? (Is it against local, state, or federal laws?)
- Is it fair? (Is it harmful to me or to others?)
- How do I feel about it? (Is it against the teachings of my parents or my religion?)



TECH TIP

Clean Clothes Are a Must

Anyone who meets the public in any business must not only be dressed appropriately, but the clothing should be clean. Service advisors and others that greet the public should also be sure that their shoes are shined. Dull, dirty, or scuffed shoes or messy appearance reflects an unprofessional look.

- Would the court of public opinion find my behavior incorrect? (Would it disappoint my family?)
- Am I fearful of what those I trust would say about my actions? (Would I be hurt or upset if someone did this to me?)

The above questions can be quite revealing when attempting to choose an ethical course of action.

COMMUNICATIONS

The five main methods of communication used in effective customer service interaction include listening, talking, nonverbal communications, reading, and writing.

LISTENING

Active listening is the ability to hear and understand what the speaker is saying. To listen to your customers or other technicians is to show them that you care about and respect their questions and concerns. It is not easy to be a good listener; it takes practice and dedication to improve your listening techniques. Listening is a skill that must continuously be developed.

Several barriers to good listening exist. A listener may be distracted from what is being said, have a closed mind to the speaker

TECH TIP

Never Use Profanity

Regardless of the situation, a true professional never resorts to the use of profanity. If tensions are high and the discussion becomes heated, try to defuse the situation by turning the situation over to someone else.

and the message, won't stop talking, or is lazy and unwilling to make the commitment to be a good listener.

Listening requires the listener to stop talking and to hear what the speaker is saying. It has been said that humans were given two ears and one mouth because we are supposed to listen twice as much as we speak. The best way to keep your mind focused on the speaker and to avoid becoming distracted is to pay attention. We can think about 10 times faster than we can speak, so frequently we have processed what speakers have said and are waiting for them to catch up with us. By focusing on speakers and on what is being said we are less likely to miss the messages being delivered. Putting that into practice is not as easy as it sounds.

A good listener does the following:

- Focuses on the speaker and what is being said.
- Looks at the speaker and makes eye contact when possible.
- Listens with an open mind.
- Rephrases what was said to clarify that the intended message is understood.
- A good listener knows the joy of sharing and communicating with others. Work to become the best listener you can be.

TALKING Talking means speaking, using words and terminology that others can comprehend. Eye contact is always important when we are communicating with others. Eye contact is allowing our eyes to make visual contact with someone else's. In our culture, eye contact conveys sincerity and interest. Avoiding eye contact may suggest a lack of concern or lack of honesty. Customers may perceive that a customer service provider is not interested in what they are saying if they do not periodically make eye contact with the customer.

When dealing with people from other cultures, customer service providers should be aware of cultural differences. In many other cultures eye avoidance is a sign of respect. Be sensitive to others but use eye contact whenever possible.

NONVERBAL COMMUNICATION The tone and inflection of the voice, facial expressions, posture, hand movements, and eye contact are all forms of nonverbal communications. These nonverbal indicators can contradict the message conveyed through another method of communication.

Nonverbal communication includes body posture such as having the arms crossed. When a person crosses their arms, or looks at other things rather than paying attention to what you are discussing, these actions could indicate one of several things including:

1. They are not interested in what you are saying
2. They don't believe what you are saying
3. They are not listening

If this type of nonverbal communication is noticed, there are several things that could be done to overcome this barrier including:



FIGURE 4–1 When answering the telephone, be sure to have paper and pen or pencil handy to record the customer information.

TECH TIP

Always Have Paper and a Pen When on the Telephone

When talking to a customer, whether in person or on the telephone, have paper and a pencil or pen to record the necessary information. In this case, the customer service representative at a dealer is using a preprinted form to record the service procedures to be performed on a customer's vehicle while talking on the phone. ● **SEE FIGURE 4–1**.

1. Ask questions, which would require them to pay attention plus it shows that you are interested in what they think.
2. Give the customer options rather than just ask them what they want such as saying "would you prefer to have this work done all at the same time or spread out over several weeks?"

TELEPHONE COMMUNICATION A large percentage of customers make first contact with a shop or dealer service department by telephone. Service technicians normally do not talk to customers directly but may be asked to help clarify a repair or a service procedure.

Some suggestions when talking on the telephone include:

- Use proper titles for the people with whom you communicate. If in doubt about whether to use a first name, call the person by the more formal *Mr.* or *Ms.* If they prefer the more informal first name, they will say so. It is better to be a little too formal than overly familiar.
- Thank people for calling. "Thank you" is the most powerful phrase in human relations and it reassures customers that you are interested in serving.
- Try to avoid technical terms and abbreviations such as EGR and other terms commonly used in the trade but will not be understood by the customer. Try to phrase the technical description by saying that you replaced or serviced a part in the emission control system and include the entire name of the part such as the "exhaust gas recirculation valve."
- Keep your comments positive and focused toward solving the problem or concern.



FIGURE 4–2 If you smile while talking on the telephone, your attitude will be transmitted to the customer.

TECH TIP

Smile While You Talk

If you smile while talking on the telephone, your voice will reflect a positive and helpful attitude, which customers or vendors will easily recognize over the telephone. ● **SEE FIGURE 4–2.**

- Avoid saying anything that makes people or your shop look unprofessional or uncaring. When dealing with customers, some words are more positive and appropriate to use. Some customer service providers find it helpful to list words to use and words to avoid on a card so that it is available for easy reference.
- Speak clearly and distinctly. Hold the telephone mouthpiece about a half-inch from your lips. Speak naturally and comfortably. Talk to your caller as you would to a friend.
- Move to a quiet area if background noise level is high.

WRITING Writing is communicating by using the written word so that others can understand the intended message. Service technicians are required to document the work that was performed on a vehicle. For some technicians this is the most difficult part of the service. If writing, be sure it is legible and if not, then print all messages and information. Writing or typing in the description of the steps performed during the diagnosis and repair of the vehicle should be worded as if the technician is talking to the customer. For example, if a coolant leak was repaired by replacing the water pump the technician should write out the following steps and operations on the work order:

1. Visually verified coolant leaking.
2. Performed a pressure test of the cooling system and located the leak as coming from the water pump.
3. Replaced the water pump and added new coolant and bled the system of trapped air.
4. Pressure tested the cooling system to verify that the leak was corrected—no leaks found.

READING Reading means the ability to read and comprehend the written word. All service technicians need to be able to read, understand, and follow written instructions and repair procedures. If some words are not understood use a dictionary or ask another technician for help. For example, a beginning technician read in the service information that the wiring connector was "adjacent to the coolant reservoir." The technician did not understand what the word adjacent meant and found out from another technician that it meant "next or close to."

If reading a note from a customer written in another language you do not understand try to ask if someone else in the shop can read it for you.

TECH TIP

Use Internet Translation

If the customer is non-English speaking, type the information into a text document and search for a translation on the Internet. Give the copy of the translated document to the customer. The customer request could also be translated into English if needed to help the shop understand exactly what the customer is requesting and needs.

TECH TIP

Google Is Your Friend

If unsure as to how something works or if you need more detailed information about something, go to *www.google.com*® and search for the topic. Using the Internet can help with locating hard-to-find facts and can even be used to help with a service procedure that you have not done before. For a link to all factory service information, go to the Web site of National Automotive Service Task Force at *www.nastf.org*. Look at the work scheduled for the next day and try to determine as much about the job as possible so you can be prepared the next day to tackle the procedure. Using the International Automotive Technicians Network at www.iatn.net is also very helpful for technical information and can help pin down hard-to-find problems.

WHAT HAPPENS THE FIRST DAY?

The first day on the job, someone, usually the shop owner or shop foreman, should:

- Introduce the new technician to key people at the shop.
- Show the new technician the facility, parking, rules, and regulations of the organization.
- Establish the new technician's work area.
- Ask questions of the new technician regarding their skills and talents.

The shop owner or foreman should:

- Review the training tasks that were completed in school.
- Try to direct work to the new technician that covers the new training material.

The first day on the job the beginning technician should:

- Smile and ask questions if needed to clarify procedures and regulations.

TECH TIP

Don't Touch Other Technician's Tools

A beginning technician seldom has all of the tools needed to perform all of the service and repair tasks. A technician's tools are very important. If a tool needs to be borrowed, the beginning technician should ask for permission to borrow a tool. Then when the tool is returned , it should be clean and replaced back exactly where the technician asks for it to be returned.

TECH TIP

If Late—Call

When running late, you may know that you will be just a few minutes late but your boss does not how late you will be. If you are going to be late, even by a few minutes, call the shop and let them know. This does not eliminate your being late from your record, but does demonstrate your concern to your service manager and other technicians who are counting on you to being on time to work every day.

TECH TIP

Regulated Terms to Use

In some states or areas where automotive service is regulated, such as in California or Michigan, it is important that the term used to describe a labor operation is the term defined by the state agency. This means that some terms used in parts and time guides may not be the same terms used by the state. Always check that the terms used are in compliance with all regulations. Some terms that could be affected include rebuild, repair, overhaul, inspection and R & R (remove and replace), and safety inspection.

TECH TIP

Ask Me about This

A good service advisor will document what the customer wants done on the work order. However, there are times when the explanation and description would take too long and too much space to be practical. In these cases, the wise service advisor simply states on the work order for the service technician to see the service advisor to discuss the situation. The service advisor can write the basic request to document what is needed.

- Be prepared to take and pass a drug test.
- Assure the service manager or shop owner that you are serious about a career as an automotive technician.

A work order, also called a **repair order** or **RO** is assigned to a technician who is best qualified to perform the work. The technician gets the keys and drives the vehicle to an assigned **service bay** (also called a **stall**), performs the proper diagnosis, gets the necessary parts from the parts department, and completes the repair.

After the service work has been performed, the service technician should then fill out the work order and describe what work was performed. These are called the "**three Cs.**"

1. **Concern**—Write on the work order what was done to confirm the customer's concern. For example, "Drove the vehicle at highway speed and verified a vibration."
2. **Cause**—The service technician should write the cause of the problem. For example, "Used a scan tool and discovered that cylinder #3 was misfiring."
3. **Correction**—The service technician should write what was done to correct the problem. For example, "Removed the spark plug wire from cylinder number three and by visual inspection found that the boot had been arcing to the cylinder head. Replaced the spark plug wire and verified that the misfire was corrected."

DUTIES OF A SERVICE TECHNICIAN

READING THE WORK ORDER A work order is selected or assigned to a service technician who then performs the listed tasks. The work order should be written so that the technician knows exactly what needs to be done. However, if there is any doubt, the technician should clarify the needed task with the service advisor or the person who spoke to the customer.

TALKING TO CUSTOMERS The typical service technician usually does not talk directly to a customer except in some smaller shops. However, there may be causes where the technician will be asked to clarify a procedure or repair to a customer. Many technicians do not like to talk to the customers and fear that they may say too much or not enough. If a technician is asked to talk to a customer, try to keep the discussion to the following without being too technical.

- The service technician should repeat the original concern. This is to simply verify to the customer and the technician the goal of the service or repair.
- The cause of the fault should be mentioned. If further diagnostic steps needed to find the cause are requested, discuss the steps followed and the equipment or tools used.
- Discuss what was done to solve the concern, including what part or parts were replaced. This step may also include what other service operations were needed to complete the repair, such as reprogramming the computer.

NOTE: If the customer speaks a foreign language that you do not understand, excuse yourself and locate someone in the shop who can assist you with communicating with the customer. Avoid using slang or abbreviation of technical terms. Ask the person if they understand and be willing to restate, if needed, until the situation is understood. This can often be difficult if discussing technical situations to persons of another language or culture.

ESTIMATING A REPAIR Sometimes a service technician is asked to help create an estimate for the customer. It is usually the responsibility of the service advisor or shop owner to create estiates.

TECH TIP

Car, Truck, or Vehicle?

When discussing a vehicle with a customer, it is best to avoid creating problems. For example, if a technician asked about a customer's "car," the customer could become concerned because they drive a truck and many owners of trucks do not want their vehicle called a car. Use of the term "vehicle," a generic term, is often recommended when talking to customers to avoid possible concerns.

FREQUENTLY ASKED QUESTION

What Can a Service Technician Do to Earn More Money?

Because service technicians are paid on a commission basis (flat-rate), the more work that is completed, the more hours the technician can "turn." Therefore, to earn the most money, the service technician could do the following to increase the amount of work performed:

- Keep up-to-date and learn the latest technical information
- Practice good habits that help avoid errors or incomplete repairs
- Learn from experienced and successful fellow technicians and try to approach the repair the same way the successful technician does
- Purchase the proper tools to do the work efficiently

NOTE: This does not mean that every technician needs to purchase all possible tools. Purchase only those tools that you know you will need and use.

The technician may be helpful by pointing out all of the operations that need to be performed to achieve a repair. The estimate for a repair includes:

- **Parts needed**—This list would also include any gaskets and/or supplies needed. The technician can help identify if extra supplies may be needed.
- **Labor**—A published time guide is usually used but many times options such as rear air conditioning or four-wheel drive may add substantial time to the operation. The technician can help with the estimate by making sure that the options are pointed out to the service advisor or shop owner.

DOCUMENTING THE WORK ORDER The service technician must document the work order. This means that the service technician must write (or type) what all was done to the vehicle including documenting defective components or conditions that were found in the course of the diagnosis. The documentation is often called "telling the story" and should include the following:

- The test equipment used to diagnose the problem. For example: Used a Tech 2 scan tool to retrieve P0300 random misfire diagnostic trouble code.
- Used a digital multimeter to determine a spark plug wire was defective.
- List what parts or service operations were performed. For example: Replaced the spark plug wire on cylinder number 3. Used a scan tool to clear the diagnostic trouble codes and verify that the engine is operating correctly.

FOLLOWING RECOMMENDED PROCEDURES All service technicians should follow the diagnostic and service procedures specified by the vehicle manufacturer. Following service information procedures includes the following:

- Follow and document the diagnostic procedure. Writing down the test results helps the customer see all that was involved in the procedure and creates the proper paper trail for future reference, if needed.
- Follow the recommended removal and reinstallation (R & R) procedures. This step helps prevent the possibility of doing harm to the vehicle if an alternative method is attempted.
- Always torque fasteners to factory specifications. This step is very important because under- or overtightened fasteners can cause problems that were not present until after the repair. The wise technician will document torque specifications on the work order.

CUSTOMER PAY **Customer pay (CP)** means that the customer will be paying for the service work at a dealership rather than the warranty. Often the same factory flat-rate number of hours is used to calculate the technician's pay, but customer pay often pays the service technician at a higher rate. For example, a service technician earning $15.00 per flat-rate hour for warranty work may be paid $18.00 per hour for customer-pay work. Obviously, service technicians prefer to work on vehicles that require customer-pay service work rather than factory-warranty service work.

NONDEALERSHIP FLAT-RATE Technicians who work for independent service facilities or at other nondealership locations use one or both of the following to set rates of pay:

- Mitchell, Motors, or Chilton parts and time guides
- Alldata, Shop-Key, Car-Quest, Auto Value, Mitchell, AC Delco, or other shop management software program.

These guides contain service operation and flat-rate times. Generally, these are about 20% higher (longer) than those specified by the factory flat-rate to compensate for rust or corrosion and other factors of time and mileage that often lengthen the time necessary to complete a repair. Again, the service technician is usually paid a dollar amount per flat-rate hour based on one of these aftermarket flat-rate guides. The guides also provide a list price for the parts for each vehicle. This information allows the service advisor to accurately estimate the total cost of the repair.

FLAGGING A WORK ORDER

When a service technician completes a service procedure or repair, a sticker or notification on the work order indicates the following:

- Technician number (number rather than a name is often used not only to shorten the identification but also to shield the actual identity of the technician from the customer)
- Work order number

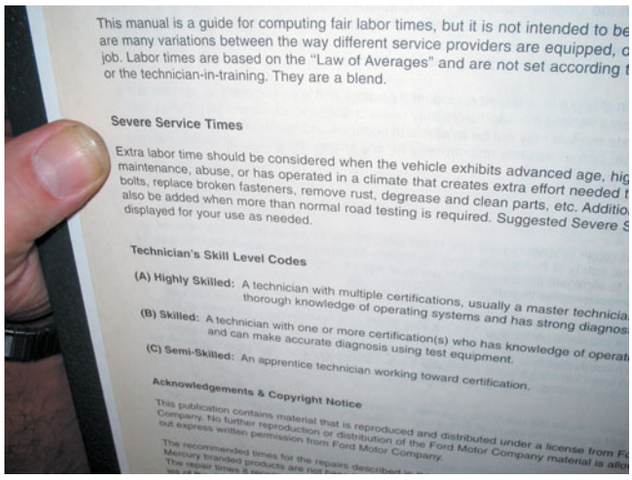


FIGURE 4–3 Note the skill levels of the technician and the extra time that should be added if work is being performed on a vehicle that has excessive rust or other factors as stated in the time guide.

TECH TIP

Technician Skill Level and Severe Service

Most aftermarket service information includes a guideline for the relative level of the technician's skill required to perform the listed service procedures. These include:

A = Highly skilled and experienced technician
B = Skilled technician who is capable of performing diagnosis of vehicle systems
C = Semi-skilled technician who is capable of performing routine service work without direct supervision

Many time guides provide additional time for vehicles that may be excessively rusted due to climate conditions or have been subjected to abuse. Be sure to quote the higher rate if any of these conditions are present on the customer's vehicle. ● **SEE FIGURE 4–3**.

- Actual clock time from a time clock record for certain jobs as needed.
- Amount of time allocated to the repair expressed in hours and tenths of an hour

The application of the service technician's sticker to the back of the work order or completing the details of the repair into the electronic service record is called **flagging the work order.**

NOTE: The actual assignment of the time is often done by another person at the dealership or service facility. This procedure assures that the correct number of hours is posted to the work order and to the technician's ticket.

SUBLET REPAIRS

Often a repair (or a part of a repair) is performed by another person or company outside of the dealership or service facility. For example, an engine needing repair that also has a defective or leaking radiator would be repaired by the original repair facility, but the radiator may be sent to a specialty radiator repair shop. The radiator repair cost is then entered on the work order as a sublet repair.

PARTS REPLACEMENT

Parts replacement is often called **R & R,** meaning **remove and replace.**

NOTE: R & R can also mean remove and repair, but this meaning is generally not used as much now as it used to be when components such as starters and air-conditioning compressors were repaired rather than replaced as an assembly.

R & I is often used to indicate **remove and inspect** to check a component for damage. The old replaced part is often returned for remanufacturing and is called a **core.** A **core charge** is often charged by parts stores when a new (or remanufactured) part is purchased. This core charge usually represents the value of the old component. Because it is needed by the remanufacturer as a starting point for the remanufacturing process, the core charge is also an incentive to return the old part for credit (or refund) of the core charge.

NOTE: Most parts stores today require that all cores be returned in the original boxes. Be sure to place the defective part into the same box that was used for the new or remanufactured part to be sure that the shop gets the proper credit for the core.

ORIGINAL EQUIPMENT PARTS Parts at a new vehicle dealership come either directly from the vehicle manufacturer or a regional dealership. If one dealership purchases from another dealership, the cost of the part is higher, but no waiting is required. If a dealership orders a part from the manufacturer directly, the cost is lower, but there is often a 7- to 10-day waiting period. **Original equipment** parts, abbreviated **OE,** are generally of the highest quality because they have to meet performance and durability standards not required of replacement parts manufacturers.

NOTE: Many service technicians will use only OE parts for certain critical systems such as fuel injection and ignition system components because, in their experience, even though the price is often higher, the extra quality seems to be worth the cost not only to the owner of the vehicle but also to the service technician who does not have to worry about having to replace the same part twice.

AFTERMARKET PARTS Parts manufactured to be sold for use after the vehicle is made are often referred to as **aftermarket parts** or **renewal parts.** Most aftermarket parts are sold at automotive parts stores or **jobbers.** A jobber or parts retailer usually gets parts from a large regional **warehouse distributor.** The warehouse distributor can either purchase parts directly from the manufacturer or from an even larger central warehouse. Because each business needs to make a profit (typically, 35%), the cost to the end user may not be lower than it is for the same part purchased at a dealership (two-step process instead of the typical three-step process) even though it costs more to manufacture the original equipment part. To determine what a 35% margin increase is for any product, simply divide the cost by 0.65. To illustrate how this works, compare the end cost of a part (part A) from a dealership and a parts store.

Retail Parts Store	New Vehicle Dealership
Manufacturer's selling price = $17.00	Manufacturer's selling price = $25.00
Warehouse distributor's selling price = $26.15 ($17.00 ÷ 0.65 = $26.15)	Parts department selling price = $38.46 ($25.00 ÷ 0.65 = $38.46)
Retail store selling price = $40.23 ($26.15 ÷ 0.65 = $40.23)	

NOTE: The cost of the part to the customer where service work is performed is increased about 35% over the base cost of the part. For example, a part that cost the repair facility $40.23 will be billed to the customer at about $61.00. The retail service customer at the dealer may pay $59.17 ($38.46 ÷ 0.65 = $59.17).

NEW VERSUS REMANUFACTURED PARTS

New parts are manufactured from raw materials and have never been used on a vehicle. A remanufactured component (also called **rebuilt**) has been used on a vehicle until the component wore out or failed. A remanufacturer totally disassembles the component, cleans, machines, and performs all the necessary steps to restore the part to a "like new" look and function. If properly remanufactured, the component can be expected to deliver the same length of service as a new component part.

The cost of a remanufactured component is often less than the cost of a new part.

CAUTION: Do not always assume that a remanufactured component is less expensive than a new component. Due to the three-step distribution process, the final cost to the end user (you) may be close to the same!

USED PARTS

Used parts offer another alternative to either new or remanufactured parts. The cost of a used component is typically one-half the cost of the component if purchased new. Wrecking and salvage yards use a Hollander manual that lists original equipment part numbers and cost and cross-references them to other parts that are the same.

WORKING WITH A MENTOR

A mentor is a person at the job site who helps the beginning service technician, also called the **trainee.** The word **mentor** comes from Greek mythology. In Homer's *The Odyssey,* Mentor was the faithful companion and friend of Ulysses (Odysseus), the King of Ithaca. Before Ulysses went to the Trojan Wars, he instructed Mentor to stay and take full charge of the royal household. This meant that Mentor had to be father figure, teacher, role model, counselor, trusted advisor, challenger, and encourager to the King's son in order that he become a wise and good ruler.

Therefore, a good definition of a mentor would be, "A highly qualified individual who is entrusted with the protection and development of an inexperienced technician."

A mentor therefore fulfills many roles, such as:

- **Teacher**—helps teach information and procedures
- **Coach**—has trainee practice service procedures
- **Counselor**—concerned about, but not trained to offer advice on personal life decisions.
- **Advisor**—helps with career-type decisions, such as what tools are needed
- **Advocate** (stands up for the trainee)—represents and helps the trainee's concerns be expressed to others
- **Role model**—presents a positive role model every day

QUALIFICATIONS OF A GOOD MENTOR

A good mentor should be assigned to a new technician. Qualifications of a good mentor include:

- **Trade proficiency**—The person selected should be a highly skilled technician.
- **Good coaching/mentoring skills and techniques**—The mentor has to have patience and be willing to help the trainee by explaining each step needed to complete a service procedure.

TECH TIP

Work Habit Hints

The following statements reflect the expectations of service managers or shop owners for their technicians:

1. Report to work every day on time. Being several minutes early every day is an easy way to show your service manager and fellow technicians that you are serious about your job and career.
2. If you *must* be late or absent, call your service manager as soon as possible.
3. Keep busy. If not assigned to a specific job, ask what activities the service manager or supervisor wants you to do.
4. Report any mistakes or accidents *immediately* to your supervisor or team leader. *Never* allow a customer to be the first to discover a mistake.
5. Never lie to your employer or to a customer.
6. Always return any borrowed tools as soon as you are done with them and in *clean* condition. *Show* the person you borrowed the tools from that you are returning them to the toolbox or workbench.
7. Keep your work area neat and orderly.
8. Always use fender covers when working under the hood.
9. Double-check your work to be sure that everything is correct.
   a. Remember: "If you are forcing something, you are probably doing something wrong."
   b. Ask for help if unclear as to what to do or how to do it.
10. Do not smoke in a customer's vehicle.
11. Avoid profanity.
12. DO NOT TOUCH THE RADIO! If the radio is turned on and prevents you from hearing noises, turn the volume down. Try to return the vehicle to the owner with the radio at the same volume as originally set.

    NOTE: Some shops have a policy that requires employees to turn the radio off.

13. Keep yourself neatly groomed including:
    a. Shirttail tucked into pants (unless shirt is designed to be worn outside)
    b. Daily bathing and use of deodorant
    c. Clean hair, regular haircuts, and hair tied back if long
    d. Men: daily shave or keep beard and/or mustache neatly trimmed
    e. Women: makeup and jewelry kept to a minimum

TECH TIP

Adhere to the Times

When starting a new job at a shop or dealership, be sure to ask about the following:

- **What time should I arrive at work?** This may be different than the scheduled work starting time. For example, the work day could start at 8 a.m. but the shop owner or service manager may want all technicians to arrive and start to get ready to work at 7:50 a.m.
- **When is break time?** Breaks may or may not be regularly scheduled and it is important for the beginning technician to know and adhere to break times.
- **When is lunch time?** In some busy shops, the lunch period is staggered to be sure that some technicians are always available for work. Always be willing to adhere to the requested lunch period.

- **Leadership/role model**—The mentor should take pride in being a professional service technician and have high ethical and professional standards.

Mentoring a trainee can be frustrating for an experienced technician. This occurs because the mentor needs to verify almost everything the trainee does until satisfied that competence has been achieved. Even very basic procedures need to be watched, such as hoisting the vehicle, changing the oil and oil filter, plus many other operations. As a result, the time taken to help the beginning technician will reduce the efficiency, and therefore, the pay of the mentor. However, after several weeks, the trainee can start helping the mentor, thereby increasing efficiency.

TEAMWORK

TEAM BUILDING

A team is a group of individuals working together to achieve a common goal. Even shops or service departments that do not use a team system with a group of technicians is still a team. All members of the service department are really part of a team effort working together to achieve efficient vehicle service and customer satisfaction. The key to building a team that works together is selecting employees that are willing to work together. While the shop owner or service manager at a dealership has hiring authority, every technician should consider what is best for the entire group to help increase repeat business and satisfied customers.

LEADERSHIP ROLES

As a technician gains experience, he or she often asks for guidance, not only for technical answers, but also for how to handle other issues in the shop, such as paperwork, use of aftermarket parts, and other issues. Therefore, the more experience the technician has, the more likely he or she will be placed in a leadership and role model position.

GOAL SETTING AND BUSINESS MEETINGS

GOAL SETTING

The wise service technician sets goals to achieve during a career and life. The purpose of goal setting is to focus efforts on improving your personal and professional life. Goals can include:

Career, physical, family, education, financial and public service. There are many helpful web sites that can be used to help set and track progress toward achieving goals. The hardest part of any goal is to write it down. Until it is written down, a goal is not real.

BUSINESS MEETINGS

All service technicians attend business (shop) meetings. A good business meeting will have the following features:

1. An agenda (list of topics to be discussed) will be given out or displayed.
2. The meeting should start on time and end on time.
3. If someone is to give a report or be asked to do a project, this topic should be discussed with the designated person before the meeting to avoid that person from being surprised and made to feel uncomfortable.
4. The meeting should be held following the "Robert's Rule of Order" guidelines.
5. Often meetings include others from inside or outside the company or shop, so try to look your best and smile to make the best impression.

ADVANCEMENT SKILLS

The job of a service technician becomes more valuable to the shop or dealership if work can be accomplished quickly and without any mistakes. Therefore, being careful to avoid errors is the first consideration for any service technician. Then, with experience, the speed of accomplishing tasks can and will increase.

More than speed is needed to become a master technician. It requires problem solving and critical thinking skills, too. While beginning technicians are usually not required to diagnose problems, troubleshooting skills are very important toward becoming a master technician. Most master technicians follow a plan which includes:

1. Always verify the customer concern.
2. Perform a thorough visual inspection and check for possible causes of the problem, including damage from road debris or accidents.
3. Use a scan tool and check for stored diagnostic trouble codes (DTCs).
4. Check service information for technical service bulletins (TSBs).
5. Check service information and follow all diagnostic trouble charts.
6. Locate and correct the root cause of the problem.
7. Verify the repair and document the work order.

The hardest part of the diagnostic process is to locate the root cause of the problem. The process of analyzing and evaluating information and making a conclusion is called **critical thinking.**

HOUSEKEEPING DUTIES

A professional service technician is usually responsible for keeping his or her work area clean and tidy. Good housekeeping includes all of the following:

- **Clean floor**—If coolant or oil is spilled on the floor during a repair procedure, it should be cleaned before starting another job.

TECH TIP

Keeping "Things" off the Floor

To make cleaning easier and for a more professional shop appearance, keep only those items on the floor that have to be on the floor and find a place off the floor for all other items.

TECH TIP

Look at the Shop from a Customer's Point of View

To determine if the shop and other technicians look professional, step outside and enter the shop through the same door as a customer. Now look around. Look at the shop and the other technicians. Does the shop give the appearance of a professional service facility? If not, try to improve the look by asking the shop owner or service manager to do the same thing in an attempt to create a more professional looking shop.

- **Tool box**—Keep work area and tool box clean and organized.
- **Items kept off the floor**—It is easy to allow parts and other items to be stored in and around the toolbox and in corners. However, having items on the floor makes keeping the area clean and neat looking very difficult.
- **Keep areas around exits and fire extinguishers clear.** Do not store or place parts, boxes, or shop equipment, such as floor jacks and testers, near exits and fire extinguishers. This helps ensure that people can have easy access to exits or the fire extinguishers in the event of an emergency.
- **Avoid spraying chemicals in the air.** To help keep the air in the shop clean, keep the use of spray chemicals, such as brake cleaner, to a minimum and avoid spraying where it could result in affecting the air others breathe.

SELF-MANAGEMENT

A professional service technician should try to maintain a professional appearance at all times. For example, if coolant or automatic transmission fluid (ATF) gets onto a shirt or pants, the wise technician would change into a clean uniform before working on another vehicle. Many shop owners and service managers recommend that shirttails always be tucked into pants to ensure a more professional appearance.

JOB EVALUATION

In most jobs, there is an evaluation of performance. A beginning technician is not expected to perform at the same level as an experienced master technician but should be able to do the following:

- **Follow instructions.** The trainee should follow the instructions of the mentor or service manager. This includes making sure that the person is notified when the job has been completed and if there were any problems.

TECH TIP

Write It Down

If a technician needs to have another technician finish a repair due to illness or some other reason, be sure to write down exactly what was done and what needs to be done. Verbal communication, while very effective, is often not a good way to explain multiple steps or processes. For example, the other technician could easily forget that the oil had not yet been added to the engine, which could cause a serious problem if the engine were to be started. If in doubt, write it down.

TECH TIP

Don't Cover Up Mistakes

Everyone makes mistakes. While a damaged component or vehicle is never a good thing to have happen, the wise technician should notify the service manager or other person in charge as soon as a problem or accident occurs. Only then can work begin to correct the problem. If a mistake is hidden, eventually someone will learn about the error and then people will not think it was wise to ignore or to cover up the situation.

- **Do no harm.** Avoid exerting a lot of force to door panels or other components to help avoid breaking clips or components. Always use the right tool for the job. For example, never use pliers to remove a bolt or nut, which could round off the flats of the fastener. Always think before acting, "Am I going to hurt something by doing this?"
- **Keep a neat and clean appearance.** It is normal to get dirty while performing service work on a vehicle. However, after each job is completed or even during the repair, try to keep as clean as possible.
- **Ask that your work be checked.** Even though the trainee thinks that the service or repair was done correctly, until confidence has been established, it is wise to ask to have all work double-checked.

CAUTION: Never allow a mistake to reach the customer. It is only a problem if it cannot be corrected.

FORMAL EVALUATION The mentor and/or service manager may or may not conduct a written evaluation on a regular basis. If a written evaluation is performed, this is called a **formal evaluation.** A formal evaluation usually includes many points of discussion. See the sample evaluation form.

INFORMAL EVALUATION In many cases, a beginning technician's activities are simply observed and noted, which is a type of **informal evaluation.** Both are usually done and both can influence the technician's pay.

NOTE: Most employees are fired from a job as the result of not being able to get along with others, rather than a lack of technical skills.

Technician Evaluation

Please check one of the spaces to the left of each characteristic which best expresses your judgment of the technician:

ATTITUDE-APPLICATION TO WORK
_____outstanding in enthusiasm
_____very interested and industrious
_____average in diligence and interest
_____somewhat indifferent
_____definitely not interested

DEPENDABILITY
_____completely dependable
_____above average in dependability
_____usually dependable
_____sometimes neglectful or careless
_____unreliable

QUALITY OF WORK
_____excellent
_____very good
_____average
_____below average
_____very poor

MATURITY
_____shows confidence
_____has good self-assurance
_____average maturity
_____seldom assertive
_____timid
_____brash

ABILITY TO LEARN
_____learned work exceptionally well
_____learned work readily
_____average in understanding work
_____rather slow in learning
_____very slow to learn

INITIATIVE
_____proceeds well on his or her own
_____proceeds independently at times
_____does all assigned work
_____hesitates
_____must be pushed frequently

RELATIONS WITH OTHERS
_____exceptionally well accepted
_____works well with others
_____gets along satisfactorily
_____has difficulty working with others
_____works very poorly with others

QUANTITY OF WORK
_____usually high output
_____more than average
_____normal amount
_____below average
_____low output, slow

JUDGMENT
_____exceptionally mature
_____above average
_____usually makes the right decision
_____often uses poor judgment

ATTENDANCE
_____regular
_____irregular

PUNCTUALITY
_____regular
_____irregular

REVIEW QUESTIONS

1. What factors are part of being a professional service technician?
2. What is a mentor?
3. What are the roles of a mentor?
4. What are the responsibilities the beginning technician has to the shop and/or mentor?
5. A formal evaluation could include what items?
6. What are the three Cs?
7. What should be included on the work order after the repair has been completed?

CHAPTER QUIZ

1. Professionalism includes which factor?
   a. Keeping your word
   b. Becoming a teammate with your co-workers
   c. Apologizing if you are wrong
   d. All of the above
2. Type of communications include _____.
   a. Verbal
   b. Written
   c. Nonverbal
   d. All of the above

3. The three Cs include _____, _____, and _____.
   a. Correction, correct torque, and customer name
   b. Concern, cause, and correction
   c. Cause, cost, and caller name
   d. Captured data, cause, and cost (of the repair)
4. When documenting the work order, what things should be listed?
   a. The test equipment used in the diagnosis
   b. The test procedure that was followed
   c. The parts that were replaced
   d. All of the above
5. Technician A says that customer-pay rate is sometimes higher than the factory flat-rate. Technician B says that the factory flat-rate times are usually longer (given more time) compared to aftermarket flat-rate time guides. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. Housekeeping duties of a technician can include _____.
   a. Cleaning the floor
   b. Keeping the work area clean and organized
   c. Keeping items off the floor whenever possible
   d. All of the above
7. If running late, the wise technician should _____.
   a. Call the shop and let them know you will be late
   b. Speed up
   c. Call the shop and take the day off
   d. Stop and eat a good breakfast before going to the shop
8. Flat-rate pay means _____.
   a. The same pay (flat-rate) every week
   b. The same number of hours every week
   c. The technician is paid according to the job, not by the number of hours worked
   d. The technician is paid overtime
9. Customer pay (CP) means _____.
   a. Customer pays for the repair or service
   b. Warranty does not pay for the repair or service
   c. The technician often gets paid more for each job
   d. All of the above
10. A mentor performs all of the following *except* _____.
   a. Helps guide diagnosis of a problem
   b. Signs paychecks
   c. Offers advice on how to do a job
   d. Advises on professional behavior

chapter 5 TECHNICIAN CERTIFICATION

OBJECTIVES: **After studying Chapter 5, the reader will be able to:** • Explain the requirements for becoming an ASE certified technician. • Describe the type of test questions asked on the certification tests. • Explain how to prepare to take the ASE certification tests. • Describe test taking skills needed to help pass the certification tests. • Explain how to register and take the ASE certification tests.

KEY TERMS: Except-type questions 36 • ASE (National Institute for Automotive service Excellence) 34 • Distracter 35 • Experience-based questions 35 • IP certification 40 • Key 35 • Least-likely-type question 36 • ASE certified master 35 • Most-likely-type question 36 • Multiple-choice question 36 • Technician A and B question 36 • Work experience 35

AUTOMOBILE TECHNICIAN CERTIFICATION TESTS

Even though individual franchises and companies often certify their own technicians, there is a nationally recognized certificate organization, the **National Institute for Automotive Service Excellence,** better known by its abbreviation, **ASE.** ● **SEE FIGURE 5–1**.

ASE is a nonprofit association founded in 1972, and its main goal is to improve the quality of vehicle service through standardized testing and volunteer certification.

WHAT AREAS OF VEHICLE SERVICE ARE COVERED BY THE ASE TESTS? Automobile test service areas include:

A1 Engine Repair
A2 Automatic Transmission/Transaxle
A3 Manual Drive Train and Axles
A4 Suspension and Steering
A5 Brakes
A6 Electrical/Electronic Systems
A7 Heating and Air Conditioning
A8 Engine Performance



FIGURE 5–1 The ASE logo. *(Courtesy of ASE)*

If a technician takes and passes all eight of the automobile tests and has achieved two or more years of work experience, ASE will award the designation of **ASE Certified Master Automobile Technician.** Contact ASE for other certification areas.

HOW CAN I CONTACT ASE?

ASE
101 Blue Seal Drive, SE
Suite 101
Leesburg, VA 20175

Toll-free: 1-877-ASE-TECH (273-8324)
1-703-669-6600
Web site: *www.ase.com*

WHEN ARE THE TESTS GIVEN AND WHERE?

The ASE written tests are given at hundreds of test sites throughout the year for online testing.

NOTE: ASE also offers tests at other times of the year electronically. Go to the ASE Web site for details.

Deadline for registration is usually in late March for the May tests and in late September for the November tests. Consult the ASE registration booklet or Web site for details and locations of the test sites.

WHAT DO I HAVE TO DO TO REGISTER?

You can register for the ASE tests in three ways:

1. Mail in the registration form that is in the registration booklet.
2. Register online at www.ase.com
3. Telephone at (866) 427-3273

Call ASE toll-free at 1-888-ASE-TEST or visit the Web site for details about cost and dates.

HOW MANY YEARS OF WORK EXPERIENCE ARE NEEDED?

ASE requires that you have two or more years of full-time, hands-on **working experience** either as an automobile, truck, truck equipment, or school bus technician, engine machinist, or in collision repair, refinishing, or damage analysis and estimating for certification, except as noted below. If you have *not* previously provided work experience information, you will receive a Work Experience Report Form with your admission ticket. You *must* complete and return this form to receive a certificate.

SUBSTITUTIONS FOR WORK EXPERIENCE. You may receive credit for up to one year of the two-year work experience requirement by substituting relevant formal training in one, or a combination, of the following:

High School Training: Three full years of training, either in automobile/truck/school bus repair or in collision repair, refinishing, or damage estimating, may be substituted for one year of work experience.

Post-High School Training: Two full years of post-high school training in a public or private trade school, technical institute, community or four-year college, or in an apprenticeship program may be counted as one year of work experience.

Short Courses: For shorter periods of post-high school training, you may substitute two months of training for one month of work experience.

You may receive full credit for the two-year work experience requirement with the following:

Completion of Apprenticeship: Satisfactory completion of either a three- or four-year bona fide apprenticeship program.

ARE THERE ANY HANDS-ON ACTIVITIES ON THE ASE TEST?

No. All ASE tests are written using objective-type questions, meaning that you must select the correct answer from four possible alternatives.

WHO WRITES THE ASE QUESTIONS?

All ASE test questions are written by a panel of industry experts, educators, and experienced ASE certified service technicians. Each question is reviewed by the committee and it is checked for the following:

- **Technically accurate.** All test questions use the correct terms and only test for vehicle manufacturer's recommended service procedures. Slang is not used nor are any aftermarket accessories included on the ASE test.
- **Manufacturer neutral.** All efforts are made to avoid using vehicle or procedures that are manufacturer specific such as to General Motors vehicles or to Toyotas. A service technician should feel comfortable about being able to answer the questions regardless of the type or brand of vehicle.
- **Logical answers.** All effort is made to be sure that all answers (not just the correct answers) are possible. While this may seem to make the test tricky, it is designed to test for real knowledge of the subject.
- **Random answer.** All efforts are made to be sure that the correct answers are not always the longest answer or that one letter, such as **c,** is not used more than any other letter.
- **Experience-based questions.** The questions asked are generally not knowledge-based questions, but rather require experience to answer correctly. Specifications are not asked for, but instead a question as to what would most likely occur if the unit is out-of-specifications could be asked.

KEY AND DISTRACTER

The **key** is the correct answer. As part of the test writing sessions, the committee is asked to create other answers which sound feasible but are not correct. These incorrect answers are called **distracters.**

WHAT TYPES OF QUESTIONS ARE ASKED ON THE ASE TEST?

All ASE test questions are objective. This means that there will not be questions where you will have to write an answer.

Instead, all you have to do is select one of the four possible answers and place a mark in the correct place on the score sheet.

- **Multiple-choice questions.** This type of question has one correct (or mostly correct) answer (called the key) and three incorrect answers. A multiple-choice question example: What part of an automotive engine does not move?

  a. Piston
  b. Connecting rod
  c. Block
  d. Valve

  The correct answer is **c** (block). This type of question asks for a specific answer. Answer **a** (piston), **b** (connecting rod), and **d** (valve) all move during normal engine operation. The best answer is **c** (block) because even though it may vibrate, it does not move as the other parts do.

- **Technician A and Technician B questions.** This type of question is generally considered to be the most difficult according to service technicians who take the ASE test. A situation or condition is usually stated and two technicians (A and B) say what they think could be the correct answer and you must decide which technician is correct.

  a. Technician A only
  b. Technician B only
  c. Both Technicians A and B
  d. Neither Technician A nor B

  The best way to answer this type of question is to carefully read the question and consider Technician A and Technician B answers to be solutions to a true or false question. If Technician A is correct, mark on the test by Technician A the letter T for true. (Yes, you can write on the test.) If Technician B is also correct, write the letter T for true by Technician B. Then mark **c** on your test score sheet, for both technicians are correct.

  Example:

  Two technicians are discussing an engine that has lower than specified fuel pressure. Technician A says that the fuel pump could be the cause. Technician B says that the fuel pressure regulator could be the cause.
  Which technician is correct?

  a. Technician A only
  b. Technician B only
  c. Both Technicians A and B
  d. Neither Technician A nor B

  Analysis:

  Is Technician A correct? The answer is yes because if the fuel pump was defective, the pump pressure could be lower than specified by the vehicle manufacturer. Is Technician B correct? The answer is yes because a stuck open regulator with a weak spring could be the cause of lower than specified fuel pressure. The correct answer is therefore **c** (Both Technicians A and B are correct).

- **Most-likely-type questions.** This type of question asks which of the four possible items listed is the most likely to cause the problem or symptom. This type of question is often considered to be difficult because recent experience may lead you to answer the question incorrectly because even though it is possible, it is not the "most likely."

  Example:

  Which of the items below is the most likely to cause blue exhaust at engine start?

  a. Valve stem seals
  b. Piston rings
  c. Clogged PCV valve
  d. A stuck oil pump regulator valve

  Analysis:

  The correct answer is **a** because valve stem seals are the most likely to cause this problem. Answer **b** is not correct because even though worn piston rings can cause the engine to burn oil and produce blue exhaust smoke, it is not the most likely cause of blue smoke at engine start. Answers **c** and **d** are not correct because even though these items could contribute to the engine burning oil and producing blue exhaust smoke, they are not the most likely.

- **Except-type questions.** ASE will sometimes use a question that includes answers that are all correct except one. You have to determine which of the four answers is not correct.

  Example:

  A radiator is being pressure tested using a hand-operated tester. This test will check for leaks in all except:

  a. Radiator
  b. Heater core
  c. Water pump
  d. Evaporator

  Analysis:

  The correct answer is **d** because the evaporator is not included in the cooling system and will not be pressurized during this test. Answers **a** (radiator), **b** (heater core), and **c** (water pump) are all being tested under pressure exerted on the cooling system by the pressure tester.

- **Least-likely-type questions.** Another type of question asked on many ASE tests is a question that asks which of the following is least likely to be the cause of a problem or symptom. In other words, all of the answers are possible, but it is up to the reader to determine which answer is the least likely to be correct.

  Example:

  Which of the following is the least likely cause of low oil pressure?

  a. Clogged oil pump screen
  b. Worn main bearing
  c. Worn camshaft bearing
  d. Worn oil pump

  Analysis:

  The correct answer is **c** because even though worn camshaft bearings can cause low oil pressure, the other answers are more likely to be the cause.

QUESTIONS OFTEN ASKED

SHOULD I GUESS IF I DON'T KNOW THE ANSWER? Yes. ASE tests simply record the correct answers, and by guessing, you will have at least a 25% (1 out of 4) chance. If you leave the answer blank, it will be scored as being incorrect. Instead of guessing entirely, try to eliminate as many of the answers as possible as not being very likely. If you can eliminate two out of the four, you have increased your chance of guessing to 50% (two out of four).

IS EACH TEST THE SAME EVERY TIME I TAKE IT? No. ASE writes many questions for each area and selects from this "test bank" for each test session. You may see some of the same questions if you take the same test in the spring and then again in the fall, but you will also see many different questions.

TECH TIP

Never Change an Answer

Some research has shown that your first answer is most likely to be correct. It is human nature to read too much into the question rather than accept the question as it was written.

CAN I SKIP QUESTIONS I DON'T KNOW AND COME BACK TO ANSWER LATER? Yes. You may skip a question if you wish, but be sure to mark the question and return to answer the question later. It is often recommended to answer the question or guess and go on with the test so that you do not run out of time to go back over the questions.

HOW MUCH TIME DO I HAVE TO TAKE THE TESTS? Each computer-based test will allow enough time for completion, usually between one and two hours for each test. The time allowed for each test is available on the ASE web site.

WILL I HAVE TO KNOW SPECIFICATIONS AND GAUGE READINGS? Yes and no. You will be asked the correct range for a particular component or operation and you must know about what the specification should be. Otherwise, the questions will state that the value is less than or greater than the allowable specification. The question will deal with how the service technician should proceed or what action should be taken.

CAN I TAKE A BREAK DURING THE TEST? Yes, you may use the restroom after receiving permission from the proctor of the test site.

CAN I LEAVE EARLY IF I HAVE COMPLETED THE TEST(S)? Yes, you may leave quietly after you have completed the test(s). You must return the score sheet(s) and the test booklets as you leave.

HOW ARE THE TESTS SCORED? The ASE tests are machine scored and the results tabulated by American College Testing (ACT).

WHAT PERCENTAGE DO I NEED TO ACHIEVE TO PASS THE ASE TEST? While there is no exact number of questions that must be answered correctly in each area, an analysis of the test results indicate that the percentage needed to pass varies from 61% to 69%. Therefore, in order to pass the Engine Repair (A1) ASE certification test, you will have to answer about 39 questions correct out of 60. In other words, you can miss about 21 questions and still pass.

WHAT HAPPENS IF I DO NOT PASS? DO I HAVE TO WAIT A YEAR BEFORE TRYING AGAIN? No. If you fail to achieve a passing score on any ASE test, you can take the test again at the next testing session (in May or November).

DO I HAVE TO PAY ANOTHER REGISTRATION FEE IF I ALREADY PAID IT ONCE? Yes. The registration fee is due at every test session in May or November whether you select to take one or more ASE tests. Therefore, it is wise to take as many tests as you can at each test session.

WILL I RECEIVE NOTICE OF WHICH QUESTIONS I MISSED? ASE sends out a summary of your test results, which shows how many questions you missed in each category, but not individual questions.

WILL ASE SEND ME THE CORRECT ANSWERS TO THE QUESTIONS I MISSED SO I WILL KNOW HOW TO ANSWER THEM IN THE FUTURE? No. ASE will not send you the answers to test questions.

TEST-TAKING TIPS

START NOW Even if you have been working on vehicles for a long time, taking an ASE certification test can be difficult. The questions will not include how things work or other "textbook" knowledge. The questions are based on "real-world" diagnosis and service. The tests may seem tricky to some because the wrong answers are designed to be similar to the correct answer.

If this is your first time taking the test or you are going to recertify, start now to prepare. Allocate time each day to study.

PRACTICE IS IMPORTANT Many service technicians do not like taking tests. As a result, many technicians rush through the test to get the pain over with quickly. Also, many service technicians have lots of experience on many different vehicles. This is what makes them good at what they do, but when an everyday problem is put into a question format (multiple choice), the answer may not be as clear as your experience has taught you.

KEYS TO SUCCESS The keys to successful test taking include:

- Practice answering similar-type questions.
- Carefully read each question two times to make sure you understand the question.
- Read each answer.
- Pick the best answer.
- Avoid reading too much into each question.
- Do not change an answer unless you are sure that the answer is definitely wrong.
- Look over the glossary of automotive terms for words that are not familiar to you.

The best preparation is practice, practice, and more practice. This is where using the ASE Test Prep practice tests can help.

PREPARE MENTALLY Practicing also helps relieve another potential problem many people have called "chronic test syndrome." This condition is basically an inability to concentrate or focus during a test. The slightest noise, fear of failure, and worries about other things all contribute. The best medicine is practice, practice, and more practice. With practice, test taking becomes almost second nature.

PREPARE PHYSICALLY Be prepared physically. Get enough sleep and eat right.

ONE MONTH BEFORE THE TEST

- Budget your time for studying. On average you will need four to six hours of study for each test that you are taking.
- Use the ASE Test Prep Online test preparation service three or more times a week for your practice.
- Study with a friend or a group if possible.

THE WEEK BEFORE THE TEST

- Studying should consist of about two hours of reviewing for each test being taken.
- Make sure you know how to get to the testing center. If possible drive to the test site and locate the room.
- Get plenty of rest.

THE DAY OF THE TEST

- Study time is over.
- Keep your work schedule light or get the day off if possible.
- Eat a small, light meal the evening of the test.
- Drink a large glass of water one to two hours before the test. (The brain and body work on electrical impulses, and water is used as a conductor.)
- Arrive at least 30 minutes early at the test center. Be ready to start on time.

WHAT TO BRING TO THE TEST

- A photo ID.
- Your Entry Ticket that came with your ASE packet.

DURING THE TEST

- BREATHE (oxygen is the most important nutrient for the brain).
- Read every question TWICE.
- Read ALL the ANSWERS.
- If you have trouble with a question, leave it blank and continue. At the end of the test, go back and try any skipped questions. (Frequently, you will get a hint in another question that follows.)

There are eight automotive certifications including:

1. Engine Repair (A1) ASE Task List

Content Area	Questions in Test	Percentage of Test
A. General Engine Diagnosis	15	28%
B. Cylinder Head and Valve Train Diagnosis and Repair	10	23%
C. Engine Block Diagnosis and Repair	10	23%
D. Lubrication and Cooling Systems Diagnosis and Repair	8	14%
E. Fuel, Electrical, Ignition, and Exhaust Systems Inspection and Service	7	12%
Total	**50**	**100%**

2. Automatic Transmission/Transaxles (A2) ASE Task List

Content Area	Questions in Test	Percentage of Test
A. General Transmission/Transaxle Diagnosis **1.** Mechanical/Hydraulic Systems (11) **2.** Electronic Systems (14)	25	50%
B. In-Vehicle Transmission/Transaxle Repair	12	16%
C. Off-Vehicle Transmission/ Transaxle Repair **1.** Removal, Disassembly, and Assembly (3) **2.** Gear Train, Shafts, Bushings, Oil Pump, and Case (4) **3.** Friction and Reaction Units (4)	13	26%
Total	**50**	**100%**

3. Manual Drive Train and Axles (A3) ASE Task List

Content Area	Questions in Test	Percentage of Test
A. Clutch Diagnosis and Repair	6	15%
B. Transmission Diagnosis and Repair	7	18%
C. Transaxle Diagnosis and Repair	7	20%
D. Drive (Half) Shaft and Universal Joint/Constant Velocity (CV) Joint Diagnosis and Repair (Front and Rear Wheel Drive)	5	13%
E. Rear Axle Diagnosis and Repair **1.** Ring and Pinion Gears (3) **2.** Differential Case Assembly (2) **3.** Limited Slip Differential (1) **4.** Axle Shafts (1)	7	17%
F. Four-Wheel Drive Component Diagnosis and Repair	8	17%
Total	**40**	**100%**

4. Suspension and Steering (A4) ASE Task List

Content Area	Questions in Test	Percentage of Test
A. Steering Systems Diagnosis and Repair **1.** Steering Columns and Manual Steering Gears (3) **2.** Power-Assisted Steering Units (4) **3.** Steering Linkage (3)	10	25%
B. Suspension Systems Diagnosis and Repair **1.** Front Suspensions (6) **2.** Rear Suspensions (5) **3.** Miscellaneous Service (2)	11	28%
C. Related Suspension and Steering Service	2	5%
D. Wheel Alignment Diagnosis, Adjustment, and Repair	12	30%
E. Wheel and Tire Diagnosis and Repair	5	12%
Total	**40**	**100%**

5. Brakes (A5) ASE Task List

Content Area	Questions in Test	Percentage of Test
A. Hydraulic System Diagnosis and Repair **1.** Master Cylinders (non-ABS) (3) **2.** Fluids, Lines, and Hoses (3) **3.** Valves and Switches (non-ABS) (4) **4.** Bleeding, Flushing, and Leak Testing (non-ABS) (4)	12	27%
B. Drum Brake Diagnosis and Repair	5	11%
C. Disc Brake Diagnosis and Repair	10	22%
D. Power Assist Units Diagnosis and Repair	4	8%
E. Miscellaneous Diagnosis and Repair	7	16%
F. Antilock Brake System Diagnosis and Repair	7	16%
Total	**45**	**100%**

6. Electrical Systems (A6) ASE Task List

Content Area	Questions in Test	Percentage of Test
A. General Electrical/Electronic System Diagnosis	13	26%
B. Battery Diagnosis and Service	4	8%
C. Starting System Diagnosis and Repair	5	10%
D. Charging System Diagnosis and Repair	5	10%
E. Lighting Systems Diagnosis and Repair **1.** Headlights, Parking Lights, Taillights, Dash Lights, and Courtesy Lights (3) **2.** Stoplights, Turn Signals, Hazard Lights, and Back-up Lights (3)	6	12%
F. Gauges, Warning Devices, and Driver Information Systems Diagnosis and Repair	6	12%
G. Horn and Wiper/Washer Diagnosis and Repair	3	6%
H. Accessories Diagnosis and Repair **1.** Body (4) **2.** Miscellaneous (4)	8	16%
Total	**50**	**100%**

7. Heating and Air Conditioning (A7) ASE Task List

Content Area	Questions in Test	Percentage of Test
A. A/C System Diagnosis and Repair	13	24%
B. Refrigeration System Component Diagnosis and Repair **1.** Compressor and Clutch (5) **2.** Evaporator, Condenser, and Related Components (5)	10	20%
C. Heating and Engine Cooling Systems Diagnosis and Repair	4	10%
D. Operating Systems and Related Controls Diagnosis and Repair **1.** Electrical (9) **2.** Vacuum/Mechanical (3) **3.** Automatic and Semi-Automatic Heating, Ventilating, and A/C Systems (5)	19	34%
E. Refrigerant Recover, Recycling, and Handling	4	12%
Total	**50**	**100%**

8. Engine Performance (A8) ASE Task List

Content Area	Questions in Test	Percentage of Test
A. General Engine Diagnosis	12	17%
B. Ignition System Diagnosis and Repair	8	17%
C. Fuel, Air Induction, and Exhaust Systems Diagnosis and Repair	9	18%
D. Emissions Control Systems Diagnosis and Repair **1.** Positive Crankcase Ventilation (1) **2.** Exhaust Gas Recirculation (3) **3.** Secondary Air Injector (AIR) and Catalytic Converter (2) **4.** Evaporative Emissions Controls (3)	8	15%
E. Computerized Engine Controls Diagnosis and Repair (Including OBD II)	13	27%
Total	**50**	**100%**

To become certified by ASE, the service technician must have two years of experience and pass a test in each area. If a technician passes all eight automotive certification tests, then the technician is considered a master certified automobile service technician. Tests are administered twice a year, in May and again in November. Registration and payment are required to be sent in early April for the May test and in early October for the November test. Test results are mailed to your home or work address about six to eight weeks after the test(s) is taken.

CANADA'S AUTOMOTIVE APPRENTICESHIP PROGRAM (RED SEAL)

In Canada, in all provinces and territories but Quebec and British Columbia, an **Inter-Provincial (IP) Certificate** is required. An apprenticeship program is in place that takes a minimum of four years, combining ten months in a shop and about two months in school training in each of the four years. Most apprentices must undergo 7200 hours of training before they can complete the IP examination. ASE certifications are currently used on a voluntary basis since 1993, however an IP Certificate is still required. Other licensing of automotive technicians may be required in some cases, such as environmental substances, liquefied petroleum gas, or steam operators.

NOTE: A valid driver's license is a must for any automotive service technician.

RE-CERTIFICATION

All ASE certifications expire after five years and the technician needs to take a recertification test to remain certified. As vehicles and technology change, it is important that all technicians attend update classes. Most experts recommend that each technician should have at least 40 hours (one full week) of update training every year. Update training classes can be found through many sources, including:

1. Many parts stores and warehouse distributors provide training classes throughout the year.
2. State or regional associations, such as the Automotive Service Association (www.asashop.org), offer update conferences.
3. Local colleges or training companies offer update training. Other training can be found listed on the International Automotive Technicians Network (www.iatn.net).

REVIEW QUESTIONS

1. What are the eight ASE test areas?
2. When are the written ASE tests given?
3. What types of questions are asked on the ASE certification tests?
4. What can a technician do to help prepare to take the certification tests?

CHAPTER QUIZ

1. Which ASE certification test would cover experience in reading an electrical schematic?
   a. A6
   b. A7
   c. A8
   d. All of the above are possible
2. How many ASE tests must be passed to become a master automotive technician?
   a. 8
   b. 6
   c. 4
   d. 2
3. How many years of experience are required to achieve ASE certification?
   a. 8 **c.** 4
   b. 6 **d.** 2
4. Credit for how many years of work experience can be substituted by attending automotive service training?
   a. None—no substitution for work experience is permitted
   b. 1 year
   c. 2 years
   d. 3 years
5. When taking an ASE certification test, _____.
   a. You can write on the test itself if you wish
   b. No marks are allowed on the test
   c. Only one test can be taken
   d. Some hands-on activities may be required
6. A type of test question *not* asked on the ASE certification test is _____.
   a. Most likely **c.** Fill in the blank
   b. Least likely **d.** Multiple choice
7. Which type of question is the same as two true-and-false-type questions?
   a. All except type
   b. Technician A and Technician B
   c. Least likely type
   d. Most likely type
8. Technician A says that you should guess if you do not know the correct answer. Technician B says that ASE will send you the correct answers to the questions you missed with your test results. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. The written ASE tests are given every _____.
   a. January and June **c.** February and September
   b. May and November **d.** March and October
10. A technician should do all of the following to prepare to take the ASE certification test *except* _____.
    a. Get a good night's sleep the night before the test
    b. Try to keep work schedule light the day of the test
    c. Eat a big meal
    d. Have photo ID and entry ticket

SECTION II

Safety, Environmental, and Health Concerns

6 Shop Safety

7 Environmental and Hazardous Materials

chapter 6

SHOP SAFETY

OBJECTIVES: **After studying Chapter 6, the reader should be able to:** • Identify situations where hearing protection should be worn. • Discuss how to safely handle tools and shop equipment. • Describe how to properly use a fire extinguisher. • Discuss shop safety procedures.

KEY TERMS: ANSI 41 • Bump cap 42 • Decibel (dB) 42 • Eye wash station 46 • Fire blankets 46 • Microbes 44 • "PASS" 45 • Personal protective equipment (PPE) 41 • Spontaneous combustion 43

PERSONAL PROTECTIVE EQUIPMENT

Safety is not just a buzzword on a poster in the work area. Safe work habits can reduce accidents and injuries, ease the workload, and keep employees pain free.

SAFETY GLASSES The most important **personal protective equipment (PPE)** a technician should wear all the time are safety glasses, which meet standard **ANSI** Z87.1. ● **SEE FIGURE 6–1.**

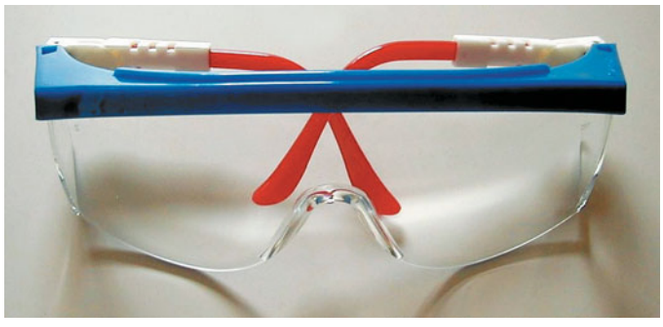


FIGURE 6–1 Safety glasses should be worn at all times when working on or around any vehicle or servicing any component.

STEEL-TOED SHOES Steel-toed safety shoes are also a good investment. ● **SEE FIGURE 6–2**. If safety shoes are not available, then leather-topped shoes offer more protection than canvas or cloth covered shoes.

GLOVES Wear gloves to protect your hands from rough or sharp surfaces. Thin rubber gloves are recommended when working around automotive liquids such as engine oil, antifreeze, transmission fluid, or any other liquids that may be hazardous. Several types of gloves and their characteristics include:

- **Latex surgical gloves.** These gloves are relatively inexpensive, but tend to stretch, swell, and weaken when exposed to gas, oil, or solvents.
- **Vinyl gloves.** These gloves are also inexpensive and are not affected by gas, oil, or solvents. ● **SEE FIGURE 6–3.**
- **Polyurethane gloves.** These gloves are more expensive, yet very strong. Even though these gloves are also not affected by gas, oil, or solvents, they tend to be slippery.
- **Nitrile gloves.** These gloves are exactly like latex gloves, but are not affected by gas, oil, or solvents, yet they tend to be expensive.



FIGURE 6–2 Steel-toed shoes are a worthwhile investment to help prevent foot injury due to falling objects. Even these well-worn shoes can protect the feet of this service technician.



FIGURE 6–3 Protective gloves such as these vinyl gloves are available in several sizes. Select the size that allows the gloves to fit snugly. Vinyl gloves last a long time and often can be worn all day to help protect your hands from dirt and possible hazardous materials.

- **Mechanic's gloves.** These gloves are usually made of synthetic leather and spandex and provide thermo protection, as well as protection from dirt and grime.

BUMP CAP Service technicians working under a vehicle should wear a **bump cap** to protect the head against under-vehicle objects and the pads of the lift. ● **SEE FIGURE 6–4**.

HANDS, JEWELRY, AND CLOTHING Remove jewelry that may get caught on something or act as a conductor to an exposed electrical circuit. ● **SEE FIGURE 6–5**.

Take care of your hands. Keep your hands clean by washing with soap and hot water that is at least 110°F (43°C). Avoid loose or dangling clothing. Also, ear protection should be worn if the sound around you requires that you raise your voice (sound level higher than 90 **decibels [dB]**).

NOTE: A typical lawnmower produces noise at a level of about 110 dB. This means that everyone who uses a lawnmower or other lawn or garden equipment should wear ear protection.



FIGURE 6–4 One version of a bump cap is this padded plastic insert that is worn inside a regular cloth cap.



FIGURE 6–5 Remove all jewelry before performing service work on any vehicle.

TECH TIP

Professional Behavior in the Shop Is a Must

To be respected as a professional service technician and for safety, always behave in a professional manner. These behaviors include, but are not limited to the following:

- Show respect to other technicians and employees. For example, the shop owner or service manager may not always be right, but they are always the boss.
- Avoid horseplay or practical jokes.
- Act as if a customer is observing your behavior at all times because this is often the case.

SAFETY TIPS FOR TECHNICIANS

- When lifting any object, get a secure grip with solid footing. Keep the load close to your body to minimize the strain. Lift with your legs and arms, not your back.



FIGURE 6–6 Always connect an exhaust hose to the tailpipe of the engine of a vehicle to be run inside a building.



FIGURE 6–7 A magnetic tray is a helpful item to keep tools needed up where they can be easily reached without having to bend over saving time and energy over the course of a long day in the shop.

- Do not twist your body when carrying a load. Instead, pivot your feet to help prevent strain on the spine.
- Ask for help when moving or lifting heavy objects.
- Push a heavy object rather than pull it. (This is opposite to the way you should work with tools—never push a wrench! If you do and a bolt or nut loosens, your entire weight is used to propel your hand(s) forward. This usually results in cuts, bruises, or other painful injury.)
- Always connect an exhaust hose to the tailpipe of any running vehicle to help prevent the buildup of carbon dioxide (CO) inside a closed garage space. ● **SEE FIGURE 6–6**.
- When standing, keep objects, parts, and tools with which you are working between chest height and waist height. If seated, work at tasks that are at elbow height. ● **SEE FIGURE 6–7**.
- Always be sure the hood is securely held open.
- Ask for help when pushing a vehicle or use a motorized pusher. ● **SEE FIGURE 6–8**.



FIGURE 6–8 An electric pusher used to push vehicles into or around the shop.



FIGURE 6–9 All oily shop cloths should be stored in a metal container equipped with a lid to help prevent spontaneous combustion.

SAFETY TIP

Shop Cloth Disposal

Always dispose of oily shop cloths in an enclosed container to prevent a fire. ● **SEE FIGURE 6–9**. Whenever oily cloths are thrown together on the floor or workbench, a chemical reaction can occur which can ignite the cloth even without an open flame. This process of ignition without an open flame is called **spontaneous combustion.**

CLEANING METHODS AND PROCESSES

There are four basic types of cleaning methods and processes used in vehicle service.

POWER WASHING Power washing uses an electric- or gasoline-powered compressor to increase the pressure of water and force it out of a nozzle. The pressure of the water itself is usually

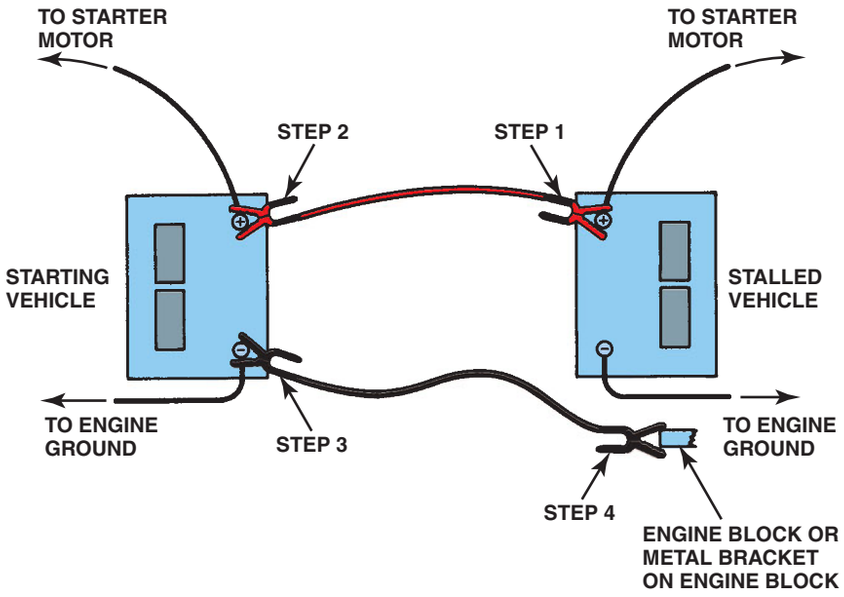


FIGURE 6–10 Jumper cable usage guide.

TECH TIP

Pound with Something Softer

If you must pound on something, be sure to use a tool that is softer than what you are about to pound on to avoid damage. Examples are given in the following table.

The Material Being Pounded	What to Pound With
Steel or cast iron	Brass or aluminum hammer or punch
Aluminum	Plastic or rawhide mallet or plastic-covered dead-blow hammer
Plastic	Rawhide mallet or plastic dead-blow hammer

enough to remove dirt, grease, and grime from vehicle components. Sometimes a chemical cleaner, such as a detergent, is added to the water to help with cleaning.

SAFE USE OF POWER WASHERS. Because water is being sprayed at high pressure, a face shield should be worn when using a power washer to protect not only the eyes but also the face in the event of the spray being splashed back toward the technician. Also use a pressure washer in an area where the runoff from the cleaning will not contaminate local groundwater or cause harm to plants or animals.

CHEMICAL/MICROBE CLEANING Chemical cleaning involves one of several cleaning solutions, including detergent, solvents, or small, living microorganisms called **microbes** that eat oil and grease. The microbes live in water and eat the hydrocarbons that are the basis of grease and oil.

SAFE USE OF CHEMICAL CLEANING. A face shield should be worn when cleaning parts using a chemical cleaner. Avoid spilling the cleaner on the floor to help prevent slipping accidents. Clean and replace the chemical cleaner regularly.

ABRASIVE CLEANING Abrasive cleaning is used to clean disassembled parts, such as engine blocks. The abrasives used include steel shot, ground walnut shells, or in the case of cleaning paint from a vehicle body, baking soda can be used.

SAFE USE OF ABRASIVE CLEANERS. Always wear a protective face shield and protective clothing, including gloves, long sleeves, and long pants.

THERMAL OVENS Thermal cleaning uses heat to bake off grease and dirt with special high-temperature ovens. This method of cleaning requires the use of expensive equipment but does not use any hazardous chemicals and is environmentally safe.

SAFE USE OF THERMAL OVENS. Because thermal ovens operate at high temperatures, often exceeding 600°F (315°C), the oven should be turned off and allowed to cool overnight before removing the parts from the oven to avoid being exposed to the high temperature.

Use correctly grounded three-prong sockets and extension cords to operate power tools. Some tools use only two-prong plugs. Make sure these are double insulated and repair or replace any electrical cords that are cut or damaged to prevent the possibility of an electrical shock. When not in use, keep electrical cords off the floor to prevent tripping over them. Tape the cords down if they are placed in high foot traffic areas.

JUMP-STARTING AND BATTERY SAFETY

To jump-start another vehicle with a dead battery, connect good-quality copper jumper cables as indicated in ● **FIGURE 6–10** or use a jump box. The last connection made should always be on the



FIGURE 6–11 The air pressure going to the nozzle should be reduced to 30 PSI or less.



FIGURE 6–12 A typical fire extinguisher designed to be used on type class A, B, or C fires.

SAFETY TIP

Compressed Air Safety

Improper use of an air nozzle can cause blindness or deafness. Compressed air must be reduced to less than 30 PSI (206 kPa). ● **SEE FIGURE 6–11**. If an air nozzle is used to dry and clean parts, make sure the air stream is directed away from anyone else in the immediate area. Always use an OSHA-approved nozzle with side slits that limit the maximum pressure at the nozzle to 30 PSI. Coil and store air hoses when they are not in use.

engine block or an engine bracket as far from the battery as possible. It is normal for a spark to be created when the jumper cables finally complete the jumper cable connections, and this spark could cause an explosion of the gases around the battery. Many newer vehicles have special ground connections built away from the battery just for the purpose of jump-starting. Check the owner manual or service information for the exact location.

Batteries contain acid and should be handled with care to avoid tipping them greater than a 45-degree angle. Always remove jewelry when working around a battery to avoid the possibility of electrical shock or burns, which can occur when the metal comes in contact with a 12 volt circuit and ground, such as the body of the vehicle.

FIRE EXTINGUISHERS

CLASSES OF FIRE EXTINGUISHERS

There are four classes of fire extinguishers. Each class should be used on specific fires only.

- *Class A* is designed for use on general combustibles, such as cloth, paper, and wood.
- *Class B* is designed for use on flammable liquids and greases, including gasoline, oil, thinners, and solvents.
- *Class C* is used only on electrical fires.
- *Class D* is effective only on combustible metals such as powdered aluminum, sodium, or magnesium.

The class rating is clearly marked on the side of every fire extinguisher. Many extinguishers are good for multiple types of fires. ● **SEE FIGURE 6–12**.

When using a fire extinguisher, remember the word **"PASS."**

P = Pull the safety pin.

A = Aim the nozzle of the extinguisher at the base of the fire.

S = Squeeze the lever to actuate the extinguisher.

S = Sweep the nozzle from side to side.

● **SEE FIGURE 6–13**.



FIGURE 6–13 A CO_2 fire extinguisher being used on a fire set in an open steel drum during a demonstration at a fire department training center.

TYPES OF FIRE EXTINGUISHERS

Types of fire extinguishers include the following:

- **Water.** A water fire extinguisher, usually in a pressurized container, is good to use on Class A fires by reducing the temperature to the point where a fire cannot be sustained.



FIGURE 6–14 A treated wool blanket is kept in this easy-to-open wall-mounted holder and should be placed in a centralized location in the shop.



FIGURE 6–15 A first aid box should be centrally located in the shop and kept stocked with the recommended supplies.

- **Carbon dioxide (CO_2).** A carbon dioxide fire extinguisher is good for almost any type of fire, especially Class B or Class C materials. A CO_2 fire extinguisher works by removing the oxygen from the fire and the cold CO_2 also helps reduce the temperature of the fire.
- **Dry chemical (yellow).** A dry chemical fire extinguisher is good for Class A, B, or C fires by coating the flammable materials, which eliminates the oxygen from the fire. A dry chemical fire extinguisher tends to be very corrosive and will cause damage to electronic devices.

FIRE BLANKETS

Fire blankets are required to be available in the shop areas. If a person is on fire, a fire blanket should be removed from its storage bag and thrown over and around the victim to smother the fire. ● **SEE FIGURE 6–14** showing a typical fire blanket.

FIRST AID AND EYE WASH STATIONS

All shop areas must be equipped with a first aid kit and an eye wash station centrally located and kept stocked with emergency supplies.

FIRST AID KIT

A first aid kit should include:

- Bandages (variety)
- Gauze pads
- Roll gauze
- Iodine swab sticks
- Antibiotic ointment
- Hydrocortisone cream
- Burn gel packets
- Eye wash solution



FIGURE 6–16 A typical eye wash station. Often a thorough flushing of the eyes with water is the best treatment in the event of eye contamination.

- Scissors
- Tweezers
- Gloves
- First aid guide

● **SEE FIGURE 6–15**. Every shop should have a person trained in first aid. If there is an accident, call for help immediately.

EYE WASH STATION

An **eye wash station** should be centrally located and used whenever any liquid or chemical gets into the eyes. If such an emergency does occur, keep eyes in a constant stream of water and call for professional assistance. ● **SEE FIGURE 6–16**.

TECH TIP

Mark Off the Service Area

Some shops rope off the service bay area to help keep traffic and distractions to a minimum, which could prevent personal injury. ● **SEE FIGURE 6–17**.



FIGURE 6–17 This area has been blocked off to help keep visitors from the dangerous work area.

REVIEW QUESTIONS

1. List four items that are personal protective equipment (PPE).
2. What are the types of fire extinguishers and their usage?
3. What items are included in a typical first aid box?

CHAPTER QUIZ

1. What do you call the service technician's protective head cover?
   a. Cap **c.** Bump cap
   b. Hat **d.** Helmet
2. All safety glasses should meet the standards set by _____.
   a. ANSI **c.** ASE
   b. SAE **d.** DOT
3. When washing hands, the water should be at what temperature?
   a. 98°F (37°C) **c.** 125°F (52°C)
   b. 110°F (43°C) **d.** 135°F (57°C)
4. Hearing protection should be worn anytime the noise level exceeds _____.
   a. 60 dB **c.** 80 dB
   b. 70 dB **d.** 90 dB
5. Two technicians are discussing the safe use of a wrench. Technician A says that a wrench should be pulled toward you. Technician B says that a wrench should be pushed away from you. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. Exhaust hoses should be used because one of the exhaust gases is deadly in high concentration. This gas is _____.
   a. Carbon monoxide (CO)
   b. Carbon dioxide (CO_2)
   c. Hydrocarbons (HC)
   d. Oxides of nitrogen (NO_X)
7. The process of combustion occurring without an open flame is called _____.
   a. Direct ignition
   b. Non-open flame combustion
   c. Spontaneous combustions
   d. Cold fusion
8. When using a fire extinguisher, what word can be used to remember what to do?
   a. PASS **c.** RED
   b. FIRE **d.** LEVER
9. Which type of fire extinguisher can create a corrosive compound when discharged?
   a. CO_2 **c.** Water
   b. Dry chemical **d.** CO
10. Which item is usually *not* included in a first aid kit?
    a. Eye wash solution **c.** Fire blanket
    b. Antibiotic cream **d.** Bandages

chapter 7

ENVIRONMENTAL AND HAZARDOUS MATERIALS

OBJECTIVES: **After studying Chapter 7, the reader should be able to:** • Prepare for the ASE assumed knowledge content required by all service technicians to adhere to environmentally appropriate actions and behavior. • Define the Occupational Safety and Health Act (OSHA). • Explain the term material safety data sheet (MSDS). • Identify hazardous waste materials in accordance with state and federal regulations and follow proper safety precautions while handling hazardous waste materials. • Define the steps required to safely handle and store automotive chemicals and waste.

KEY TERMS: Aboveground storage tank (AGST) 51 • Asbestosis 49 • BCI 53 • CAA 49 • CFR 48 • EPA 48 • Hazardous waste material 48 • HEPA vacuum 50 • Mercury 54 • MSDS 49 • OSHA 48 • RCRA 49 • Right-to-know laws 49 • Solvent 50 • Underground storage tank (UST) 51 • Used oil 50 • WHMIS 49

HAZARDOUS WASTE

DEFINITION OF HAZARDOUS WASTE

Hazardous waste materials are chemicals, or components, that the shop no longer needs that pose a danger to the environment and people if they are disposed of in ordinary garbage cans or sewers. However, no material is considered hazardous waste until the shop has finished using it and is ready to dispose of it.

PERSONAL PROTECTIVE EQUIPMENT (PPE)

When handling hazardous waste material, one must always wear the proper protective clothing and equipment detailed in the right-to-know laws. This includes respirator equipment. All recommended procedures must be followed accurately. Personal injury may result from improper clothing, equipment, and procedures when handling hazardous materials.

FEDERAL AND STATE LAWS

OCCUPATIONAL SAFETY AND HEALTH ACT

The United States Congress passed the **Occupational Safety and Health Act (OSHA)** in 1970. This legislation was designed to assist and encourage the citizens of the United States in their efforts to assure:

- Safe and healthful working conditions by providing research, information, education, and training in the field of occupational safety and health.
- Safe and healthful working conditions for working men and women by authorizing enforcement of the standards developed under the Act.

Because about 25% of workers are exposed to health and safety hazards on the job, the OSHA standards are necessary to monitor, control, and educate workers regarding health and safety in the workplace.

EPA

The **Environmental Protection Agency (EPA)** publishes a list of hazardous materials that is included in the **Code of Federal Regulations (CFR).** The EPA considers waste hazardous if it is included on the EPA list of hazardous materials, or it has one or more of the following characteristics:

- **Reactive.** Any material that reacts violently with water or other chemicals is considered hazardous.
- **Corrosive.** If a material burns the skin, or dissolves metals and other materials, a technician should consider it hazardous. A pH scale is used, with the number 7 indicating neutral. Pure water has a pH of 7. Lower numbers indicate an acidic solution and higher numbers indicate a caustic solution. If a material releases cyanide gas, hydrogen sulfide gas, or similar gases when exposed to low pH acid solutions, it is considered hazardous.
- **Toxic.** Materials are hazardous if they leak one or more of eight different heavy metals in concentrations greater than 100 times the primary drinking water standard.
- **Ignitable.** A liquid is hazardous if it has a flash point below 140°F (60°C), and a solid is hazardous if it ignites spontaneously.
- **Radioactive.** Any substance that emits measurable levels of radiation is radioactive. When individuals bring containers of a highly radioactive substance into the shop environment, qualified personnel with the appropriate equipment must test them.



WARNING

Hazardous waste disposal laws include serious penalties for anyone responsible for breaking these laws.



FIGURE 7–1 Material safety data sheets (MSDS) should be readily available for use by anyone in the area who may come into contact with hazardous materials.

RIGHT-TO-KNOW LAWS The **right-to-know laws** state that employees have a right to know when the materials they use at work are hazardous. The right-to-know laws started with the Hazard Communication Standard published by OSHA in 1983. Originally, this document was intended for chemical companies and manufacturers that required employees to handle hazardous materials in their work situation but the federal courts have decided to apply these laws to all companies, including automotive service shops. Under the right-to-know laws, the employer has responsibilities regarding the handling of hazardous materials by their employees. All employees must be trained about the types of hazardous materials they will encounter in the workplace. The employees must be informed about their rights under legislation regarding the handling of hazardous materials.

MATERIAL SAFETY DATA SHEETS (MSDS). All hazardous materials must be properly labeled, and information about each hazardous material must be posted on **material safety data sheets (MSDS)** available from the manufacturer. In Canada, MSDS information is called **Workplace Hazardous Materials Information Systems (WHMIS).**

The employer has a responsibility to place MSDS information where they are easily accessible by all employees. The MSDS information provide the following information about the hazardous material: chemical name, physical characteristics, protective handling equipment, explosion/fire hazards, incompatible materials, health hazards, medical conditions aggravated by exposure, emergency and first aid procedures, safe handling, and spill/leak procedures.

The employer also has a responsibility to make sure that all hazardous materials are properly labeled. The label information must include health, fire, and reactivity hazards posed by the material, as well as the protective equipment necessary to handle the material. The manufacturer must supply all warning and precautionary information about hazardous materials. This information must be read and understood by the employee before handling the material. ● **SEE FIGURE 7–1**.

RESOURCE CONSERVATION AND RECOVERY ACT (RCRA) Federal and state laws control the disposal of hazardous waste materials and every shop employee must be familiar with these laws. Hazardous waste disposal laws include the **Resource Conservation and Recovery Act (RCRA).** This law states that hazardous material users are responsible for hazardous materials from the time they become a waste until the proper waste disposal is completed. Many shops hire an independent hazardous waste hauler to dispose of hazardous waste material. The shop owner, or manager, should have a written contract with the hazardous waste hauler. Rather than have hazardous waste material hauled to an approved hazardous waste disposal site, a shop may choose to recycle the material in the shop. Therefore, the user must store hazardous waste material properly and safely, and be responsible for the transportation of this material until it arrives at an approved hazardous waste disposal site, where it can be processed according to the law. The RCRA controls the following types of automotive waste:

- Paint and body repair products waste
- Solvents for parts and equipment cleaning
- Batteries and battery acid
- Mild acids used for metal cleaning and preparation
- Waste oil, and engine coolants or antifreeze
- Air-conditioning refrigerants and oils
- Engine oil filters

CLEAN AIR ACT Air-conditioning (A/C) systems and refrigerant are regulated by the **Clean Air Act (CAA),** Title VI, Section 609. Technician certification and service equipment is also regulated. Any technician working on automotive A/C systems must be certified. A/C refrigerants must not be released or vented into the atmosphere, and used refrigerants must be recovered.

ASBESTOS HAZARDS

Friction materials such as brake and clutch linings often contain asbestos. While asbestos has been eliminated from most original equipment friction materials, the automotive service technician cannot know whether the vehicle being serviced is or is not equipped with friction materials containing asbestos. It is important that all friction materials be handled as if they do contain asbestos.

Asbestos exposure can cause scar tissue to form in the lungs. This condition is called **asbestosis.** It gradually causes increasing shortness of breath, and the scarring to the lungs is permanent.

Even low exposures to asbestos can cause *mesothelioma*, a type of fatal cancer of the lining of the chest or abdominal cavity. Asbestos exposure can also increase the risk of *lung cancer* as well as cancer of the voice box, stomach, and large intestine. It usually takes 15 to 30 years or more for cancer or asbestos lung scarring to show up after exposure. Scientists call this the *latency period*.

Government agencies recommend that asbestos exposure be eliminated or controlled to the lowest level possible. These agencies have developed recommendations and standards that the automotive service technician and equipment manufacturer should follow. These U.S. federal agencies include the National Institute for Occupational Safety and Health (NIOSH), Occupational Safety and Health Administration (OSHA), and Environmental Protection Agency (EPA).

ASBESTOS OSHA STANDARDS The Occupational Safety and Health Administration (OSHA) has established three levels of asbestos exposure. Any vehicle service establishment that does either

brake or clutch work must limit employee exposure to asbestos to less than 0.2 fibers per cubic centimeter (cc) as determined by an air sample.

If the level of exposure to employees is greater than specified, corrective measures must be performed and a large fine may be imposed.

NOTE: Research has found that worn asbestos fibers such as those from automotive brakes or clutches may not be as hazardous as first believed. Worn asbestos fibers do not have sharp flared ends that can latch onto tissue, but rather are worn down to a dust form that resembles talc. Grinding or sawing operations on unworn brake shoes or clutch discs *will* contain *harmful* asbestos fibers. To limit health damage, always use proper handling procedures while working around any component that may contain asbestos.

ASBESTOS EPA REGULATIONS

The federal Environmental Protection Agency (EPA) has established procedures for the removal and disposal of asbestos. The EPA procedures require that products containing asbestos be "wetted" to prevent the asbestos fibers from becoming airborne. According to the EPA, asbestos-containing materials can be disposed of as regular waste. Only when asbestos becomes airborne is it considered to be hazardous.

ASBESTOS HANDLING GUIDELINES

The air in the shop area can be tested by a testing laboratory, but this can be expensive. Tests have determined that asbestos levels can easily be kept below the recommended levels by using a liquid, like water, or a special vacuum.

NOTE: The service technician cannot tell whether the old brake pads, shoes, or clutch discs contain asbestos. Therefore, to be safe, the technician should assume that all brake pads, shoes, or clutch discs contain asbestos.

HEPA VACUUM. A special **high-efficiency particulate air (HEPA) vacuum** system has been proven to be effective in keeping asbestos exposure levels below 0.1 fibers per cubic centimeter.

SOLVENT SPRAY. Many technicians use an aerosol can of brake cleaning solvent to wet the brake dust and prevent it from becoming airborne. A **solvent** is a liquid that is used to dissolve dirt, grime, or solid particles. Commercial brake cleaners are available that use a concentrated cleaner that is mixed with water. ● **SEE FIGURE 7–2**. The waste liquid is filtered, and when dry, the filter can be disposed of as solid waste.

DISPOSAL OF BRAKE DUST AND BRAKE SHOE. The hazard of asbestos occurs when asbestos fibers are airborne. Once the asbestos has been wetted down, it is then considered to be solid waste, rather than hazardous waste. Old brake shoes and pads should be enclosed, preferably in a plastic bag, to help prevent any of the brake material from becoming airborne. *Always follow current federal and local laws concerning disposal of all waste.*

WARNING

Never use compressed air to blow brake dust. The fine talclike brake dust can create a health hazard even if asbestos is not present or is present in dust rather than fiber form.

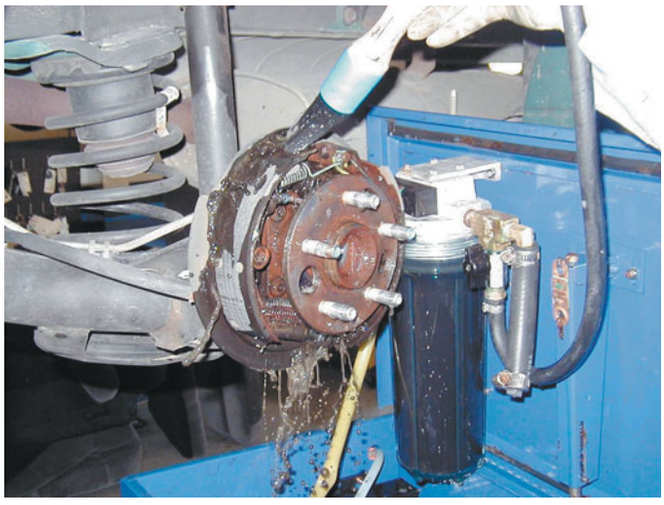


FIGURE 7–2 All brakes should be moistened with water or solvent to help prevent brake dust from becoming airborne.

USED BRAKE FLUID

Most brake fluid is made from polyglycol, is water soluble, and can be considered hazardous if it has absorbed metals from the brake system.

STORAGE AND DISPOSAL OF BRAKE FLUID

- Collect brake fluid in a container clearly marked to indicate that it is designated for that purpose.
- If the waste brake fluid is hazardous, be sure to manage it appropriately and use only an authorized waste receiver for its disposal.
- If the waste brake fluid is nonhazardous (such as old, but unused), determine from your local solid waste collection provider what should be done for its proper disposal.
- Do not mix brake fluid with used engine oil.
- Do not pour brake fluid down drains or onto the ground.
- Recycle brake fluid through a registered recycler.

USED OIL

Used oil is any petroleum-based or synthetic oil that has been used. During normal use, impurities such as dirt, metal scrapings, water, or chemicals can get mixed in with the oil. Eventually, this used oil must be replaced with virgin or re-refined oil. The EPA's used oil management standards include a three-pronged approach to determine if a substance meets the definition of *used oil*. To meet the EPA's definition of used oil, a substance must meet each of the following three criteria.

- **Origin.** The first criterion for identifying used oil is based on the oil's origin. Used oil must have been refined from crude oil or made from synthetic materials. Animal and vegetable oils are excluded from the EPA's definition of used oil.
- **Use.** The second criterion is based on whether and how the oil is used. Oils used as lubricants, hydraulic fluids, heat transfer fluids, and for other similar purposes are considered



FIGURE 7–3 A typical aboveground oil storage tank.

used oil. The EPA's definition also excludes products used as cleaning agents, as well as certain petroleum-derived products like antifreeze and kerosene.

- **Contaminants.** The third criterion is based on whether the oil is contaminated with either physical or chemical impurities. In other words, to meet the EPA's definition, used oil must become contaminated as a result of being used. This aspect of the EPA's definition includes residues and contaminants generated from handling, storing, and processing used oil.

NOTE: The release of only 1 gallon of used oil (a typical oil change) can make 1 million gallons of fresh water undrinkable.

If used oil is dumped down the drain and enters a sewage treatment plant, concentrations as small as 50 to 100 parts per million (ppm) in the wastewater can foul sewage treatment processes. Never mix a listed hazardous waste, gasoline, wastewater, halogenated solvent, antifreeze, or an unknown waste material with used oil. Adding any of these substances will cause the used oil to become contaminated, which classifies it as hazardous waste.

STORAGE AND DISPOSAL OF USED OIL

Once oil has been used, it can be collected, recycled, and used over and over again. An estimated 380 million gallons of used oil are recycled each year. Recycled used oil can sometimes be used again for the same job or can take on a completely different task. For example, used engine oil can be re-refined and sold at some discount stores as engine oil or processed for furnace fuel oil. After collecting used oil in an appropriate container such as a 55 gallon steel drum, the material must be disposed of in one of two ways.

- Shipped offsite for recycling
- Burned in an onsite or offsite EPA-approved heater for energy recovery

Used oil must be stored in compliance with an existing **underground storage tank (UST)** or an **aboveground storage tank (AGST)** standard, or kept in separate containers. ● **SEE FIGURE 7–3**. Containers are portable receptacles, such as a 55 gallon steel drum.

KEEP USED OIL STORAGE DRUMS IN GOOD CONDITION. This means that they should be covered, secured from vandals, properly labeled, and maintained in compliance with local fire codes. Frequent inspections for leaks, corrosion, and spillage are an essential part of container maintenance.

NEVER STORE USED OIL IN ANYTHING OTHER THAN TANKS AND STORAGE CONTAINERS. Used oil may also be stored in units that are permitted to store regulated hazardous waste.

USED OIL FILTER DISPOSAL REGULATIONS. Used oil filters contain used engine oil that may be hazardous. Before an oil filter is placed into the trash or sent to be recycled, it must be drained using one of the following hot-draining methods approved by the EPA.

- Puncture the filter antidrainback valve or filter dome end and hot drain for at least 12 hours
- Hot draining and crushing
- Dismantling and hot draining
- Any other hot-draining method, which will remove all the used oil from the filter

After the oil has been drained from the oil filter, the filter housing can be disposed of in any of the following ways.

- Sent for recycling
- Picked up by a service contract company
- Disposed of in regular trash

SOLVENTS

The major sources of chemical danger are liquid and aerosol brake cleaning fluids that contain chlorinated hydrocarbon solvents. Several other chemicals that do not deplete the ozone, such as heptane, hexane, and xylene, are now being used in nonchlorinated brake cleaning solvents. Some manufacturers are also producing solvents they describe as environmentally responsible, which are biodegradable and noncarcinogenic (not cancer causing).

There is no specific standard for physical contact with chlorinated hydrocarbon solvents or the chemicals replacing them. All contact should be avoided whenever possible. The law requires an employer to provide appropriate protective equipment and ensure proper work practices by an employee handling these chemicals.

EFFECTS OF CHEMICAL POISONING

The effects of exposure to chlorinated hydrocarbon and other types of solvents can take many forms. Short-term exposure at low levels can cause symptoms such as:

- Headache
- Nausea
- Drowsiness
- Dizziness
- Lack of coordination
- Unconsciousness

It may also cause irritation of the eyes, nose, and throat, and flushing of the face and neck. Short-term exposure to higher concentrations can cause liver damage with symptoms such as yellow jaundice or dark urine. Liver damage may not become evident until several weeks after the exposure.

HAZARDOUS SOLVENTS AND REGULATORY STATUS

Most solvents are classified as hazardous wastes. Other characteristics of solvents include the following:

- Solvents with flash points below 140°F (60°C) are considered flammable and, like gasoline, are federally regulated by the Department of Transportation (DOT).



FIGURE 7–4 Washing hands and removing jewelry are two important safety habits all service technicians should practice.



FIGURE 7–5 Typical fireproof flammable storage cabinet.

SAFETY TIP

Hand Safety

Service technicians should wash their hands with soap and water after handling engine oil, differential oil, or transmission fluids or wear protective rubber gloves. Another safety hint is that the service technician should not wear watches, rings, or other jewelry that could come in contact with electrical or moving parts of a vehicle. ● **SEE FIGURE 7–4**.

- Solvents and oils with flash points above 60°C are considered combustible and, like engine oil, are also regulated by the DOT. All flammable items must be stored in a fireproof container. ● **SEE FIGURE 7–5**.

It is the responsibility of the repair shop to determine if its spent solvent is hazardous waste. Solvent reclaimers are available that clean and restore the solvent so it lasts indefinitely.

USED SOLVENTS Used or spent solvents are liquid materials that have been generated as waste and may contain xylene, methanol, ethyl ether, and methyl isobutyl ketone (MIBK). These materials must be stored in OSHA-approved safety containers with the lids or caps closed tightly. Additional requirements include the following:

- Containers should be clearly labeled "Hazardous Waste" and the date the material was first placed into the storage receptacle should be noted.
- Labeling is not required for solvents being used in a parts washer.
- Used solvents will not be counted toward a facility's monthly output of hazardous waste if the vendor under contract removes the material.
- Used solvents may be disposed of by recycling with a local vendor, such as SafetyKleen®, to have the used solvent removed according to specific terms in the vendor agreement.
- Use aqueous-based (nonsolvent) cleaning systems to help avoid the problems associated with chemical solvents. ● **SEE FIGURE 7–6**.



FIGURE 7–6 Using a water-based cleaning system helps reduce the hazards from using strong chemicals.

FREQUENTLY ASKED QUESTION

How Can You Tell If a Solvent Is Hazardous?

If a solvent or any of the ingredients of a product contains "fluor" or "chlor" then it is likely to be hazardous. Check the instructions on the label for proper use and disposal procedures.

COOLANT DISPOSAL

Coolant is a mixture of antifreeze and water. New antifreeze is not considered to be hazardous even though it can cause death if ingested. Used antifreeze may be hazardous due to dissolved metals from the engine and other components of the cooling system. These metals can include iron, steel, aluminum, copper, brass, and lead



FIGURE 7–7 Used antifreeze coolant should be kept separate and stored in a leakproof container until it can be recycled or disposed of according to federal, state, and local laws. Note that the storage barrel is placed inside another container to catch any coolant that may spill out of the inside barrel.

(from older radiators and heater cores). Coolant should be disposed of in one of the following ways:

- Coolant should be recycled either onsite or offsite.
- Used coolant should be stored in a sealed and labeled container. ● **SEE FIGURE 7–7**.
- Used coolant can often be disposed of into municipal sewers with a permit. Check with local authorities and obtain a permit before discharging used coolant into sanitary sewers.

LEAD-ACID BATTERY WASTE

About 70 million spent lead-acid batteries are generated each year in the United States alone. Lead is classified as a toxic metal and the acid used in lead-acid batteries is highly corrosive. The vast majority (95% to 98%) of these batteries are recycled through lead reclamation operations and secondary lead smelters for use in the manufacture of new batteries.

BATTERY DISPOSAL Used lead-acid batteries must be reclaimed or recycled in order to be exempt from hazardous waste regulations. Leaking batteries must be stored and transported as hazardous waste. Some states have more strict regulations, which require special handling procedures and transportation. According to the **Battery Council International (BCI),** battery laws usually include the following rules.

1. Lead-acid battery disposal is prohibited in landfills or incinerators. Batteries are required to be delivered to a battery retailer, wholesaler, recycling center, or lead smelter.
2. All retailers of automotive batteries are required to post a sign that displays the universal recycling symbol and indicates the retailer's specific requirements for accepting used batteries.
3. Battery electrolyte contains sulfuric acid, which is a very corrosive substance capable of causing serious personal injury, such as skin burns and eye damage. In addition, the battery plates contain lead, which is highly poisonous. For this reason, disposing of batteries improperly can cause environmental contamination and lead to severe health problems.



FIGURE 7–8 This red gasoline container holds about 30 gallons of gasoline and is used to fill vehicles used for training.

BATTERY HANDLING AND STORAGE Batteries, whether new or used, should be kept indoors if possible. The storage location should be an area specifically designated for battery storage and must be well ventilated (to the outside). If outdoor storage is the only alternative, a sheltered and secured area with acid-resistant secondary containment is strongly recommended. It is also advisable that acid-resistant secondary containment be used for indoor storage. In addition, batteries should be placed on acid-resistant pallets and never stacked.

FUEL SAFETY AND STORAGE

Gasoline is a very explosive liquid. The expanding vapors that come from gasoline are extremely dangerous. These vapors are present even in cold temperatures. Vapors formed in gasoline tanks on many vehicles are controlled, but vapors from gasoline storage may escape from the can, resulting in a hazardous situation. Therefore, place gasoline storage containers in a well-ventilated space. Although diesel fuel is not as volatile as gasoline, the same basic rules apply to diesel fuel and gasoline storage. These rules include the following:

1. Use storage cans that have a flash-arresting screen at the outlet. These screens prevent external ignition sources from igniting the gasoline within the can when someone pours the gasoline or diesel fuel.
2. Use only a red approved gasoline container to allow for proper hazardous substance identification. ● **SEE FIGURE 7–8**.

3. Do not fill gasoline containers completely full. Always leave the level of gasoline at least 1 in. from the top of the container. This action allows expansion of the gasoline at higher temperatures. If gasoline containers are completely full, the gasoline will expand when the temperature increases. This expansion forces gasoline from the can and creates a dangerous spill. If gasoline or diesel fuel containers must be stored, place them in a designated storage locker or facility.
4. Never leave gasoline containers open, except while filling or pouring gasoline from the container.
5. Never use gasoline as a cleaning agent.
6. Always connect a ground strap to containers when filling or transferring fuel or other flammable products from one container to another to prevent static electricity that could result in explosion and fire. These ground wires prevent the buildup of a static electric charge, which could result in a spark and disastrous explosion.

AIRBAG HANDLING

Airbag modules are pyrotechnic devices that can be ignited if exposed to an electrical charge or if the body of the vehicle is subjected to a shock. Airbag safety should include the following precautions.

1. Disarm the airbag(s) if you will be working in the area where a discharged bag could make contact with any part of your body. Consult service information for the exact procedure to follow for the vehicle being serviced.
2. If disposing of an airbag, the usual procedure is to deploy the airbag using a 12 volt power supply, such as a jump-start box, using long wires to connect to the module to ensure a safe deployment.
3. Do not expose an airbag to extreme heat or fire.
4. Always carry an airbag pointing away from your body.
5. Place an airbag module facing upward.
6. Always follow the manufacturer's recommended procedure for airbag disposal or recycling, including the proper packaging to use during shipment.
7. Wear protective gloves if handling a deployed airbag.
8. Always wash your hands or body well if exposed to a deployed airbag. The chemicals involved can cause skin irritation and possible rash development.

USED TIRE DISPOSAL

ENVIRONMENTAL CONCERN Used tires are an environmental concern because of several reasons, including the following:

1. In a landfill, they tend to "float" up through the other trash and rise to the surface.
2. The inside of tires traps and holds rainwater, which is a breeding ground for mosquitoes. Mosquito-borne diseases include encephalitis and dengue fever.
3. Used tires present a fire hazard and, when burned, create a large amount of black smoke that contaminates the air.

DISPOSAL METHODS Used tires should be disposed of in one of the following ways.

1. Used tires can be reused until the end of their useful life.
2. Tires can be retreaded.
3. Tires can be recycled or shredded for use in asphalt.
4. Derimmed tires can be sent to a landfill (most landfill operators will shred the tires because it is illegal in many states to landfill whole tires).
5. Tires can be burned in cement kilns or other power plants where the smoke can be controlled.
6. A registered scrap tire handler should be used to transport tires for disposal or recycling.

AIR-CONDITIONING REFRIGERANT OIL DISPOSAL

Air-conditioning refrigerant oil contains dissolved refrigerant and is therefore considered to be hazardous waste. This oil must be kept separated from other waste oil or the entire amount of oil must be treated as hazardous. Used refrigerant oil must be sent to a licensed hazardous waste disposal company for recycling or disposal. ● **SEE FIGURE 7–9**.

WASTE CHART All automotive service facilities create some waste and while most of it is handled properly, it is important that all hazardous and nonhazardous waste be accounted for and properly disposed. **SEE CHART 7–1** for a list of typical wastes generated at automotive shops, plus a checklist for keeping track of how these wastes are handled.



FIGURE 7–9 Air-conditioning refrigerant oil must be kept separated from other oils because it contains traces of refrigerant and must be treated as hazardous waste.

WASTE STREAM	TYPICAL CATEGORY IF NOT MIXED WITH OTHER HAZARDOUS WASTE	IF DISPOSED IN LANDFILL AND NOT MIXED WITH A HAZARDOUS WASTE	IF RECYCLED
Used oil	Used oil	Hazardous waste	Used oil
Used oil filters	Nonhazardous solid waste, if completely drained	Nonhazardous solid waste, if completely drained	Used oil, if not drained
Used transmission fluid	Used oil	Hazardous waste	Used oil
Used brake fluid	Used oil	Hazardous waste	Used oil
Used antifreeze	Depends on characterization	Depends on characterization	Depends on characterization
Used solvents	Hazardous waste	Hazardous waste	Hazardous waste
Used citric solvents	Nonhazardous solid waste	Nonhazardous solid waste	Hazardous waste
Lead-acid automotive batteries	Not a solid waste if returned to supplier	Hazardous waste	Hazardous waste
Shop rags used for oil	Used oil	Depends on used oil characterization	Used oil
Shop rags used for solvent or gasoline spills	Hazardous waste	Hazardous waste	Hazardous waste
Oil spill absorbent material	Used oil	Depends on used oil characterization	Used oil
Spill material for solvent and gasoline	Hazardous waste	Hazardous waste	Hazardous waste
Catalytic converter	Not a solid waste if returned to supplier	Nonhazardous solid waste	Nonhazardous solid waste
Spilled or unused fuels	Hazardous waste	Hazardous waste	Hazardous waste
Spilled or unusable paints and thinners	Hazardous waste	Hazardous waste	Hazardous waste
Used tires	Nonhazardous solid waste	Nonhazardous solid waste	Nonhazardous solid waste

CHART 7–1

Typical wastes generated at auto repair shops and typical category (hazardous or nonhazardous) by disposal method.

TECH TIP

Remove Components That Contain Mercury

Some vehicles have a placard near the driver's side door that lists the components that contain the heavy metal, mercury. **Mercury** can be absorbed through the skin and is a heavy metal that once absorbed by the body does not leave. ● **SEE FIGURE 7–10**.

These components should be removed from the vehicle before the rest of the body is sent to be recycled to help prevent releasing mercury into the environment.



FIGURE 7–10 Placard near driver's door, including what devices in the vehicle contain mercury.

TECH TIP

What Every Technician Should Know

The Hazardous Materials Identification Guide (HMIG) is the standard labeling for all materials. The service technician should be aware of the meaning of the label. ● **SEE FIGURE 7–11**.

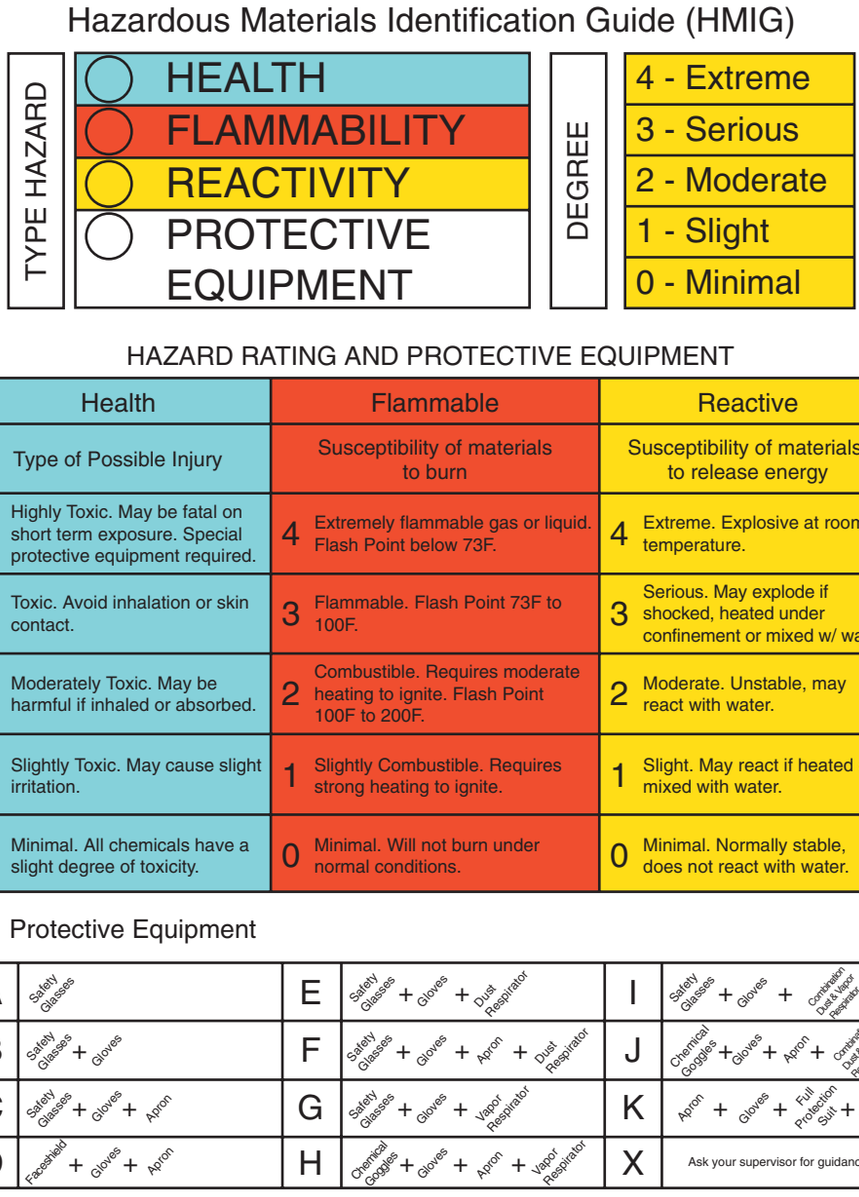


FIGURE 7–11 The Environmental Protection Agency (EPA) Hazardous Materials Identification Guide is a standardized listing of the hazards and the protective equipment needed.

REVIEW QUESTIONS

1. List five common automotive chemicals or products that may be considered hazardous materials.
2. List five precautions to which every technician should adhere when working with automotive products and chemicals.

CHAPTER QUIZ

1. Hazardous materials include all of the following *except* _____.
   a. Engine oil
   b. Asbestos
   c. Water
   d. Brake cleaner
2. To determine if a product or substance being used is hazardous, consult _____.
   a. A dictionary
   b. An MSDS
   c. SAE standards
   d. EPA guidelines
3. Exposure to asbestos dust can cause what condition?
   a. Asbestosis
   b. Mesothelioma
   c. Lung cancer
   d. All of the above
4. Wetted asbestos dust is considered to be _____.
   a. Solid waste
   b. Hazardous waste
   c. Toxic
   d. Poisonous
5. An oil filter should be hot drained for how long before disposing of the filter?
   a. 30 to 60 minutes
   b. 4 hours
   c. 8 hours
   d. 12 hours

6. Used engine oil should be disposed of by all *except* the following methods.
   a. Disposed of in regular trash
   b. Shipped offsite for recycling
   c. Burned onsite in a waste oil-approved heater
   d. Burned offsite in a waste oil-approved heater
7. All of the following are the proper ways to dispose of a *drained* oil filter *except* _____.
   a. Sent for recycling
   b. Picked up by a service contract company
   c. Disposed of in regular trash
   d. Considered to be hazardous waste and disposed of accordingly
8. Which act or organization regulates air-conditioning refrigerant?
   a. Clean Air Act (CAA)
   b. MSDS
   c. WHMIS
   d. Code of Federal Regulations (CFR)
9. Gasoline should be stored in approved containers that include what color(s)?
   a. A red container with yellow lettering
   b. A red container
   c. A yellow container
   d. A yellow container with red lettering
10. What automotive devices may contain mercury?
   a. Rear seat video displays
   b. Navigation displays
   c. HID headlights
   d. All of the above

SECTION III

Tools, Shop Equipment, and Measuring

8 Fasteners and Thread Repair
9 Hand Tools
10 Power Tools and Shop Equipment
11 Vehicle Lifting and Hoisting
12 Measuring Systems and Tools

chapter 8

FASTENERS AND THREAD REPAIR

OBJECTIVES: **After studying Chapter 8, the reader should be able to:** • Explain the terms used to identify bolts and other threaded fasteners. • Explain the strength ratings of threaded fasteners. • Describe the proper use of nonthreaded fasteners. • Discuss how snap rings are used.

KEY TERMS: Bolts 58 • Cap screws 58 • Capillary action 64 • Christmas tree clips 62 • Cotter pins 63 • Crest 58 • Die 60 • Grade 58 • Helical insert 64 • Heli-Coil® 65 • Jam nut 63 • Metric bolts 58 • Pal nut 63 • Penetrating oil 64 • Pitch 58 • Pop rivet 63 • Prevailing torque nuts 60 • Self-tapping screw 62 • Snap ring 62 • Stud 58 • Tap 60 • Tensile strength 59 • Threaded insert 65 • UNC (Unified National Coarse) 58 • UNF (Unified National Fine) 58 • Washers 62

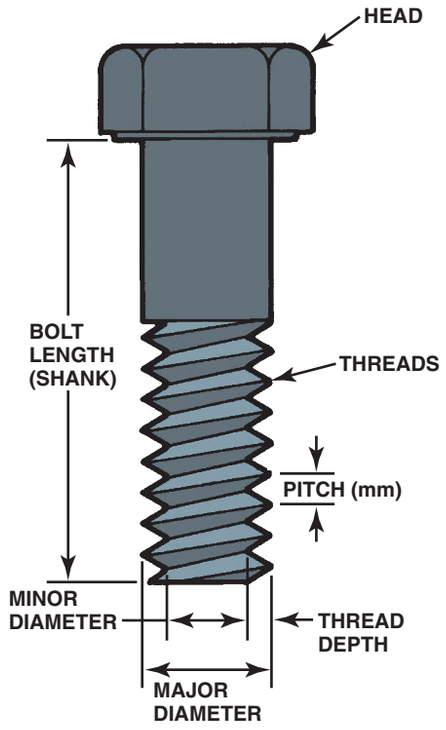


FIGURE 8–1 The dimensions of a typical bolt showing where sizes are measured. The major diameter is called the crest.

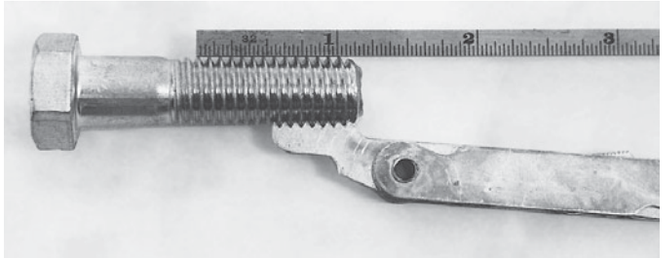


FIGURE 8–2 Thread pitch gauge used to measure the pitch of the thread. This bolt has 13 threads to the inch.

THREADED FASTENERS

TERMINOLOGY Most of the threaded fasteners used on vehicles are cap screws. They are called **cap screws** when they are threaded into a casting. Automotive service technicians usually refer to these fasteners as **bolts,** regardless of how they are used. In this chapter, they are called bolts. Sometimes, studs are used for threaded fasteners. A **stud** is a short rod with threads on both ends. Often, a stud will have coarse threads on one end and fine threads on the other end. The end of the stud with coarse threads is screwed into the casting. A nut is used on the opposite end to hold the parts together.

The fastener threads *must* match the threads in the casting or nut. The threads may be measured either in fractions of an inch (called fractional) or in metric units. The size is measured across the outside of the threads, called the **crest** of the thread. ● **SEE FIGURE 8–1.**

THREAD SIZES Fractional threads are either coarse or fine. The coarse threads are called **Unified National Coarse (UNC),** and the fine threads are called **Unified National Fine (UNF).** Standard combinations of sizes and number of threads per inch (called **pitch**) are used. Pitch can be measured with a thread pitch gauge as shown in ● **FIGURE 8–2**.

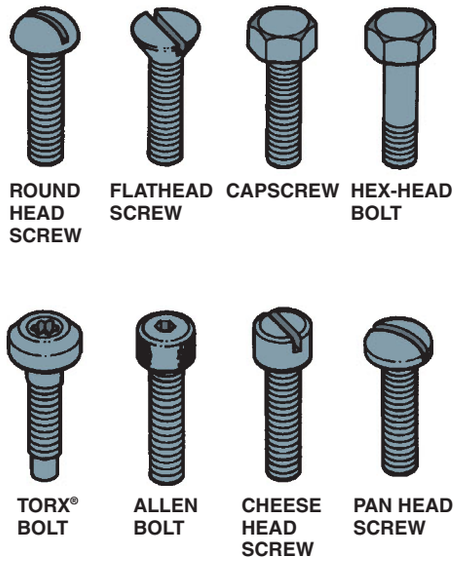


FIGURE 8–3 Bolts and screws have many different heads which determine what tool must be used.

Bolts are identified by their diameter and length as measured from below the head, and not by the size of the head or the size of the wrench used to remove or install the bolt. Bolts and screws have many different-shaped heads. ● **SEE FIGURE 8–3**.

Fractional thread sizes are specified by the diameter in fractions of an inch and the number of threads per inch. Typical UNC thread sizes would be 5/16-18 and 1/2-13. Similar UNF thread sizes would be 5/16-24 and1/2-20. ● **SEE CHART 8–1**.

METRIC BOLTS

The size of a **metric bolt** is specified by the letter *M* followed by the diameter in millimeters (mm) across the outside (crest) of the threads. Typical metric sizes would be M8 and M12. Fine metric threads are specified by the thread diameter followed by *X* and the distance between the threads measured in millimeters (M8 × 1.5). ● **SEE FIGURE 8–4**.

GRADES OF BOLTS

Bolts are made from many different types of steel, and for this reason some are stronger than others. The strength or classification of a bolt is called the **grade**. The bolt heads are marked to indicate their grade strength. Graded bolts are commonly used in the suspension parts of the vehicle but can be used almost anywhere in the vehicle.

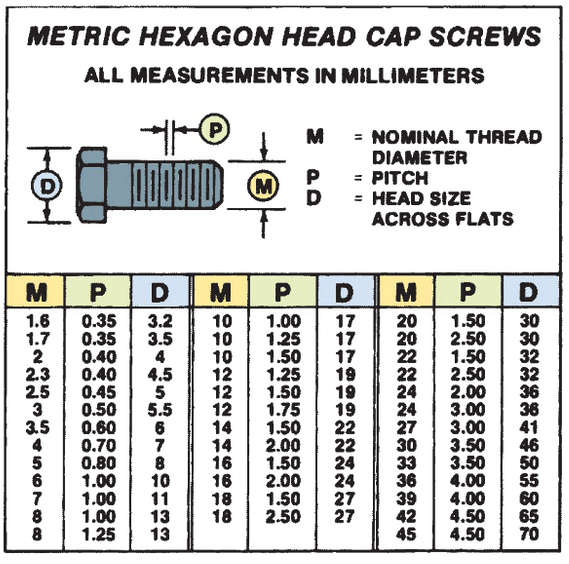
The actual grade of bolts is two more than the number of lines on the bolt head. Metric bolts have a decimal number to indicate the grade. More lines or a higher grade number indicate a stronger bolt. Higher grade bolts usually have threads that are rolled rather than cut, which also makes them stronger. ● **SEE FIGURE 8–5**. In some cases, nuts and machine screws have similar grade markings.

CAUTION: *Never* use hardware store (nongraded) bolts, studs, or nuts on any vehicle steering, suspension, or brake component. Always use the exact size and grade of hardware that is specified and used by the vehicle manufacturer.

SIZE	THREADS PER INCH NC UNC	THREADS PER INCH NF UNF	OUTSIDE DIAMETER INCHES
0	. .	80	0.0600
1	64	. .	0.0730
1	. .	72	0.0730
2	56	. .	0.0860
2	. .	64	0.0860
3	48	. .	0.0990
3	. .	56	0.0990
4	40	. .	0.1120
4	. .	48	0.1120
5	40	. .	0.1250
5	. .	44	0.1250
6	32	. .	0.1380
6	. .	40	0.1380
8	32	. .	0.1640
8	. .	36	0.1640
10	24	. .	0.1900
10	. .	32	0.1900
12	24	. .	0.2160
12	. .	28	0.2160
1/4	20	. .	0.2500
1/4	. .	28	0.2500
5/16	18	. .	0.3125
5/16	. .	24	0.3125
3/8	16	. .	0.3750
3/8	. .	24	0.3750
7/16	14	. .	0.4375
7/16	. .	20	0.4375
1/2	13	. .	0.5000
1/2	. .	20	0.5000
9/16	12	. .	0.5625
9/16	. .	18	0.5625
5/8	11	. .	0.6250
5/8	. .	18	0.6250
3/4	10	. .	0.7500
3/4	. .	16	0.7500
7/8	9	. .	0.8750
7/8	. .	14	0.8750

CHART 8–1

The American National System is one method of sizing fasteners.



M	P	D	M	P	D	M	P	D
1.6	0.35	3.2	10	1.00	17	20	1.50	30
1.7	0.35	3.5	10	1.25	17	20	2.50	30
2	0.40	4	10	1.50	17	22	1.50	32
2.3	0.40	4.5	12	1.25	19	22	2.50	32
2.5	0.45	5	12	1.50	19	24	2.00	36
3	0.50	5.5	12	1.75	19	24	3.00	36
3.5	0.60	6	14	1.50	22	27	3.00	41
4	0.70	7	14	2.00	22	30	3.50	46
5	0.80	8	16	1.50	24	33	3.50	50
6	1.00	10	16	2.00	24	36	4.00	55
7	1.00	11	18	1.50	27	39	4.00	60
8	1.00	13	18	2.50	27	42	4.50	65
8	1.25	13				45	4.50	70

FIGURE 8–4 The metric system specifies fasteners by diameter, length, and pitch.

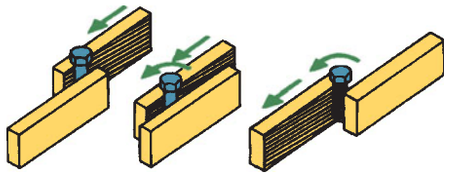


FIGURE 8–5 Stronger threads are created by cold-rolling a heat-treated bolt blank instead of cutting the threads using a die.

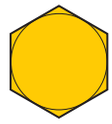
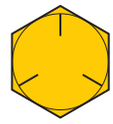
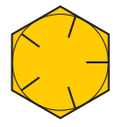
TENSILE STRENGTH

Graded fasteners have a higher tensile strength than nongraded fasteners. **Tensile strength** is the maximum stress used under tension (lengthwise force) without causing failure of the fastener. Tensile strength is specified in pounds per square inch (PSI). See the following chart that shows the grade and specified tensile strength.

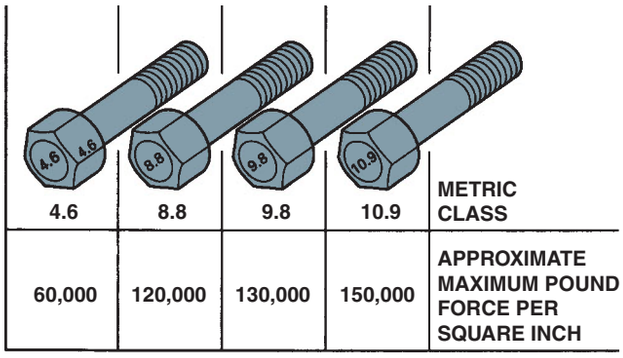
The strength and type of steel used in a bolt is supposed to be indicated by a raised mark on the head of the bolt. The type of mark depends on the standard to which the bolt was manufactured. Most often, bolts used in machinery are made to SAE Standard J429.

Metric bolt tensile strength property class is shown on the head of the bolt as a number, such as 4.6, 8.8, 9.8, and 10.9; the higher the number, the stronger the bolt. ● **SEE FIGURE 8–6**.

SAE Bolt Designations

SAE Grade No.	Size Range	Tensile Strength, PSI	Material	Head Marking
1	1/4 through 1-1/2	60,000	Low or medium carbon steel	
2	1/4 through 3/4 7/8 through 1-1/2	74,000 60,000		
5	1/4 through 1 1-1/8 through 1-1/2	120,000 105,000	Medium carbon steel, quenched & tempered	
5.2	1/4 through 1	120,000	Low carbon martensite steel*, quenched & tempered	
7	1/4 through 1-1/2	133,000	Medium carbon alloy steel, quenched & tempered	
8	1/4 through 1-1/2	150,000	Medium carbon alloy steel, quenched & tempered	
8.2	1/4 through 1	150,000	Low carbon Martensite steel*, quenched & tempered	

*Martensite steel is steel that has been cooled rapidly, thereby increasing its hardness. It is named after a German metallurgist, Adolf Martens.



METRIC CLASS	4.6	8.8	9.8	10.9
APPROXIMATE MAXIMUM POUND FORCE PER SQUARE INCH	60,000	120,000	130,000	150,000

FIGURE 8–6 Metric bolt (cap screw) grade markings and approximate tensile strength.

TECH TIP

A 1/2 In. Wrench Does Not Fit a 1/2 In. Bolt

A common mistake made by persons new to the automotive field is to think that the size of a bolt or nut is the size of the head. The size of the bolt or nut (outside diameter of the threads) is usually smaller than the size of the wrench or socket that fits the head of the bolt or nut. Examples are given in the following table.

Wrench Size	Thread Size
7/16 in.	1/4 in.
1/2 in.	5/16 in.
9/16 in.	3/8 in.
5/8 in.	7/16 in.
3/4 in.	1/2 in.
10 mm	6 mm
12 mm or 13 mm*	8 mm
14 mm or 17 mm*	10 mm

*European (Système International d'Unités-SI) metric.

HINT: An open-end wrench can be used to gauge bolt sizes. A 3/8 in. wrench will fit the threads of a 3/8 in. bolt.

NUTS

Most nuts used on cap screws have the same hex size as the cap screw head. Some inexpensive nuts use a hex size larger than the cap screw head. Metric nuts are often marked with dimples to show their strength. More dimples indicate stronger nuts. Some nuts and cap screws use interference fit threads to keep them from accidentally loosening. This means that the shape of the nut is slightly distorted or that a section of the threads is deformed. Nuts can also be kept from loosening with a nylon washer fastened in the nut or with a nylon patch or strip on the threads. ● **SEE FIGURE 8–7**.

NOTE: Most of these "locking nuts" are grouped together and are commonly referred to as prevailing torque nuts. This means that the nut will hold its tightness or torque and not loosen with movement or vibration. Most prevailing torque nuts should be replaced whenever removed to ensure that the nut will not loosen during service. Always follow the manufacturer's recommendations. Anaerobic sealers, such as Loctite®, are used on the threads where the nut or cap screw must be both locked and sealed.

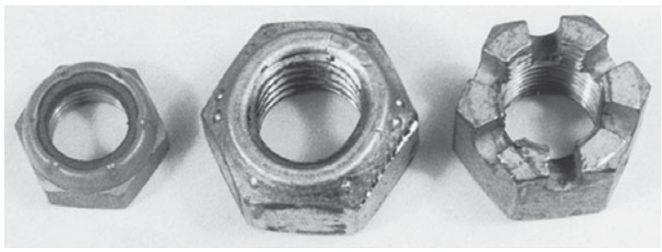


FIGURE 8–7 Types of lock nuts. On the left, a nylon ring; in the center, a distorted shape; and on the right, a castle for use with a cotter key.

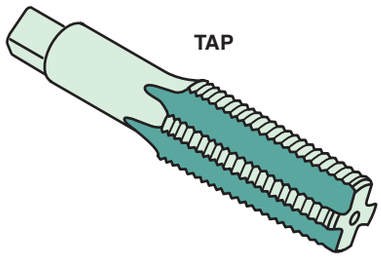


FIGURE 8–8 A typical bottoming tap used to create threads in holes that are not open, but stop in a casting, such as an engine block.

TAPS AND DIES

Taps and dies are used to cut threads. **Taps** are used to cut threads in holes drilled to an exact size depending on the size of the tap. A **die** is used to cut threads on round rods or studs. Most taps and dies come as a complete set for the most commonly used fractional and metric threads.

TAPS

There are two commonly used types of taps, including:

- **Taper tap.** This is the most commonly used tap and is designed to cut threads by gradually enlarging the threaded hole.
- **Bottoming tap.** This tap has a flat bottom instead of a tapered tip to allow it to cut threads to the bottom of a drilled hole. ● **SEE FIGURE 8–8**.

All taps must be used in the proper size hole called a "tap drill size." This information is often stamped on the tap itself or in a chart that is included with a tap and die tool set. ● **SEE FIGURE 8–9**.

DIES

A die is a hardened steel round cutter with teeth on the inside of the center hole. ● **SEE FIGURE 8–10**. A die is rotated using a die handle over a rod to create threads.

PROPER USE OF TAPS AND DIES

Taps and dies are used to cut threads on rods in the case of a die or in a hole for a tap. A small tap can be held using a T-handle tap wrench but for larger taps a tap handle is needed to apply the needed force to cut threads. **SEE FIGURES 8–11A AND 8–11B**.

TAP USAGE. Be sure that the hole is the correct size for the tap and start by inserting the tap straight into the hole. Lubricate the tap using tapping lubricant. Rotate the tap about one full turn clockwise, then reverse the direction of the tap one-half turn to break the chip that was created. Repeat the procedure until the hole is completely threaded.

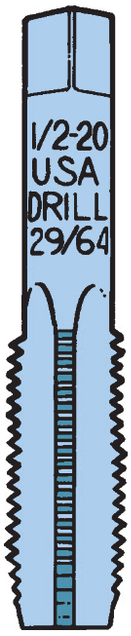


FIGURE 8–9 Many taps, especially larger ones, have the tap drill size printed on the top.

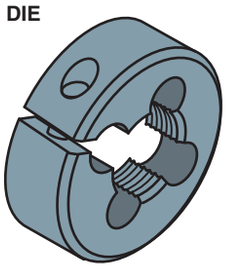


FIGURE 8–10 A die is used to cut threads on a metal rod.

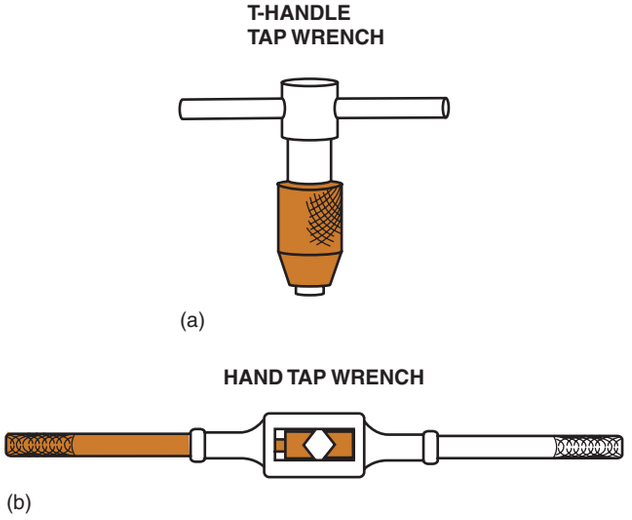


FIGURE 8–11 (a) A T-handle is used to hold and rotate small taps. (b) A tap wrench is used to hold and drive larger taps.

DIE USAGE. A die should be used on the specified diameter rod for the size of the thread. Install the die securely into the die handle. ● **SEE FIGURE 8–12.**

Lubricate the die and the rod and place the die onto the end of the rod to be threaded. Rotate the die handle one full turn clockwise, then reverse the direction and rotate the die handle about a half turn counterclockwise to break the chip that was created. Repeat the process until the threaded portion has been completed.



FIGURE 8–12 A die handle used to rotate a die while cutting threads on a metal rod.

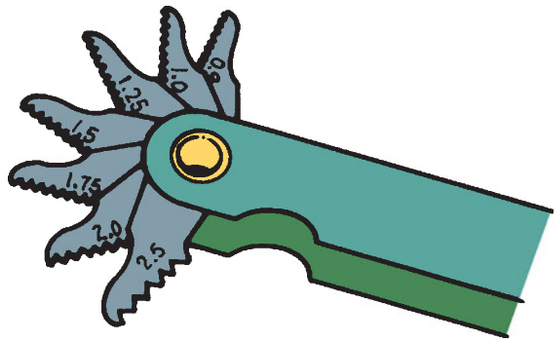


FIGURE 8–13 A typical metric thread pitch gauge.

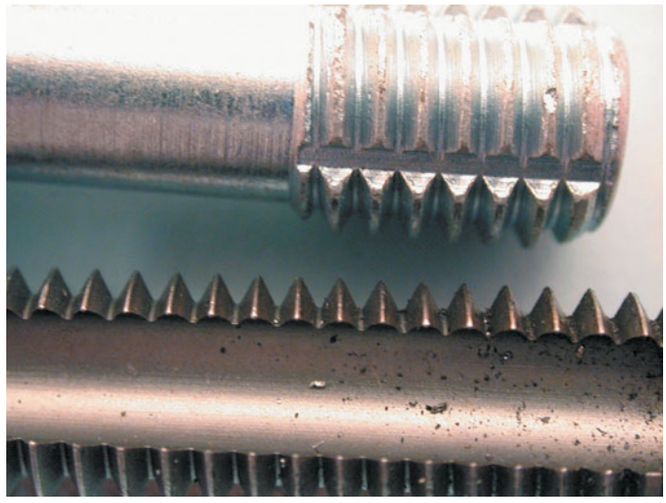


FIGURE 8–14 A thread chaser is shown at the top compared to a tap on the bottom. A thread chaser is used to clean threads without removing metal.

THREAD PITCH GAUGE

A thread pitch gauge is a hand tool that has the outline of various thread sizes machined on stamped blades. To determine the thread pitch size of a fastener, the technician matches the thread of the thread pitch gauge to the threads of the fastener. ● **SEE FIGURE 8–13.**

? FREQUENTLY ASKED QUESTION

What Is the Difference Between a Tap and a Thread Chaser?

A tap is a cutting tool and is designed to cut new threads. A thread chaser has more rounded threads and is designed to clean dirty threads without removing metal. Therefore, when cleaning threads, it is best to use a thread chaser rather than a tap to prevent the possibility of removing metal, which would affect the fit of the bolt being installed. ● **SEE FIGURE 8–14**

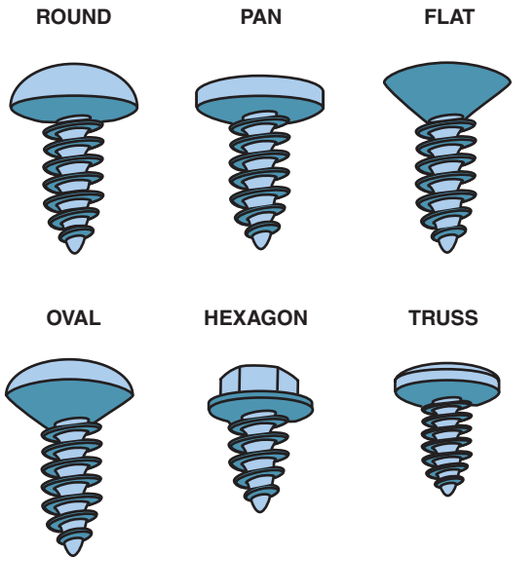


FIGURE 8–15 Sheet metal screws come with many head types.

SHEET METAL SCREWS

Sheet metal screws are fully threaded screws with a point for use in sheet metal. Also called **self-tapping screws,** they are used in many places on the vehicle, including fenders, trim, and door panels. ● **SEE FIGURE 8–15**.

These screws are used in unthreaded holes and the sharp threads cut threads as they are installed. This makes for a quick and easy installation when installing new parts, but the sheet metal screw can easily strip out the threads when used on the same part over and over, so care is needed.

When reinstalling self-tapping screws, first turn the screw lightly backwards until you feel the thread drop into the existing thread in the screw hole. Then, turn the screw in; if it threads in easily, continue to tighten the screw. If the screw seems to turn hard, stop and turn it backwards about another half turn to locate the existing thread and try again. This technique can help prevent stripped holes in sheet metal and plastic parts.

Sheet metal screws are sized according to their major thread diameter.

Size	Diameter Decimal (inch)	Diameter Nearest Fraction Inch
4	0.11	7/64
6	0.14	9/64
8	0.17	11/64
10	0.19	3/16
12	0.22	7/32
14	0.25	1/4

WASHERS

Washers are often used under cap screw heads and under nuts. ● **SEE FIGURE 8–16**.

Plain flat washers are used to provide an even clamping load around the fastener. Lock washers are added to prevent accidental loosening. In some accessories, the washers are locked onto the nut to provide easy assembly.

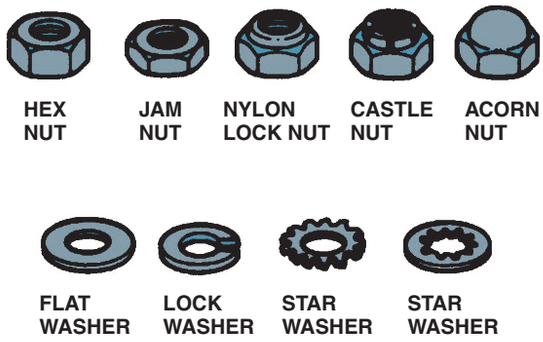


FIGURE 8–16 Various types of nuts (top) and washers (bottom) serve different purposes and all are used to secure bolts or cap screws.

Flat washers are placed underneath a nut to spread the load over a wide area and prevent gouging of the material. However, flat washers do not prevent a nut from loosening.

Lock washers are designed to prevent a nut from loosening. Spring-type lock washers resemble a loop out of a coil spring. As the nut or bolt is tightened, the washer is compressed. The tension of the compressed washer holds the fastener firmly against the threads to prevent it from loosening. Lock washers should not be used on soft metal such as aluminum. The sharp ends of the steel washers would gouge the aluminum badly, especially if they are removed and replaced often.

Another type of locking washer is the star washer. The teeth on a star washer can be external or internal, and they bite into the metal because they are twisted to expose their edges. Star washers are used often on sheet metal or body parts. They are seldom used on engines. The spring steel lock washer also uses the tension of the compressed washer to prevent the fastener from loosening. The waves in this washer make it look like a distorted flat washer.

SNAP RINGS AND CLIPS

SNAP RINGS

Snap rings are not threaded fasteners, but instead attach with a springlike action. Snap rings are constructed of spring steel and are used to attach parts without using a threaded fastener. There are several different types of snap rings and most require the use of a special pair of pliers, called snap ring pliers, to release or install. The types of snap rings include:

- Expanding (internal)
- Contracting (external)
- E-clip
- C-clip
- Holeless snap rings in both expanding and contracting styles.

● **SEE FIGURE 8–17**.

DOOR PANEL CLIPS

Interior door panels and other trim pieces are usually held in place with plastic clips. Due to the tapered and fluted shape, these clips are often called **Christmas tree clips.** ● **SEE FIGURE 8–18**.

A special tool is often used to remove interior door panels without causing any harm. ● **SEE FIGURE 8–19**.

CAUTION: Use extreme care when removing panels that use plastic or nylon clips. It is very easy to damage the door panel or clip during removal.

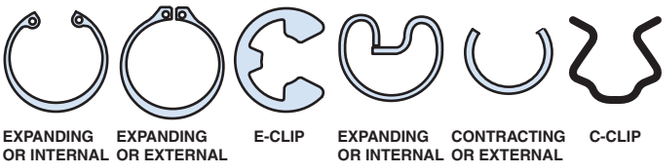


FIGURE 8–17 Some different types of snap rings. An internal snap ring fits inside of a housing or bore, into a groove. An external snap ring fits into a groove on the outside of a shaft or axle. An E-clip fits into a groove in the outside of a shaft. A C-clip shown is used to retain a window regulator handle on its shaft.

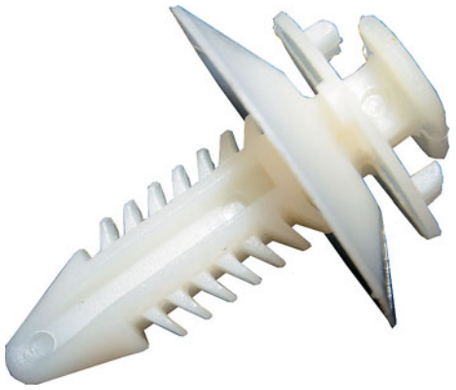


FIGURE 8–18 A typical door panel retaining clip.



FIGURE 8–19 Plastic or metal trim tools are available to help the technician remove interior door panels and other trim without causing harm.

PINS

Cotter pins, also called a cotter key, are used to keep linkage or a threaded nut in place or to keep it retained. The word *cotter* is an Old English verb meaning "to close or fasten." There are many other types of pins used in vehicles, including clevis pins, roll pins, and hair pins. ● **SEE FIGURE 8–20**.

Pins are used to hold together shafts and linkages, such as shift linkages and cable linkages. The clevis pin is held in place with a cotter pin, while the taper and roll pins are driven in and held by friction. The hair pin snaps into a groove on a shaft.

RIVETS

Rivets are used in many locations to retain components, such as window mechanisms, that do not require routine removal and/or do not have access to the back side for a nut. A drill is usually used to remove a rivet and a rivet gun is needed to properly install

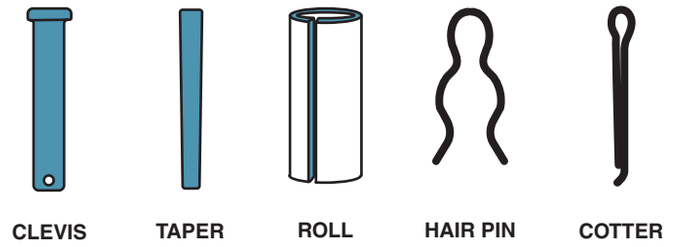


FIGURE 8–20 Pins come in various types.

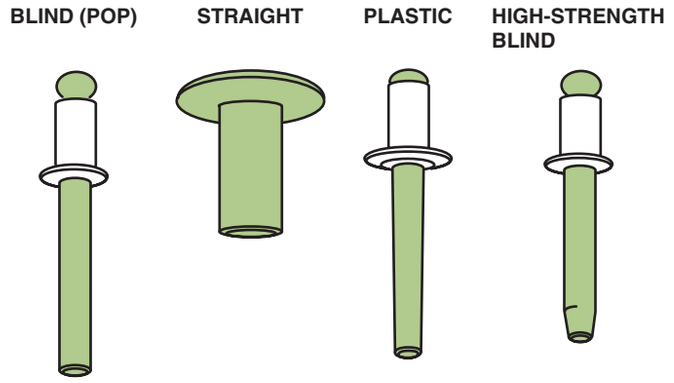


FIGURE 8–21 Various types of rivets.

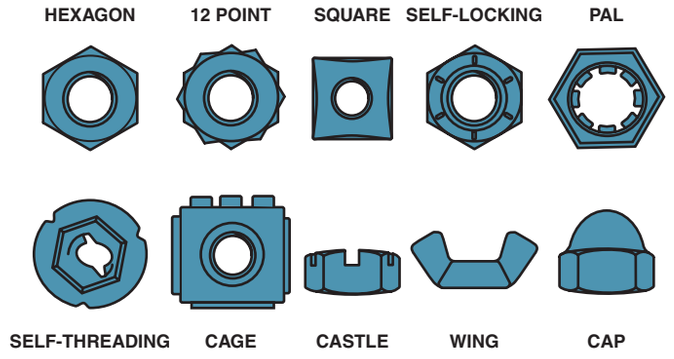


FIGURE 8–22 All of the nuts shown are used by themselves except for the pal nut, which is used to lock another nut to a threaded fastener so they will not be loosened by vibration.

a rivet. Some rivets are plastic and are used to hold some body trim pieces. The most common type of rivet is called a **pop rivet** because as the rivet tool applies a force to the shaft of the pop rivet, it causes the rivet to expand and tighten the two pieces together. When the shaft of the rivet, which looks like a nail, is pulled to its maximum, the shaft breaks, causing a "pop" sound.

Rivets may be used in areas of the vehicle where a semipermanent attachment is needed and in places where there is no access to the back side of the workpiece. They are installed using a rivet gun or by peening with a ball-peen hammer. ● **SEE FIGURE 8–21**.

Both types of blind rivets require the use of a rivet gun to install. The straight rivet is placed through the workpieces and then peened over with a ball-peen hammer or an air-operated tool. The plastic rivet is used with a rivet gun to install some body trim parts.

LOCKING NUTS

Some nuts, called jam nuts, are used to keep bolts and screws from loosening. **Jam nuts** screw on top of a regular nut and jam against the regular nut to prevent loosening. A jam nut is so called because of its intended use, rather than a special design. Some jam nuts are thinner than a standard nut. Jam nuts are also called **pal nuts.** ● **SEE FIGURE 8–22**.

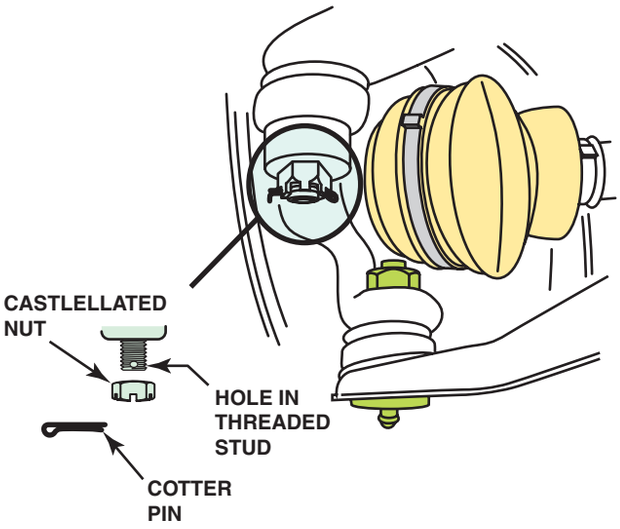


FIGURE 8–23 A castellated nut is locked in place with a cotter pin.

There are also self-locking nuts of various types. Some have threads that are bent inward to grip the threads of the bolt. Some are oval-shaped at one end to fit tightly on a bolt. Fiber lock nuts have a fiber insert near the top of the nut or inside it; this type of nut is also made with a plastic or nylon insert. When the bolt turns through the nut, it cuts threads in the fiber or plastic. This puts a drag on the threads that prevents the bolt from loosening.

One of the oldest types of retaining nuts is the castle nut. It looks like a small castle, with slots for a cotter pin. A castellated nut is used on a bolt that has a hole for the cotter pin. ● **SEE FIGURE 8–23**.

HOW TO AVOID BROKEN FASTENERS

Try not to break, strip, or round off fasteners in the first place. There are several ways that you can minimize the number of fasteners you damage. First, never force fasteners loose during disassembly. Taking a few precautionary steps will often prevent damage. If a bolt or nut will not come loose with normal force, try tightening it in slightly and then backing it out. Sometimes turning the fastener the other way will break corrosion loose, and the fastener will then come out easily. Another method that works well is to rest a punch on the head of a stubborn bolt and strike it a sharp blow with a hammer. Often this method will break the corrosion loose.

LEFT-HANDED THREADS Although rare, left-handed fasteners are occasionally found on engine assemblies. These fasteners will loosen when you turn them clockwise, and tighten when you turn them counterclockwise. Left-handed fasteners are used to fasten parts to the ends of rotating assemblies that turn counterclockwise, such as crankshafts and camshafts. Most automobile engines do not use left-handed threads; however, they will be found on many older motorcycle engines. Some left-handed fasteners are marked with an "L" on the bolt head for easy identification, others are not. Left-handed threads are also found inside some transaxles.

PENETRATING OIL **Penetrating oil** is a lightweight lubricant similar to kerosene, which soaks into small crevices in the threads by **capillary action**. The chemical action of penetrating oils helps to break up and dissolve rust and corrosion. The oil forms a layer of boundary lubrication on the threads to reduce friction and make the fastener easier to turn.

For best results, allow the oil time to soak in before removing the nuts and bolts. To increase the effectiveness of penetrating oil, tap on the bolt head or nut with a hammer, or alternately work the fastener back and forth with a wrench. This movement weakens the bond of the corrosion and lets more of the lubricant work down into the threads.



FIGURE 8–24 Helical inserts look like small, coiled springs. The outside is a thread to hold the coil in the hole, and the inside is threaded to fit the desired fastener.

PROPER TIGHTENING Proper tightening of bolts and nuts is critical for proper clamping force, as well as to prevent breakage. All fasteners should be tightened using a torque wrench. A torque wrench allows the technician to exert a known amount of torque to the fasteners. However, rotating torque on a fastener does not mean clamping force because up to 80% of the torque used to rotate a bolt or nut is absorbed by friction by the threads. Therefore, for accurate tightening, two things must be performed:

- The threads must be clean and lubricated if service information specifies that they be lubricated.
- Always use a torque wrench to not only ensure proper clamping force, but also to ensure that all fasteners are tightened the same.

THREAD REPAIR INSERTS

Thread repair inserts are used to replace the original threaded hole when it has become damaged beyond use. The original threaded hole is enlarged and tapped for threads and a threaded insert is installed to restore the threads to the original size.

HELICAL INSERTS A **helical insert** looks like a small, stainless-steel spring. ● **SEE FIGURE 8–24**.

To install a helical insert, a hole must be drilled to a specified oversize, and then it is tapped with a special tap designed for the thread inserts. The insert is then screwed into the hole. ● **SEE FIGURE 8–25**.

The insert stays in the casting as a permanent repair and bolts can be removed and replaced without disturbing the insert. One advantage of a helical insert is that the original bolt can be used because the internal threads are the same size. When correctly installed, an insert is often stronger than the original threads, especially in aluminum castings. Some vehicle manufacturers, such as BMW, specify that the threads be renewed using an insert if the cylinder head has

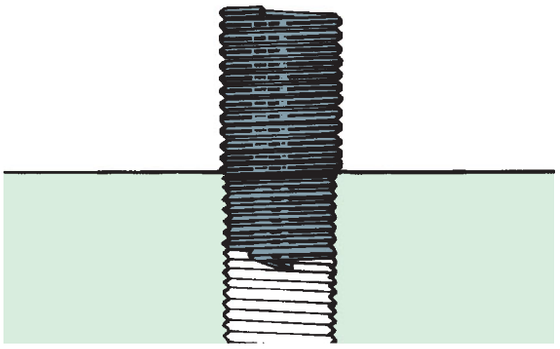


FIGURE 8–25 The insert provides new, stock-size threads inside an oversize hole so that the original fastener can be used.



FIGURE 8–26 Heli-Coil® kits, available in a wide variety of sizes, contain everything needed to repair a damaged hole back to its original size.

to be removed and reinstalled. Plus many high-performance engine rebuilders install inserts in blocks, manifolds, and cylinder heads as a precaution.

One of the best known of the helical fasteners is the **Heli-Coil®,** manufactured by Heli-Coil® Products. To install Heli-Coil® inserts, you will need to have a thread repair kit. The kit includes a drill bit, tap, installation mandrel, and inserts. Repair kits are available for a wide variety of diameters and pitch to fit both American Standard and metric threads. A simple kit contains the tooling for one specific thread size. Master kits that cover a range of sizes are also available. Installing an insert is similar to tapping new threads. A summary of the procedures includes:

1. Select the Heli-Coil® kit designed for the specific diameter and thread pitch of the hole to be repaired. ● **SEE FIGURE 8–26**.
2. Use the drill bit supplied with the kit. The drill size is also specified on the Heli-Coil® tap, to open up the hole to the necessary diameter and depth.
3. Tap the hole with the Heli-Coil® tap, being sure to lubricate the tap. Turn it in slowly and rotate counterclockwise occasionally to break the chip that is formed.
4. Thread an insert onto the installation mandrel until it seats firmly. Apply a light coating of the recommended thread locking compound to the external threads of the insert.
5. Use the mandrel to screw the insert into the tapped hole. Once started, spring tension prevents the insert from unscrewing. Stop when the top of the insert is 1/4 to 1/2 turn below the surface.

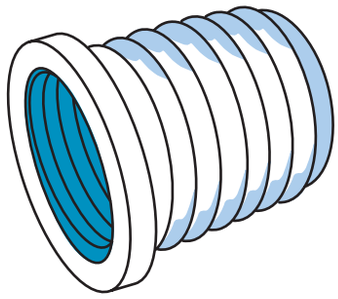


FIGURE 8–27 This solid-bushing insert is threaded on the outside, to grip the workpiece. The inner threads match the desired bolt size.

6. Remove the mandrel by unscrewing it from the insert, and then use a small punch or needle-nose pliers to break off the tang at the base of the insert. Never leave the tang in the bore. The finished thread is ready for use immediately.

THREADED INSERTS

Threaded inserts are tubular, case-hardened, solid steel wall pieces that are threaded inside and outside. The inner thread of the insert is sized to fit the original fastener of the hole to be repaired. The outer thread design will vary. These may be self-tapping threads that are installed in a blank hole, or machine threads that require the hole to be tapped. Threaded inserts return a damaged hole to original size by replacing part of the surrounding casting so drilling is required. Most inserts fit into three categories.

- Self-tapping
- Solid-bushing
- Key-locking

SELF-TAPPING INSERTS

The external threads of a self-tapping insert are designed to cut their own way into a casting. This eliminates the need of running a tap down the hole. To install a typical self-tapping insert, follow this procedure.

1. Drill out the damaged threads to open the hole to the proper size, using the specified size drill bit.
2. Select the proper insert and mandrel. As with Heli-Coils®, the drill bit, inserts, and mandrel are usually available as a kit.
3. Thread the insert onto the mandrel. Use a tap handle or wrench to drive the insert into the hole. Because the insert will cut its own path into the hole, it may require a considerable amount of force to drive the insert in.
4. Thread the insert in until the nut or flange at the bottom of the mandrel touches the surface of the workpiece. This is the depth stop to indicate the insert is seated.
5. Hold the nut or flange with a wrench, and turn the mandrel out of the insert. The threads are ready for immediate use.

SOLID-BUSHING INSERTS

The external threads of solid-bushing inserts are ground to a specific thread pitch, so you will have to run a tap into the hole. ● **SEE FIGURE 8–27**.

Some inserts use a machine thread so a standard tap can be used; others have a unique thread and you have to use a special tap. The thread inserts come with a matching installation kit. ● **SEE FIGURE 8–28**.

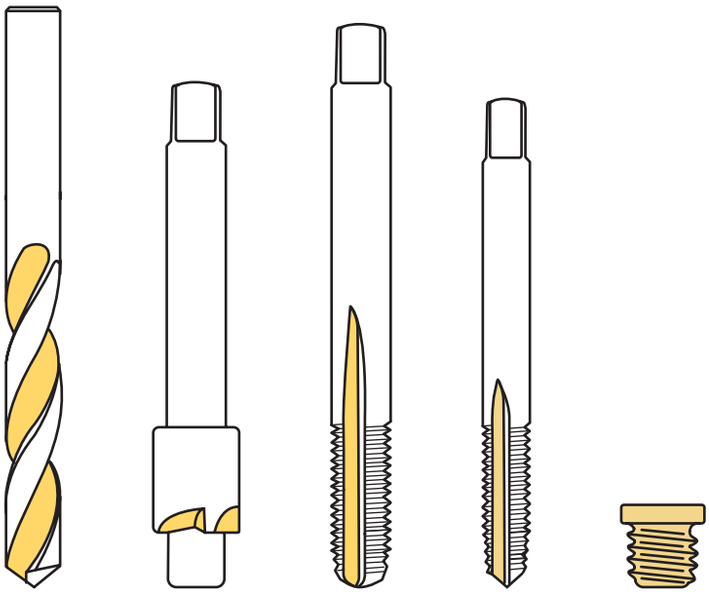


FIGURE 8–28 A Timesert® kit includes the drill (a), the recess cutter (b), a special tap (c), the installer (d), and the Timesert® threaded bushing (e).



FIGURE 8–29 Drill out the damaged threads with the correct bit.

To install threaded inserts, follow this procedure.

1. Drill out the damaged threads to open the hole to the proper size. The drill bit supplied with the kit must be the one used because it is properly sized to the tap. ● **SEE FIGURE 8–29**.
2. Cut the recess in the top of the hole with the special tool, then clean the hole with a brush or compressed air.
3. Use the previously detailed tapping procedures to thread the hole. ● **SEE FIGURE 8–30**. Be sure to tap deep enough; the top of the insert must be flush with the casting surface.
4. Thread the insert onto the installation driver, using the driver to screw the insert into the hole. Some inserts require that a thread-locking compound be applied; others go in dry.

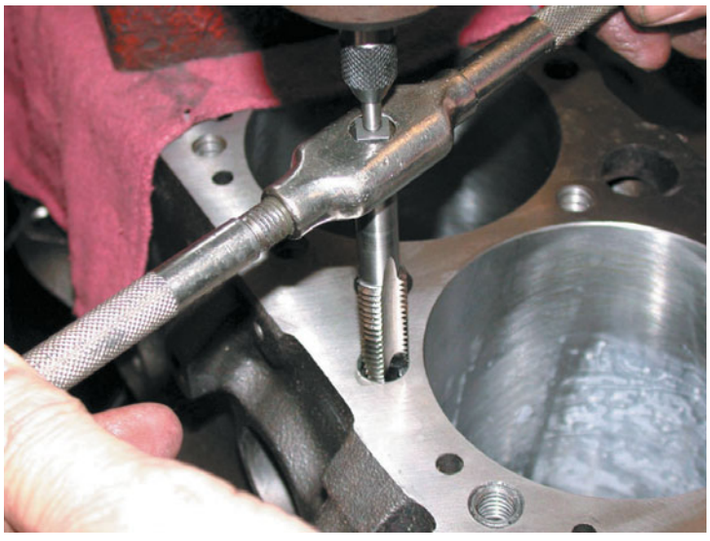


FIGURE 8–30 Use a special tap for the insert.



FIGURE 8–31 Put some thread-locking compound on the insert.

5. Remove the installation driver, and the new threads are ready for service with the original fastener.

KEY-LOCKING INSERTS Key-locking inserts are similar to solid-bushing inserts, but are held in place by small keys. After the insert has been installed, the keys are driven into place—perpendicular to the threads—to keep the insert from turning out. A typical installation procedure includes the following steps.

1. Drill out the damaged thread with the specified drill size.
2. Tap the drilled hole with the specified tap.
3. After putting thread locking compound on the insert, use the mandrel to screw the insert into the tapped hole until it is slightly below the surface. ● **SEE FIGURE 8–31**. The keys act as a depth stop and prevent the insert from turning.
4. Drive the keys down using the driver supplied with the insert kit. Be sure the keys are flush with the top of the insert. ● **SEE FIGURES 8–32 AND 8–33**.

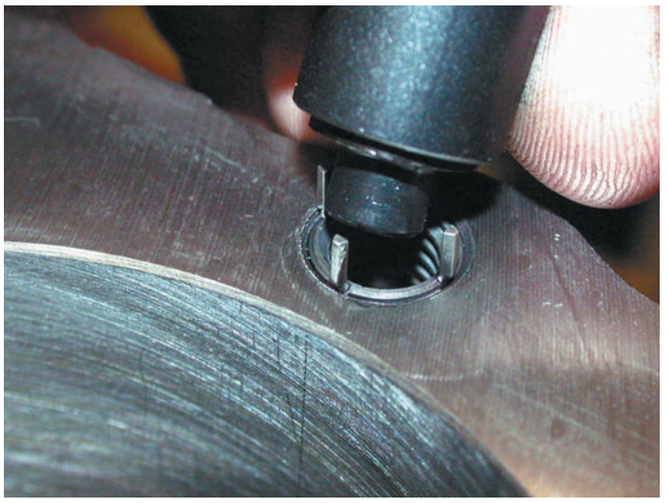


FIGURE 8–32 Use the driver to drive the keys down flush with the surface of the workpiece.



FIGURE 8–33 The insert and insert locks should be below the surface of the workpiece.

REVIEW QUESTIONS

1. What is the difference between a bolt and a stud?
2. How is the size of a metric bolt expressed?
3. What is meant by the grade of a threaded fastener?
4. How do prevailing torque nuts work?
5. How are threaded inserts installed?

CHAPTER QUIZ

1. The thread pitch of a bolt is measured in what units?
   a. Millimeters
   b. Threads per inch
   c. Fractions of an inch
   d. Both a and b
2. Technician A says that the diameter of a bolt is the same as the wrench size used to remove or install the fastener. Technician B says that the length is measured from the top of the head of the bolt to the end of the bolt. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. The grade of a fastener, such as a bolt, is a measure of its _____.
   a. Tensile strength **c.** Finish
   b. Hardness **d.** Color
4. Which of the following is a metric bolt?
   a. 5/16 − 18 **c.** M12 × 1.5
   b. 1/2 − 20 **d.** 8 mm
5. A bolt that is threaded into a casting is often called a _____.
   a. Stud **c.** Block bolt
   b. Cap screw **d.** Crest bolt
6. The marks (lines) on the heads of bolts indicate _____.
   a. Size **c.** Tensile strength
   b. Grade **d.** Both b and c
7. A bolt that requires a 1/2 in. wrench to rotate is usually what size when measured across the threads?
   a. 1/2 in. **c.** 3/8 in.
   b. 5/16 in. **d.** 7/16 in.
8. A screw that can make its own threads when installed is called a _____ screw.
   a. Sheet metal
   b. Tapered
   c. Self-tapping
   d. Both a and c
9. All of the following are types of clips *except* _____.
   a. E-clip
   b. Cotter
   c. C-clip
   d. Internal
10. What type of fastener is commonly used to retain interior door panels?
    a. Christmas tree clips
    b. E-clips
    c. External clips
    d. Internal clips

chapter 9

HAND TOOLS

OBJECTIVES: After studying Chapter 9, the reader should be able to: • Describe what tool is the best to use for each job. • Discuss how to safely use hand tools. • Explain the difference between the brand name (trade name) and the proper name for tools. • Explain how to maintain hand tools.

KEY TERMS: Adjustable wrench 68 • Aviation tin snips 75 • Beam-type torque wrench 70 • Box-end wrench 68 • Breaker bar (flex handle) 69 • Cheater bar 80 • Chisel 76 • Clicker-type torque wrench 70 • Close-end wrench 68 • Cold chisel 76 • Combination wrench 68 • Crowfoot socket 70 • Dead-blow hammer 73 • Diagonal (side-cut or dike) pliers 73 • Double-cut file 75 • Drive size 70 • Easy out 77 • Extension 70 • Files 75 • Fitting wrench 68 • Flare-nut wrench 68 • Flat-tip (straight blade) screwdriver 72 • Hacksaw 77 • Locking pliers 74 • Multigroove adjustable pliers 73 • Needle-nose pliers 74 • Nut splitter 76 • Offset left aviation snip 75 • Offset right aviation snip 75 • Open-end wrench 68 • Punch 75 • Ratchet 69 • Removers 76 • Screwdriver 72 • Seal driver 79 • Seal puller 79 • Single-cut file 75 • Slip-joint pliers 73 • Snap-ring pliers 75 • Socket 69 • Socket adapter 71 • Straight cut aviation snip 75 • Stud removal tool 76 • Stud remover 76 • Tin snips 75 • Torque wrench 70 • Tube-nut wrench 68 • Universal joint 70 • Utility knife 75 • Vise-Grip® 74 • Water pump pliers 73 • Wrench 68

WRENCHES

Wrenches are the most used hand tool by service technicians. Most wrenches are constructed of forged alloy steel, usually chrome-vanadium steel. ● **SEE FIGURE 9–1**.

After the wrench is formed, it is hardened, tempered to reduce brittleness, and then chrome plated. Wrenches are available in both fractional and metric sizes. There are several types of wrenches.



FIGURE 9–1 A forged wrench after it has been forged but before the flashing, extra material around the wrench, has been removed.

OPEN-END WRENCH

An **open-end wrench** is often used to loosen or tighten bolts or nuts that do not require a lot of torque. An open-end wrench can be easily placed on a bolt or nut with an angle of 15 degrees, which allows the wrench to be flipped over and used again to continue to rotate the fastener. The major disadvantage of an open-end wrench is the lack of torque that can be applied due to the fact that the open jaws of the wrench only contact two flat surfaces of the fastener. An open-end wrench has two different sizes, one at each end. ● **SEE FIGURE 9–2**.

BOX-END WRENCH

A **box-end wrench** is placed over the top of the fastener and grips the points of the fastener. A box-end wrench is angled 15 degrees to allow it to clear nearby objects. ● **SEE FIGURE 9–3**.

Therefore, a box-end wrench should be used to loosen or to tighten fasteners. A box-end wrench is also called a **close-end wrench**. A box-end wrench has two different sizes, one at each end. ● **SEE FIGURE 9–4**.

COMBINATION WRENCH

Most service technicians purchase **combination wrenches,** which have the open end at one end and the same size box end on the other. ● **SEE FIGURE 9–5**.

A combination wrench allows the technician to loosen or tighten a fastener using the box end of the wrench, turn it around, and use the open end to increase the speed of rotating the fastener.

ADJUSTABLE WRENCH

An **adjustable wrench** is often used where the exact size wrench is not available or when a large nut, such as a wheel spindle nut, needs to be rotated but not tightened. An adjustable wrench should not be used to loosen or tighten fasteners because the torque applied to the wrench can cause the movable jaws to loosen their grip on the fastener, causing it to become rounded. ● **SEE FIGURE 9–6**.

LINE WRENCHES

Line wrenches are also called **flare-nut wrenches, fitting wrenches,** or **tube-nut wrenches** and are designed to grip almost all the way around a nut used to retain a fuel or refrigerant line, and yet be able to be installed over the line. ● **SEE FIGURE 9–7**.

SAFE USE OF WRENCHES. Wrenches should be inspected before use to be sure they are not cracked, bent, or damaged. All wrenches should be cleaned after use before being returned to the toolbox.

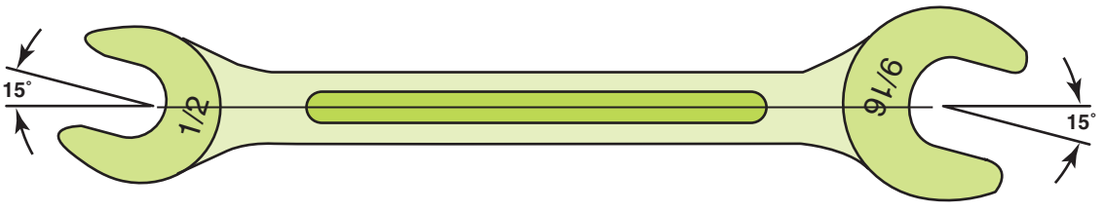


FIGURE 9–2 A typical open-end wrench. The size is different on each end and notice that the head is angled 15 degrees at each end.

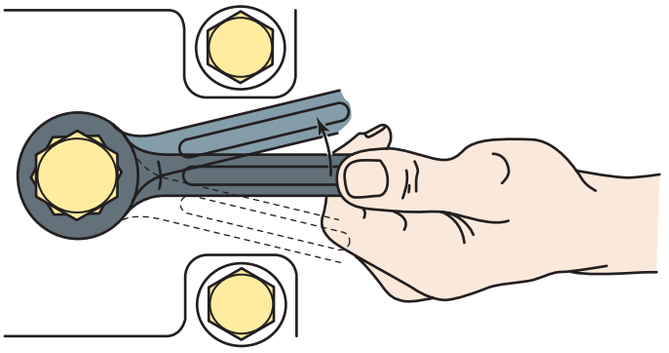


FIGURE 9–3 A typical box-end wrench is able to grip the bolt or nut at points completely around the fastener. Each end is a different size.

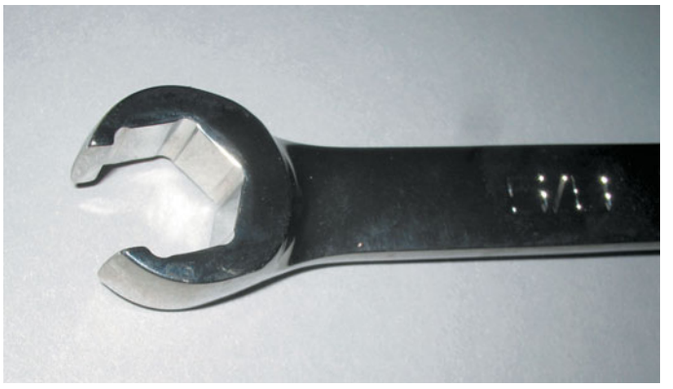


FIGURE 9–7 The end of a typical line wrench, which shows that it is capable of grasping most of the head of the fitting.

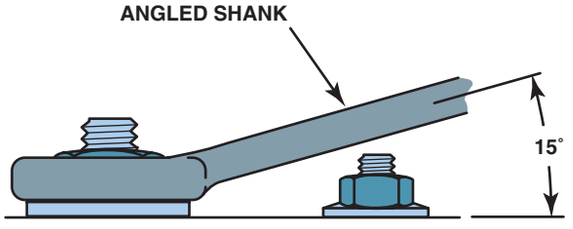


FIGURE 9–4 The end of a box-end wrench is angled 15 degrees to allow clearance for nearby objects or other fasteners.

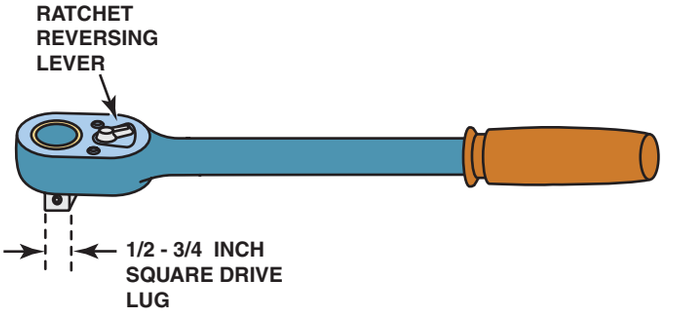


FIGURE 9–8 A typical ratchet used to rotate a socket. A ratchet makes a ratcheting noise when it is being rotated in the opposite direction from loosening or tightening. A knob or lever on the ratchet allows the user to switch directions.

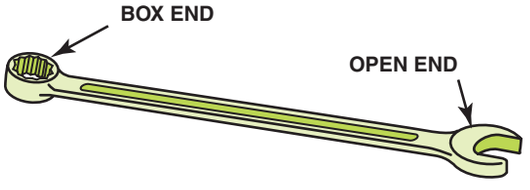


FIGURE 9–5 A combination wrench has an open end at one end and a box end at the other with the same size at each end.

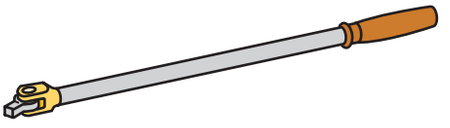


FIGURE 9–9 A typical flex handle used to rotate a socket, also called a breaker bar because it usually has a longer handle than a ratchet and, therefore, can be used to apply more torque to a fastener than a ratchet.

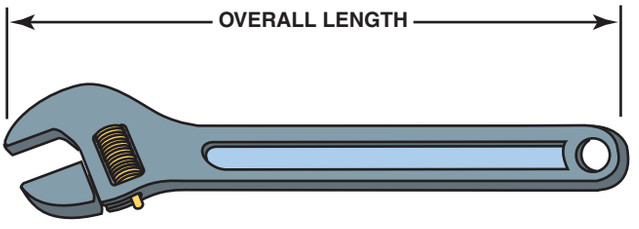


FIGURE 9–6 An adjustable wrench. Adjustable wrenches are sized by the overall length of the wrench and not by how far the jaws open. Common sizes of adjustable wrenches include 8, 10, and 12 in.

Always use the correct size of wrench for the fastener being loosened or tightened to help prevent the rounding of the flats of the fastener. When attempting to loosen a fastener, pull a wrench—do not push a wrench. If a wrench is pushed, your knuckles can be hurt when forced into another object if the fastener breaks loose.

RATCHETS, SOCKETS, AND EXTENSIONS

A **socket** fits over the fastener and grips the points and/or flats of the bolt or nut. The socket is rotated (driven) using either a long bar called a **breaker bar (flex handle)** or a **ratchet.** ● **SEE FIGURES 9–8 AND 9–9**.

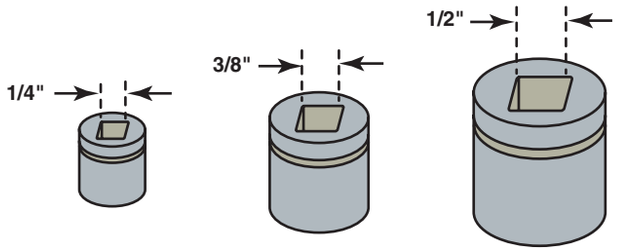


FIGURE 9–10 The most commonly used socket drive sizes include 1/4 in., 3/8 in., and 1/2 in. drive.

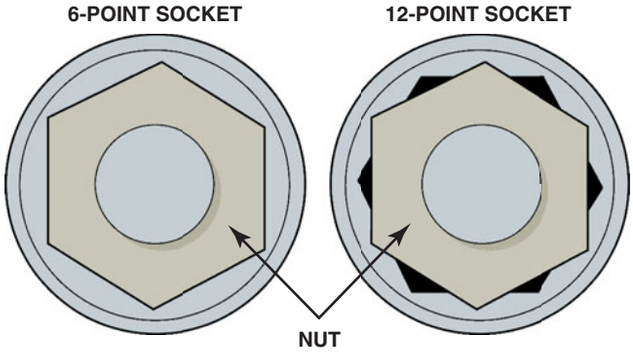


FIGURE 9–11 A 6-point socket fits the head of the bolt or nut on all sides. A 12-point socket can round off the head of a bolt or nut if a lot of force is applied.

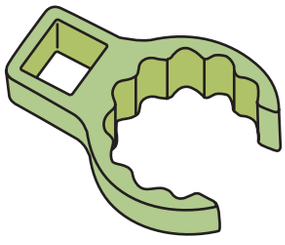


FIGURE 9–12 A crowfoot socket is designed to reach fasteners using a ratchet or breaker bar with an extension.

A ratchet turns the socket in only one direction and allows the rotating of the ratchet handle back and forth in a narrow space. Socket **extensions** and **universal joints** are also used with sockets to allow access to fasteners in restricted locations.

Sockets are available in various **drive sizes,** including 1/4 in., 3/8 in., and 1/2 in. sizes for most automotive use. ● **SEE FIGURES 9–10 AND 9–11**.

Many heavy-duty truck and/or industrial applications use 3/4 in. and 1 in. sizes. The drive size is the distance of each side of the square drive. Sockets and ratchets of the same size are designed to work together.

CROWFOOT SOCKETS

A **crowfoot socket** is a socket that is an open-end or line wrench to allow access to fasteners that cannot be reached using a conventional wrench. ● **SEE FIGURE 9–12**.

Crowfoot sockets are available in the following categories.

- Fractional inch open-end wrench
- Metric open-end wrench
- Fractional line wrench
- Metric line wrench

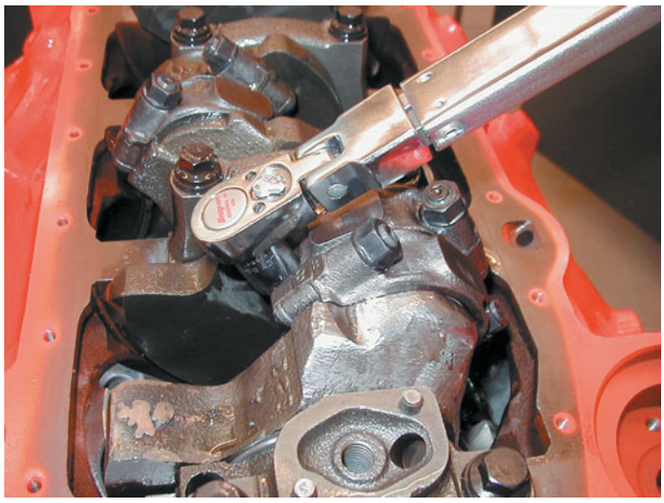


FIGURE 9–13 Using a torque wench to tighten connecting rod nuts on an engine.



FIGURE 9–14 A beam-type torque wrench that displays the torque reading on the face of the dial. The beam display is read as the beam deflects, which is in proportion to the amount of torque applied to the fastener.

TECH TIP

Right to Tighten

It is sometimes confusing which way to rotate a wrench or screwdriver, especially when the head of the fastener is pointing away from you. To help visualize while looking at the fastener, say “righty tighty, lefty loosey.”

TORQUE WRENCHES

Torque wrenches are socket turning handles that are designed to apply a known amount of force to the fastener. There are two basic types of torque wrenches.

1. A **clicker-type torque wrench** is first set to the specified torque and then it “clicks” when the set torque value has been reached. When force is removed from the torque wrench handle, another click is heard. The setting on a clicker-type torque wrench should be set back to zero after use and checked for proper calibration regularly. ● **SEE FIGURE 9–13**.
2. A **beam- or dial-type torque wrench** is used to measure torque, but instead of presetting the value, the actual torque is displayed on the dial of the wrench as the fastener is being tightened. Beam-type torque wrenches are available in 1/4 in., 3/8 in., and 1/2 in. drives and both English and metric units. ● **SEE FIGURE 9–14**.

SAFE USE OF SOCKETS AND RATCHETS. Always use the proper size socket that correctly fits the bolt or nut. All sockets and ratchets

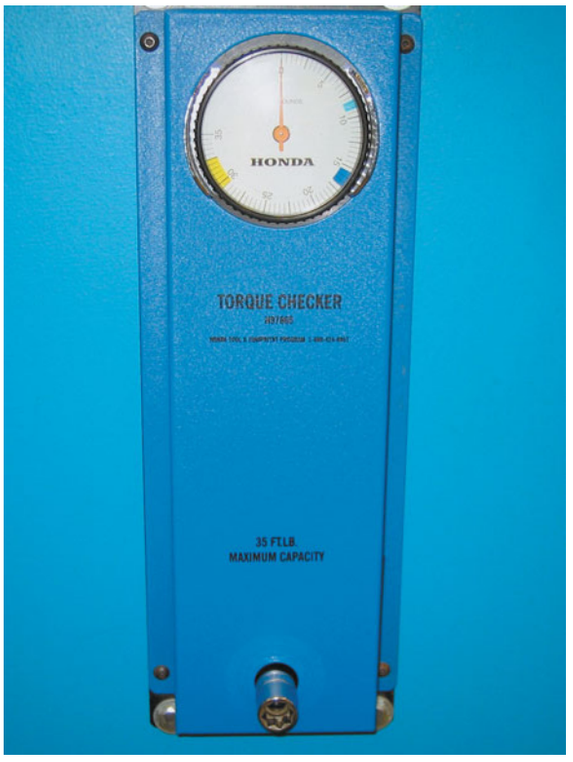


FIGURE 9–15 Torque wrench calibration checker.

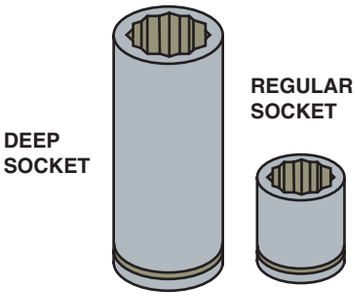


FIGURE 9–16 Deep sockets allow access to the nut that has a stud plus other locations needing great depth, such as spark plugs.

TECH TIP

Check Torque Wrench Calibration Regularly

Torque wrenches should be checked regularly. For example, Honda has a torque wrench calibration setup at each of their training centers. It is expected that a torque wrench be checked for accuracy before every use. Most experts recommend that torque wrenches be checked and adjusted as needed at least every year and more often if possible. ● **SEE FIGURE 9–15**.

should be cleaned after use before being placed back into the toolbox. Sockets are available in short and deep well designs. ● **SEE FIGURE 9–16**.

Also select the appropriate drive size. For example, for small work, such as on the dash, select a 1/4 in. drive. For most general service work, use a 3/8 in. drive and for suspension and steering and other large fasteners, select a 1/2 in. drive. When loosening a fastener, always pull the ratchet toward you rather than push it outward.

FREQUENTLY ASKED QUESTION

Is It Lb-Ft or Ft-Lb of Torque?

The unit for torque is expressed as a force times the distance (leverage) from the object. Therefore, the official unit for torque is lb-ft (pound-feet) or newton-meters (a force times a distance). However, it is commonly expressed in ft-lb and even some torque wrenches are labeled with this unit.

TECH TIP

Double-Check the Specifications

Misreading torque specifications is easy to do but can have serious damaging results. Specifications for fasteners are commonly expressed lb-ft. Many smaller fasteners are tightened to specifications expressed in lb-in.

1 lb-ft = 12 lb-in.

Therefore, if a fastener were to be accidentally tightened to 24 lb-ft instead of 24 lb-in., the actual torque applied to the fastener will be 288 lb-in. instead of the specified 24 lb-in.

This extra torque will likely break the fastener, but it could also warp or distort the part being tightened. Always double-check the torque specifications.

TECH TIP

Use Socket Adapters with Caution

Socket adapters are available and can be used for different drive size sockets on a ratchet. Combinations include:

- 1/4 in. drive—3/8 in. sockets
- 3/8 in. drive—1/4 in. sockets
- 3/8 in. drive—1/2 in. sockets
- 1/2 in. drive—3/8 in. sockets

Using a larger drive ratchet or breaker bar on a smaller size socket can cause the application of too much force to the socket, which could crack or shatter. Using a smaller size drive tool on a larger socket will usually not cause any harm, but would greatly reduce the amount of torque that can be applied to the bolt or nut.

TECH TIP

Avoid Using "Cheater Bars"

Whenever a fastener is difficult to remove, some technicians will insert the handle of a ratchet or a breaker bar into a length of steel pipe. The extra length of the pipe allows the technician to exert more torque than can be applied using the drive handle alone. However, the extra torque can easily overload the socket and ratchet, causing them to break or shatter, which could cause personal injury.

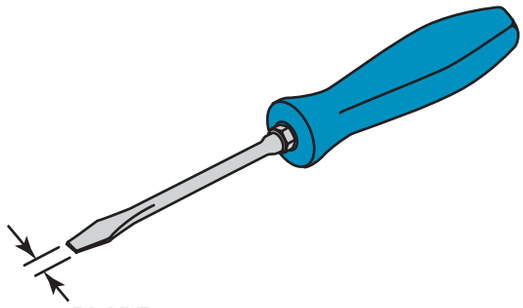


FIGURE 9–17 A flat-tip (straight blade) screwdriver. The width of the blade should match the width of the slot in the fastener being loosened or tightened.

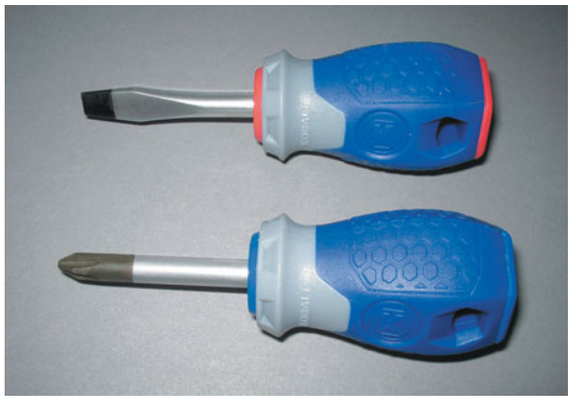


FIGURE 9–18 Two stubby screwdrivers that are used to access screws that have limited space above. A straight blade is on top and a #2 Phillips screwdriver is on the bottom.

SCREWDRIVERS

Many smaller fasteners are removed and installed by using a **screwdriver.** Screwdrivers are available in many sizes and tip shapes. The most commonly used screwdriver is called a **flat tip** or **straight blade.**

Flat-tip screwdrivers are sized by the width of the blade and this width should match the width of the slot in the screw. ● **SEE FIGURE 9–17**.

CAUTION: Do not use a screwdriver as a pry tool or as a chisel. Always use the proper tool for each application.

Another type of commonly used screwdriver is called a Phillips screwdriver, named for Henry F. Phillips, who invented the crosshead screw in 1934. Due to the shape of the crosshead screw and screwdriver, a Phillips screw can be driven with more torque than can be achieved with a slotted screw.

A Phillips head screwdriver is specified by the length of the handle and the size of the point at the tip. A #1 tip has a sharp point, a #2 tip is the most commonly used, and a #3 tip is blunt and is only used for larger sizes of Phillips head fasteners. For example, a #2 × 3 in. Phillips screwdriver would typically measure 6 in. from the tip of the blade to the end of the handle (3 in. long handle and 3 in. long blade) with a #2 tip.

Both straight blade and Phillips screwdrivers are available with a short blade and handle for access to fasteners with limited room. ● **SEE FIGURE 9–18**.

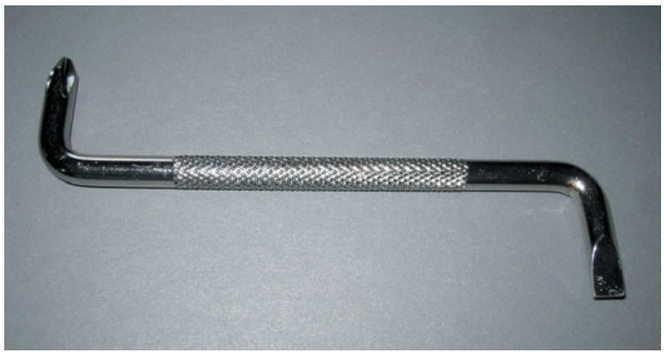


FIGURE 9–19 An offset screwdriver is used to install or remove fasteners that do not have enough space above to use a conventional screwdriver.



FIGURE 9–20 An impact screwdriver used to remove slotted or Phillips head fasteners that cannot be broken loose using a standard screwdriver.

? **FREQUENTLY ASKED QUESTION**

What Are Torx and Robertson Screwdrivers?

A Torx is a six-pointed star-shaped tip that was developed by Camcar (formerly Textron) to offer greater loosening and tightening torque than is possible with a straight (flat tip) or Phillips screwdriver. Torx is commonly used in the automotive field for fastening of many components.

P. L. Robertson invented the Robertson screw and screwdriver in 1908, which uses a square-shaped tip with a slight taper. The Robertson screwdriver uses color-coded handles because different size screws require different tip sizes. Robertson screws are commonly used in Canada and in the recreational vehicle (RV) industry in the United States.

OFFSET SCREWDRIVERS Offset screwdrivers are used in places where a conventional screwdriver cannot fit. An offset screwdriver is bent at the ends and is used similar to a wrench. Most offset screwdrivers have a straight blade at one end and a Phillips end at the opposite end. ● **SEE FIGURE 9–19**.

IMPACT SCREWDRIVER An impact screwdriver is used to break loose or tighten a screw. A hammer is used to strike the end after the screwdriver holder is placed in the head of the screw and rotated in the desired direction. The force from the hammer blow does two things: It applies a force downward holding the tip of the screwdriver in the slot and then applies a twisting force to loosen (or tighten) the screw. ● **SEE FIGURE 9–20**.



FIGURE 9–21 A typical ball-peen hammer.



FIGURE 9–22 A rubber mallet used to deliver a force to an object without harming the surface.

SAFE USE OF SCREWDRIVERS. Always use the proper type and size screwdriver that matches the fastener. Try to avoid pressing down on a screwdriver because if it slips, the screwdriver tip could go into your hand, causing serious personal injury. All screwdrivers should be cleaned after use. Do not use a screwdriver as a pry bar; always use the correct tool for the job.

HAMMERS AND MALLETS

HAMMERS

Hammers and mallets are used to force objects together or apart. The shape of the back part of the hammer head (called the *peen*) usually determines the name. For example, a ball-peen hammer has a rounded end like a ball and it is used to straighten oil pans and valve covers, using the hammer head, and for shaping metal, using the ball peen. ● **SEE FIGURE 9–21**.

NOTE: A claw hammer has a claw used to remove nails and is not used for automotive service.

A hammer is usually sized by the weight of the head of the hammer and the length of the handle. For example, a commonly used ball-peen hammer has an 8 oz head with an 11 in. handle.

MALLETS

Mallets are a type of hammer with a large striking surface, which allows the technician to exert force over a larger area than a hammer, so as not to harm the part or component. Mallets are made from a variety of materials including rubber, plastic, or wood. ● **SEE FIGURE 9–22**.

A shot-filled plastic hammer is called a **dead-blow hammer.** The small lead balls (shot) inside a plastic head prevent the hammer from bouncing off of the object when struck. ● **SEE FIGURE 9–23**.

SAFE USE OF HAMMERS AND MALLETS. All mallets and hammers should be cleaned after use and not exposed to extreme temperatures. Never use a hammer or mallet that is damaged in any way and always use caution to avoid doing damage to the components and the surrounding area. Always follow the hammer manufacturer's recommended procedures and practices.



FIGURE 9–23 A dead-blow hammer that was left outside in freezing weather. The plastic covering was damaged, which destroyed this hammer. The lead shot is encased in the metal housing and then covered.

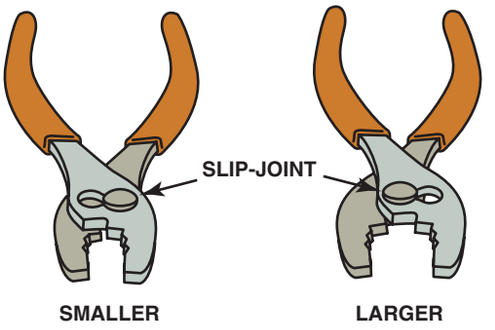


FIGURE 9–24 Typical slip-joint pliers, which are also common household pliers. The slip joint allows the jaws to be opened to two different settings.

PLIERS

SLIP-JOINT PLIERS

Pliers are capable of holding, twisting, bending, and cutting objects and are an extremely useful classification of tools. The common household type of pliers is called the **slip-joint pliers.** There are two different positions where the junction of the handles meets to achieve a wide range of sizes of objects that can be gripped. ● **SEE FIGURE 9–24**.

MULTIGROOVE ADJUSTABLE PLIERS

For gripping larger objects, a set of **multigroove adjustable pliers** is a commonly used tool of choice by many service technicians. Originally designed to remove the various size nuts holding rope seals used in water pumps, the name **water pump pliers** is also used. ● **SEE FIGURE 9–25**.

LINESMAN'S PLIERS

Linesman's pliers are specifically designed for cutting, bending, and twisting wire. While commonly used by construction workers and electricians, linesman's pliers are very useful tools for the service technician who deals with wiring. The center parts of the jaws are designed to grasp round objects such as pipe or tubing without slipping. ● **SEE FIGURE 9–26**.

DIAGONAL PLIERS

Diagonal pliers are designed for cutting only. The cutting jaws are set at an angle to make it easier to cut

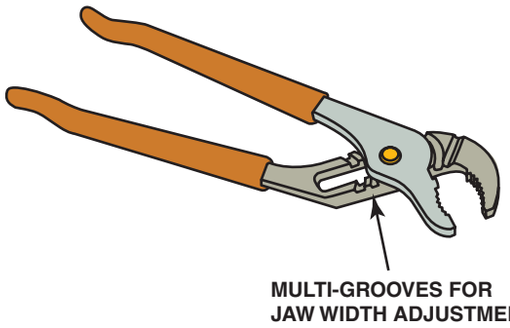


FIGURE 9–25 Multigroove adjustable pliers are known by many names, including the trade name Channel Locks.

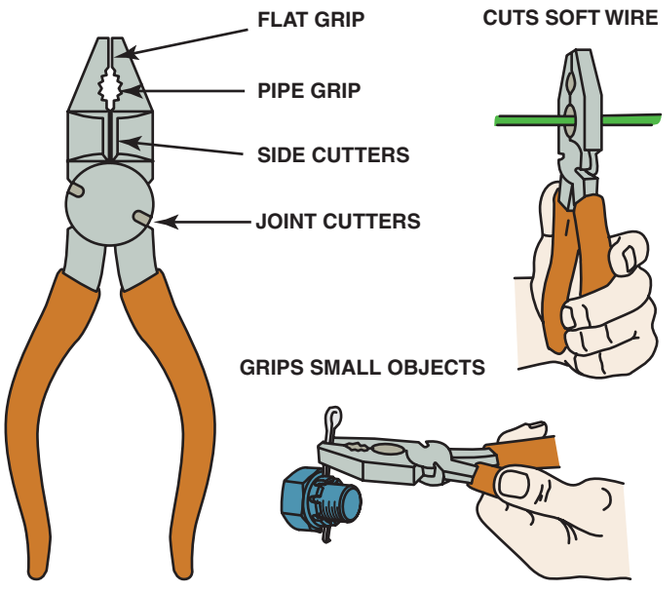


FIGURE 9–26 A linesman's pliers are very useful because they can help perform many automotive service jobs.

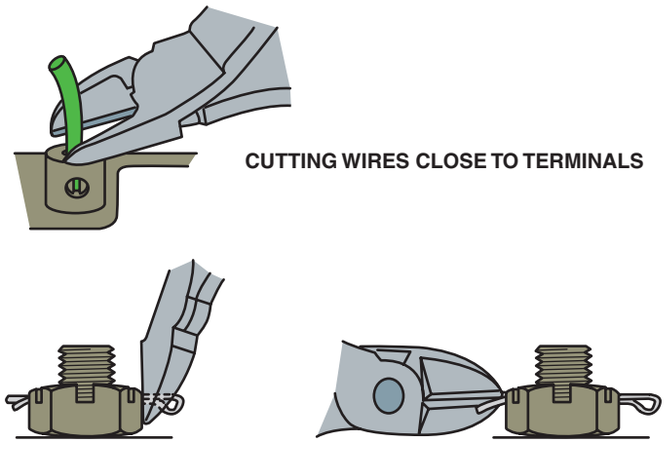


FIGURE 9–27 Diagonal-cut pliers are another common tool that has many names.

wires. Diagonal pliers are also called **side cuts** or **dikes.** These pliers are constructed of hardened steel and they are used mostly for cutting wire. ● **SEE FIGURE 9–27**.

NEEDLE-NOSE PLIERS

Needle-nose pliers are designed to grip small objects or objects in tight locations. Needle-nose pliers have long, pointed jaws, which allow the tips to reach into narrow openings or groups of small objects. ● **SEE FIGURE 9–28**.

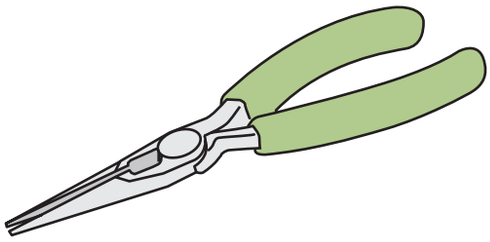


FIGURE 9–28 Needle-nose pliers are used where there is limited access to a wire or pin that needs to be installed or removed.

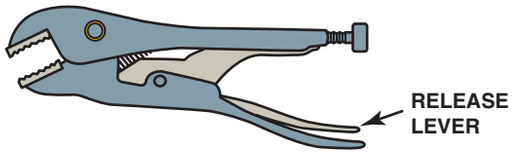


FIGURE 9–29 Locking pliers are best known by their trade name Vise-Grip®.

TECH TIP

Brand Name Versus Proper Term

Technicians often use slang or brand names of tools rather than the proper term. This results in some confusion for new technicians. Some examples are given in the following table.

Brand Name	Proper Term	Slang Name
Crescent wrench	Adjustable wrench	Monkey wrench
Vise Grip	Locking pliers	
Channel Locks	Water pump pliers or multigroove adjustable pliers	Pump pliers
	Diagonal cutting pliers	Dikes or side cuts

TECH TIP

Use Chalk

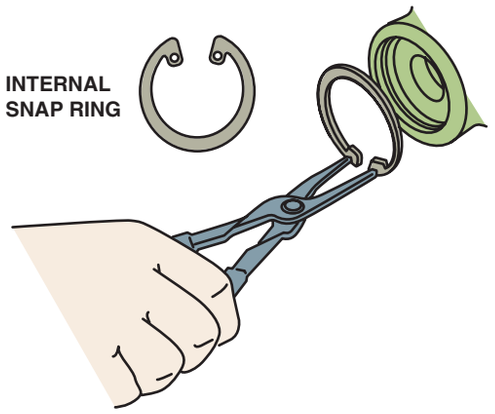
Often soft metal particles can become stuck in a file, especially when using it to file aluminum or other soft metals. Rub some chalk into the file before using it to prevent this from happening.

Most needle-nose pliers have a wire cutter located at the base of the jaws near the pivot. There are several variations of needle-nose pliers, including right angle jaws or slightly angled to allow access to certain cramped areas.

LOCKING PLIERS

Locking pliers are adjustable pliers that can be locked to hold objects from moving. Most locking pliers also have wire cutters built into the jaws near the pivot point. Locking pliers come in a variety of styles and sizes and are commonly referred to by their trade name **Vise-Grip®.** The size is the length of the pliers, not how far the jaws open. ● **SEE FIGURE 9–29**.

SAFE USE OF PLIERS. Pliers should not be used to remove any bolt or other fastener. Pliers should only be used when specified for use by the vehicle manufacturer.



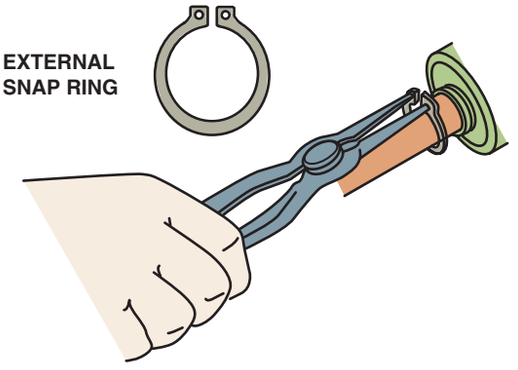


FIGURE 9–30 Snap-ring pliers are also called lock-ring pliers and are designed to remove internal and external snap rings (lock rings).

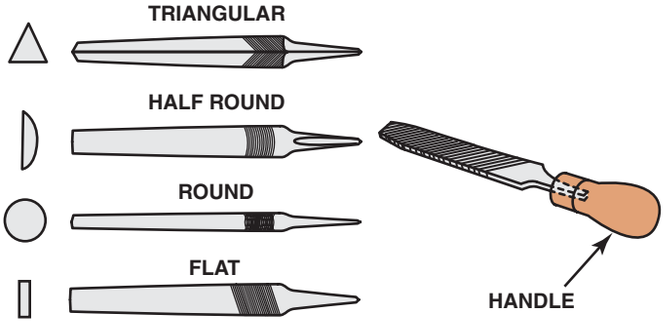


FIGURE 9–31 Files come in many different shapes and sizes. Never use a file without a handle.

SNAP-RING PLIERS **Snap-ring pliers** are used to remove and install snap rings. Many snap-ring pliers are designed to be able to remove and install inward, as well as outward, expanding snap rings. Snap-ring pliers can be equipped with serrated-tipped jaws for grasping the opening in the snap ring, while others are equipped with points, which are inserted into the holes in the snap ring. ● **SEE FIGURE 9–30**.

FILES **Files** are used to smooth metal and are constructed of hardened steel with diagonal rows of teeth. Files are available with a single row of teeth called a **single-cut file,** as well as two rows of teeth cut at an opposite angle called a **double-cut file.** Files are available in a variety of shapes and sizes from small flat files, half-round files, and triangular files. ● **SEE FIGURE 9–31**.

SAFE USE OF FILES. Always use a file with a handle. Because files only cut when moved forward, a handle must be attached to prevent possible personal injury. After making a forward strike, lift the file and return the file to the starting position; avoid dragging the file backward.

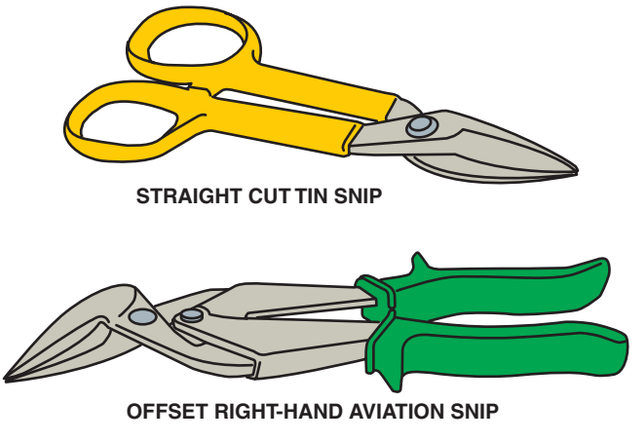


FIGURE 9–32 Tin snips are used to cut thin sheets of metal or carpet.

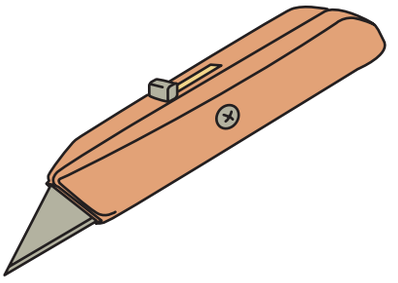


FIGURE 9–33 A utility knife uses replaceable blades and is used to cut carpet and other materials.

CUTTERS

SNIPS Service technicians are often asked to fabricate sheet metal brackets or heat shields and need to use one or more types of cutters available. The simplest is called **tin snips,** which are designed to make straight cuts in a variety of materials, such as sheet steel, aluminum, or even fabric. A variation of the tin snips is called **aviation tin snips.** There are three designs of aviation snips including one designed to cut straight (called a **straight cut aviation snip**), one designed to cut left (called an **offset left aviation snip**), and one designed to cut right (called an **offset right aviation snip**). The handles are color coded for easy identification. These include yellow for straight, red for left, and green for right. ● **SEE FIGURE 9–32**.

UTILITY KNIFE A **utility knife** uses a replaceable blade and is used to cut a variety of materials such as carpet, plastic, wood, and paper products, such as cardboard. ● **SEE FIGURE 9–33**.

SAFE USE OF CUTTERS. Whenever using cutters, always wear eye protection or a face shield to guard against the possibility of metal pieces being ejected during the cut. Always follow recommended procedures.

PUNCHES AND CHISELS

PUNCHES A **punch** is a small diameter steel rod that has a smaller diameter ground at one end. A punch is used to drive a pin out that is used to retain two components. Punches come in a variety of sizes, which are measured across the diameter of the machined end. Sizes include 1/16 in., 1/8 in., 3/16 in., and 1/4 in. ● **SEE FIGURE 9–34**.

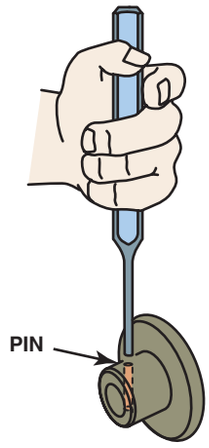


FIGURE 9–34 A punch used to drive pins from assembled components. This type of punch is also called a pin punch.



FIGURE 9–35 Warning stamped in the side of a punch warning that goggles should be worn when using this tool. Always follow safety warnings.

CHISELS A **chisel** has a straight, sharp cutting end that is used for cutting off rivets or to separate two pieces of an assembly. The most common design of chisel used for automotive service work is called a **cold chisel.**

SAFE USE OF PUNCHES AND CHISELS. Always wear eye protection when using a punch or a chisel because the hardened steel is brittle and parts of the punch could fly off and cause serious personal injury. See the warning stamped on the side of this automotive punch in ● **FIGURE 9–35**.

Punches and chisels can also have the top rounded off, which is called "mushroomed." This material must be ground off to help avoid the possibility that the overhanging material is loosened and becomes airborne during use. ● **SEE FIGURE 9–36**.

REMOVERS

Removers are tools used to remove damaged fasteners. A remover tool is not normally needed during routine service unless the fastener is corroded or has been broken or damaged by a previous attempt to remove the bolt or nut.

To help prevent the need for a remover tool, all rusted and corroded fasteners should be sprayed with penetrating oil. Penetrating oil is a low viscosity oil that is designed to flow in between the threads of a fastener or other small separation between two parts. Commonly used penetrating oils include WD-40®, Kroil®, and CRC 5-56.

CAUTION: Do not use penetrating oil as a lubricating oil because it is volatile and will evaporate soon after usage leaving little lubricant behind for protection.

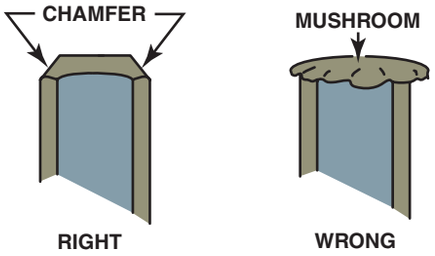


FIGURE 9–36 Use a grinder or a file to remove the mushroom material on the end of a punch or chisel.

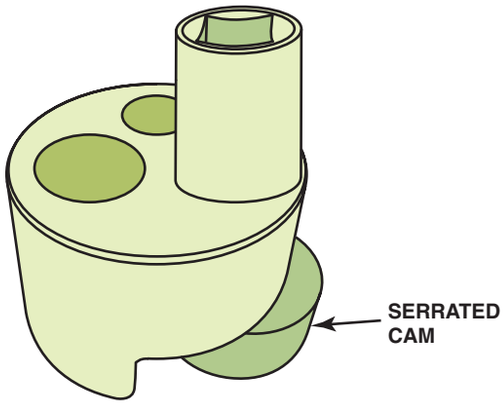


FIGURE 9–37 A stud remover uses an offset serrated wheel to grasp the stud so it will be rotated when a ratchet or breaker bar is used to rotate the assembly.

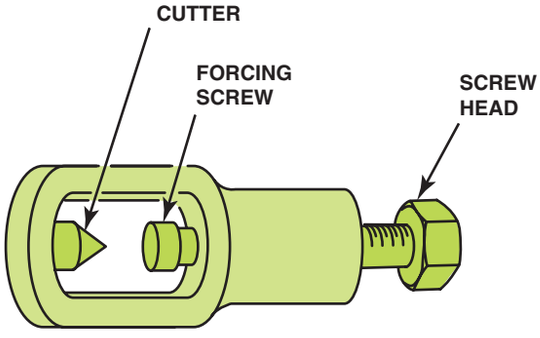


FIGURE 9–38 A nut splitter is used to split a nut that cannot be removed. After the nut has been split, a chisel is then used to remove the nut.

Removers are a classification of tool used to remove stuck or broken fasteners. Over time, rust and corrosion can cause the threads of the fastener to be attached to the nut or the casting making it very difficult to remove. There are several special tools that can be used to remove damaged fasteners. Which one to use depends on the type of damage.

DAMAGED HEADS If the bolt head or a nut becomes damaged or rounded, there are two special tools that can be used, including:

- **Stud remover.** A **stud removal tool** grips the part of the stud above the surface and uses a cam or wedge to grip the stud as it is being rotated by a ratchet or breaker bar. ● **SEE FIGURE 9–37**.
- **Nut splitter.** A **nut splitter** is used to remove the nut by splitting it from the bolt. A nut splitter is used by inserting the cutter against a flat of the nut and tightening the threaded bolt of the splitter. The nut will be split away from the bolt and can then be removed. ● **SEE FIGURE 9–38**.



FIGURE 9–39 A set of bolt extractors, commonly called easy outs.



FIGURE 9–40 Removing plugs or bolts is easier if the plug is first heated to cherry red color, using a torch, and then applying wax. During cooling, the wax flows in between the threads, making it easier to remove.

CAUTION: Do not rotate the entire nut splitter or damage to the cutting wedge will occur.

BROKEN BOLTS, STUDS, OR SCREWS Often, bolts, studs, or screws break even with, or below the surface, making stud removal tools impossible to use. Bolt extractors are commonly called **easy outs.** An easy out is constructed of hardened steel with flutes or edges ground into the side in an opposite direction of most threads. ● **SEE FIGURE 9–39.**

NOTE: Always select the largest extractor that can be used to help avoid the possibility of breaking the extractor while attempting to remove the bolt.

A hole is drilled into the center of a broken bolt. Then, the extractor (easy out) is inserted into the hole and rotated counterclockwise using a wrench. As the extractor rotates, the grooves grip tighter into the wall of the hole drilled in the broken bolt. As a result, most extractors are capable of removing most broken bolts.

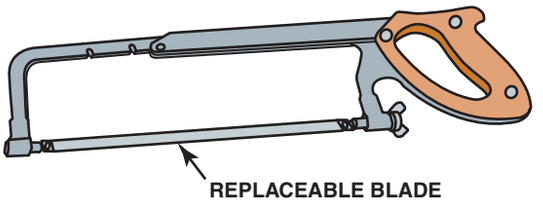


FIGURE 9–41 A typical hacksaw that is used to cut metal. If cutting sheet metal or thin objects, a blade with more teeth should be used.

TECH TIP

The Wax Trick

Many times rusted fasteners can be removed by using heat to expand the metal and break the rust bond between the fastener and the nut or casting. Many technicians heat the fastener using a torch and then apply paraffin wax or a candle to the heated fastener. ● **SEE FIGURE 9–40.** The wax will melt and as the part cools, will draw the liquid wax down between the threads. After allowing the part to cool, attempt to remove the fastener. It will often be removed without any trouble.

FREQUENTLY ASKED QUESTION

I Broke Off an Easy Out—Now What?

An extractor (easy out) is hardened steel and removing this and the broken bolt is now a job for a professional machine shop. The part, which could be as large as an engine block, needs to be removed from the vehicle and taken to a machine shop that is equipped to handle this type of job. One method involves using an electrical discharge machine (EDM). An EDM uses a high amperage electrical current to produce thousands of arcs between the electrode and the broken tool. The part is submerged in a non-conducting liquid and each tiny spark vaporizes a small piece of the broken tool.

HACKSAWS

A **hacksaw** is used to cut metals, such as steel, aluminum, brass, or copper. The cutting blade of a hacksaw is replaceable and the sharpness and number of teeth can be varied to meet the needs of the job. Use 14 or 18 teeth per inch (tpi) for cutting plaster or soft metals, such as aluminum and copper. Use 24 or 32 teeth per inch for steel or pipe. Hacksaw blades should be installed with the teeth pointing away from the handle. This means that a hacksaw cuts while the blade is pushed in the forward direction, and then pressure should be released as the blade is pulled rearward before repeating the cutting operation. ● **SEE FIGURE 9–41.**

SAFE USE OF HACKSAWS. Check that the hacksaw is equipped with the correct blade for the job and that the teeth are pointed away from the handle. When using a hacksaw, move the hacksaw slowly away from you, then lift slightly and return for another cut.

TECH TIP

Hide Those from the Boss

An apprentice technician started working for a dealership and put his top tool box on a workbench. Another technician observed that, along with a complete set of good-quality tools, the box contained several adjustable wrenches. The more experienced technician said, "Hide those from the boss." If any adjustable wrench is used on a bolt or nut, the movable jaw often moves or loosens and starts to round the head of the fastener. If the head of the bolt or nut becomes rounded, it becomes that much more difficult to remove.



FIGURE 9–42 A typical beginning technician tool set that includes the basic tools to get started.

BASIC HAND TOOL LIST

Hand tools are used to turn fasteners (bolts, nuts, and screws). The following is a list of hand tools every automotive technician should possess. Specialty tools are not included.

- Safety glasses
- Tool chest
- 1/4 in. drive socket set (1/4 to 9/16 in. standard and deep sockets; 6 to 15 mm standard and deep sockets)
- 1/4 in. drive ratchet
- 1/4 in. drive 2 in. extension
- 1/4 in. drive 6 in. extension
- 1/4 in. drive handle
- 3/8 in. drive socket set (3/8 to 7/8 in. standard and deep sockets; 10 to 19 mm standard and deep sockets)
- 3/8 in. drive Torx set (T40, T45, T50, and T55)
- 3/8 in. drive 13/16 in. plug socket
- 3/8 in. drive 5/8 in. plug socket
- 3/8 in. drive ratchet
- 3/8 in. drive 1 1/2 in. extension
- 3/8 in. drive 3 in. extension
- 3/8 in. drive 6 in. extension
- 3/8 in. drive 18 in. extension
- 3/8 in. drive universal
- 1/2 in. drive socket set (1/2 to 1 in. standard and deep sockets; 9 to 19 mm standard and deep metric sockets)
- 1/2 in. drive ratchet
- 1/2 in. drive breaker bar
- 1/2 in. drive 5 in. extension
- 1/2 in. drive 10 in. extension
- 3/8 to 1/4 in. adapter
- 1/2 to 3/8 in. adapter
- 3/8 to 1/2 in. adapter
- Crowfoot set (fractional inch)
- Crowfoot set (metric)
- 3/8 through 1 in. combination wrench set
- 10 through 19 mm combination wrench set
- 1/16 through 1/4 in. hex (Allen) wrench set
- 2 through 12 mm hex (Allen) wrench set
- 3/8 in. hex socket
- 13 to 14 mm flare nut wrench
- 15 to 17 mm flare nut wrench
- 5/16 to 3/8 in. flare nut wrench
- 7/16 to 1/2 in. flare nut wrench
- 1/2 to 9/16 in. flare nut wrench
- Diagonal pliers
- Needle pliers
- Adjustable-jaw pliers
- Locking pliers
- Snap-ring pliers
- Stripping or crimping pliers
- Ball-peen hammer
- Rubber hammer
- Dead-blow hammer
- Five-piece standard screwdriver set
- Four-piece Phillips screwdriver set
- #15 Torx screwdriver
- #20 Torx screwdriver
- File
- Center punch
- Pin punches (assorted sizes)
- Chisel
- Utility knife
- Valve core tool
- Filter wrench (large filters)
- Filter wrench (smaller filters)
- Test light
- Feeler gauge
- Scraper
- Magnet

TOOL SETS AND ACCESSORIES

A beginning service technician may wish to start with a small set of tools before spending a lot of money on an expensive, extensive tool box. ● **SEE FIGURES 9–42 AND 9–43.**



FIGURE 9–43 A typical large tool box, showing just one of many drawers.



FIGURE 9–44 A seal puller being used to remove a seal from a rear axle.

TECH TIP

Need to Borrow a Tool More than Twice? Buy It!

Most service technicians agree that it is okay for a beginning technician to borrow a tool occasionally. However, if a tool has to be borrowed more than twice, then be sure to purchase it as soon as possible. Also, whenever a tool is borrowed, be sure that you clean the tool and let the technician you borrowed the tool from know that you are returning the tool. These actions will help in any future dealings with other technicians.

TECH TIP

The Valve Grinding Compound Trick

Apply a small amount of valve grinding compound to a Phillips or Torx screw or bolt head. The gritty valve grinding compound "grips" the screwdriver or tool bit and prevents the tool from slipping up and out of the screw head. Valve grinding compound is available in a tube from most automotive parts stores.

SEAL PULLERS AND DRIVERS

SEAL PULLERS

Grease seals are located on many automotive components, including brake rotors, transmission housings, and differentials. A **seal puller** is used to properly remove grease seals, as shown in ● **FIGURE 9–44**.

SEAL DRIVERS

A **seal driver** can be either plastic or metal, usually aluminum, and is used to seat the outer lip of a grease seal into the grease seal pocket. A seal is usually driven into position using a plastic mallet and a seal driver that is the same size as the outside diameter of the grease seal retainer. ● **SEE FIGURE 9–45**.

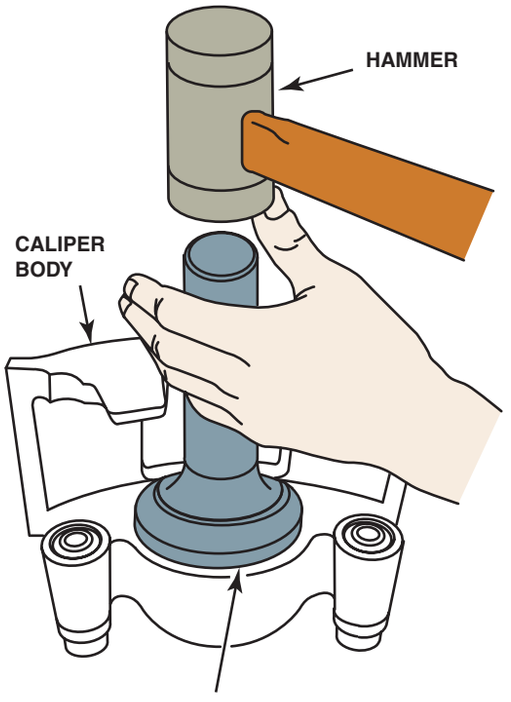


FIGURE 9–45 A seal driver or installer is usually plastic and is designed to seat the seal.

ELECTRICAL HAND TOOLS

TEST LIGHTS

A test light is used to test for electricity. A typical automotive test light consists of a clear plastic screwdriver-like handle that contains a light bulb. A wire is attached to one terminal of the bulb, which the technician connects to a clean metal part of the vehicle. The other end of the bulb is attached to a point that can be used to test for electricity at a connector or wire. When there is power at the point and a good connection at the other end, the light bulb lights. ● **SEE FIGURE 9–46**.

SOLDERING GUNS

- **Electric soldering gun.** This type of soldering gun is usually powered by 110 volt AC and often has two power settings expressed in watts. A typical electric soldering gun will



FIGURE 9–46 A typical 12 volt test light.

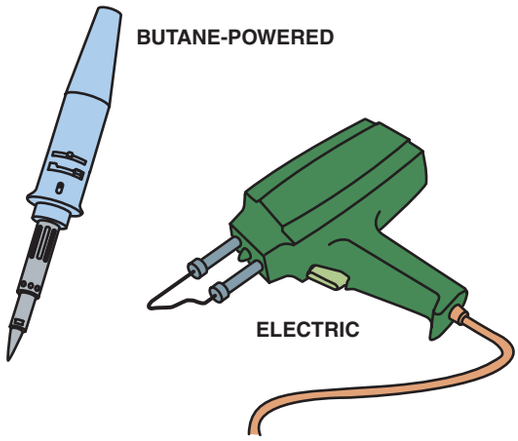


FIGURE 9–47 An electric soldering gun used to make electrical repairs. Soldering guns are sold by the wattage rating. The higher the wattage, the greater amount of heat created. Most solder guns used for automotive electrical work usually fall within the 60 to 160 watt range.

produce from 85 to 300 watts of heat at the tip, which is more than adequate for soldering. ● **SEE FIGURE 9–47**.

- **Electric soldering pencil.** This type of soldering iron is less expensive and creates less heat than an electric soldering gun. A typical electric soldering pencil (iron) creates 30 to 60 watts of heat and is suitable for soldering smaller wires and connections.
- **Butane-powered soldering iron.** A butane-powered soldering iron is portable and very useful for automotive service work because an electrical cord is not needed. Most butane-powered soldering irons produce about 60 watts of heat, which is enough for most automotive soldering.

In addition to a soldering iron, most service technicians who do electrical-related work should have the following:

- Wire cutters
- Wire strippers
- Wire crimpers
- Heat gun

A digital meter is a necessary tool for any electrical diagnosis and troubleshooting. A digital multimeter, abbreviated DMM, is usually capable of measuring the following units of electricity.

- DC volts
- AC volts
- Ohms
- Amperes

SAFETY TIPS FOR USING HAND TOOLS

The following safety tips should be kept in mind whenever you are working with hand tools.

- Always *pull* a wrench toward you for best control and safety. Never push a wrench.
- Keep wrenches and all hand tools clean to help prevent rust and to allow for a better, firmer grip.
- Always use a 6-point socket or a box-end wrench to break loose a tight bolt or nut.
- Use a box-end wrench for torque and an open-end wrench for speed.
- Never use a pipe extension or other type of "**cheater bar**" on a wrench or ratchet handle. If more force is required, use a larger tool or use penetrating oil and/or heat on the frozen fastener. (If heat is used on a bolt or nut to remove it, always replace it with a new part.)
- Always use the proper tool for the job. If a specialized tool is required, use the proper tool and do not try to use another tool improperly.
- Never expose any tool to excessive heat. High temperatures can reduce the strength ("draw the temper") of metal tools.
- Never use a hammer on any wrench or socket handle unless you are using a special "staking face" wrench designed to be used with a hammer.
- Replace any tools that are damaged or worn.

TECH TIP

It Just Takes a Second

Whenever removing any automotive component, it is wise to screw the bolts back into the holes a couple of threads by hand. This ensures that the right bolt will be used in its original location when the component or part is put back on the vehicle. Often, the same diameter of fastener is used on a component, but the length of the bolt may vary. Spending just a couple of seconds to put the bolts and nuts back where they belong when the part is removed can save a lot of time when the part is being reinstalled. Besides making certain that the right fastener is being installed in the right place, this method helps prevent bolts and nuts from getting lost or kicked away. How much time have you wasted looking for that lost bolt or nut?

HAND TOOL MAINTENANCE

Most hand tools are constructed of rust-resistant metals but they can still rust or corrode if not properly maintained. For best results and long tool life, the following steps should be taken.

- Clean each tool before placing it back into the tool box.
- Keep tools separated. Moisture on metal tools will start to rust more readily if the tools are in contact with another metal tool.

TECH TIP

Use a Binder Clip

A binder clip (size 1 1/4 in. wide) is used by wise technicians to help keep fender covers in place. ● **SEE FIGURE 9–48**. Binder clips are found at office supply stores.



FIGURE 9–48 A binder clip being used to keep a fender cover from falling.

- Line the drawers of the tool box with a material that will prevent the tools from moving as the drawers are opened and closed. This helps to quickly locate the proper tool and size.
- Release the tension on all "clicker-type" torque wrenches after use.
- Keep the tool box secure.

REVIEW QUESTIONS

1. Why are wrenches offset 15 degrees?
2. What are the other names for a line wrench?
3. What are the standard automotive drive sizes for sockets?
4. Which type of screwdriver requires the use of a hammer or mallet?
5. What is inside a dead-blow hammer?
6. What type of cutter is available in left and right cutters?

CHAPTER QUIZ

1. When working with hand tools, always _____.
   a. Push the wrench—don't pull toward you
   b. Pull a wrench—don't push a wrench
2. The proper term for Channel Locks is _____.
   a. Vise Grips
   b. Crescent wrench
   c. Locking pliers
   d. Multigroove adjustable pliers
3. The proper term for Vise Grips is _____.
   a. Locking pliers **c.** Side cuts
   b. Slip-joint pliers **d.** Multigroove adjustable pliers
4. Which tool listed is a brand name?
   a. Locking pliers **c.** Side cutters
   b. Monkey wrench **d.** Vise Grips
5. Two technicians are discussing torque wrenches. Technician A says that a torque wrench is capable of tightening a fastener with more torque than a conventional breaker bar or ratchet. Technician B says that a torque wrench should be calibrated regularly for the most accurate results. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. What type of screwdriver should be used if there is very limited space above the head of the fastener?
   a. Offset screwdriver
   b. Stubby screwdriver
   c. Impact screwdriver
   d. Robertson screwdriver
7. Where is the "peen" of the hammer?
   a. The striking face
   b. The handle
   c. The back part opposite the striking face
   d. The part that connects to the handle
8. What type of hammer is plastic coated, has a metal casing inside, and is filled with small lead balls?
   a. Dead-blow hammer
   b. Soft-blow hammer
   c. Sledge hammer
   d. Plastic hammer
9. Which type of pliers is capable of fitting over a large object?
   a. Slip-joint pliers **c.** Locking pliers
   b. Linesman's pliers **d.** Multigroove adjustable pliers
10. Which tool has a replaceable cutting edge?
    a. Side-cut pliers **c.** Utility knife
    b. Tin snips **d.** Aviation snips

chapter 10

POWER TOOLS AND SHOP EQUIPMENT

OBJECTIVES: After studying Chapter 10, the reader should be able to: • Identify commonly used power tools. • Identify commonly used shop equipment. • Discuss the proper use of power tools and shop equipment. • Describe the safety procedures that should be followed when working with power tools and shop equipment.

KEY TERMS: Air-blow gun 84 • Air compressor 82 • Air drill 84 • Air ratchet 83 • Bearing splitter 85 • Bench grinder 85 • Bench vise 85 • Die grinder 84 • Engine stand 86 • Hydraulic press 85 • Impact wrench 82 • Incandescent light 84 • Light-emitting diode (LED) 84 • Portable crane 85 • Stone wheel 84 • Trouble light 84 • Wire brush wheel 84 • Work light 84

AIR COMPRESSOR

A shop air compressor is usually located in a separate room or an area away from the customer area of a shop. An **air compressor** is powered by a 220 V AC electric motor and includes a storage tank and the compressor itself, as well as the pressure switches, which are used to maintain a certain minimum level of air pressure in the system. The larger the storage tank, expressed in gallons, the longer an air tool can be operated in the shop without having the compressor start operating. ● **SEE FIGURE 10–1.**

SAFE USE OF COMPRESSED AIR Air under pressure can create dangerous situations. For example, an object, such as a small piece of dirt, could be forced out of an air hose blow gun with enough force to cause serious personal injury. All OSHA-approved air nozzles have air vents drilled around the outside of the main discharge hole to help reduce the force of the air blast. Also, the air pressure used by an air nozzle (blow gun) must be kept to 30 PSI (207 kPa) or less. ● **SEE FIGURE 10–2.**



FIGURE 10–1 A typical shop compressor. It is usually placed out of the way, yet accessible to provide for maintenance to the unit.

AIR AND ELECTRICALLY OPERATED TOOLS

IMPACT WRENCH An **impact wrench**, either air (pneumatic) or electrically powered, is a tool that is used to remove and install fasteners. The air-operated 1/2 in. drive impact wrench is the most commonly used unit. ● **SEE FIGURE 10–3.**

The direction of rotation is controlled by a switch. ● **SEE FIGURE 10–4.**

Electrically powered impact wrenches commonly include:

- Battery-powered units. ● **SEE FIGURE 10–5.**
- 110-volt AC-powered units. This type of impact wrench is very useful, especially if compressed air is not readily available.

CAUTION: Always use impact sockets with impact wrenches, and be sure to wear eye protection in case the socket or fastener shatters. Impact sockets are thicker walled and constructed with premium alloy steel. They are hardened with a black oxide finish to help prevent corrosion and distinguish them from regular sockets. ● SEE FIGURE 10–6.

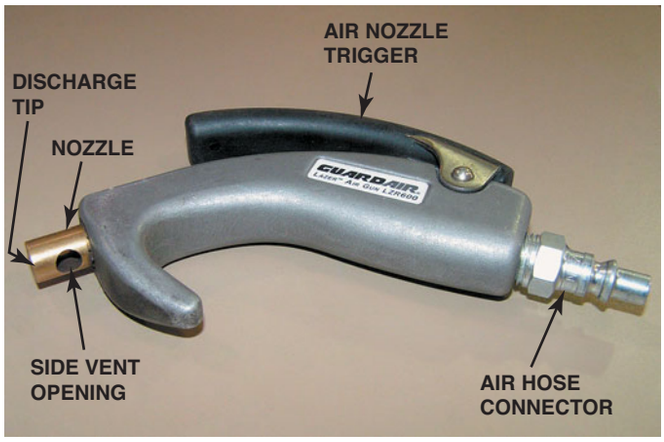


FIGURE 10–2 Always use an air nozzle that is OSHA approved. The openings in the side are used to allow air to escape if the nozzle tip were to become clogged.



FIGURE 10–3 A typical 1/2 in. drive impact wrench.



FIGURE 10–4 This impact wrench features a variable torque setting using a rotary knob. The direction of rotation can be changed by pressing the button at the bottom.



FIGURE 10–5 A typical battery-powered 3/8 in. drive impact wrench.



FIGURE 10–6 A black impact socket. Always use impact-type sockets whenever using an impact wrench to avoid the possibility of shattering the socket, which can cause personal injury.



FIGURE 10–7 An air ratchet is a very useful tool that allows fast removal and installation of fasteners, especially in areas that are difficult to reach or do not have room enough to move a hand ratchet wrench.

REAL WORLD FIX

The Case of the Rusty Air Impact Wrenches

In one busy shop, it was noticed by several technicians that water was being pumped through the air compressor lines and out of the vents of air impact wrenches whenever they were used. It is normal for moisture in the air to condense in the air storage tank of an air compressor. One of the routine service procedures is to drain the water from the air compressor. The water had been drained regularly from the air compressor at the rear of the shop, but the problem continued. Then someone remembered that there was a second air compressor mounted over the parts department. No one could remember ever draining the tank from that compressor. After that tank was drained, the problem of water in the lines was solved. The service manager assigned a person to drain the water from both compressors every day and to check the oil level. The oil in the compressor is changed every six months to help ensure long life of the expensive compressors.

AIR RATCHET

An **air ratchet** is used to remove and install fasteners that would normally be removed or installed using a ratchet and a socket. An air ratchet is much faster, yet has an air hose attached, which reduces accessibility to certain places. ● **SEE FIGURE 10–7**.



FIGURE 10–8 This typical die grinder surface preparation kit includes the air-operated die grinder, as well as a variety of sanding discs for smoothing surfaces or removing rust.



FIGURE 10–9 A fluorescent trouble light operates cooler and is safer to use in the shop because it is protected against accidental breakage where gasoline or other flammable liquids would happen to come in contact with the light.

DIE GRINDER A **die grinder** is a commonly used air-powered tool, which can also be used to sand or remove gaskets and rust. ● **SEE FIGURE 10–8.**

AIR DRILL An **air drill** is a drill that rotates faster than electric drills (up to 20,000 RPM). Air drills are commonly used in auto body work when many holes need to be drilled for plug welding.

AIR-BLOW GUN An **air-blow gun** is used to clean equipment and other purposes where a stream of air would be needed. Automotive air-blow guns should meet OSHA requirements and include passages to allow air to escape outward at the nozzle, thereby relieving pressure if the nozzle were to become blocked.

AIR-OPERATED GREASE GUN An air-operated grease gun uses shop air to operate a plunger, which then applies a force to the grease cartridge. Most air-operated grease guns use a 1/4 in. air inlet and operate on 90 PSI of air pressure.

BATTERY-POWERED GREASE GUN Battery-powered grease guns are more expensive than air-operated grease guns but offer the convenience of not having an air hose attached, making use easier. Many use rechargeable 14 to 18 volt batteries and use standard grease cartridges.

TROUBLE LIGHTS

INCANDESCENT **Incandescent lights** use a filament that produces light when electric current flows through the bulb. This was the standard **trouble light**, also called a **work light**, for many years until safety issues caused most shops to switch to safer fluorescent or LED lights. If incandescent light bulbs are used, try to locate bulbs that are rated "rough service," which is designed to withstand shock and vibration more than conventional light bulbs.

WARNING

Do not use incandescent trouble lights around gasoline or other flammable liquids. The liquids can cause the bulb to break and the hot filament can ignite the flammable liquid.

FLUORESCENT A trouble light is an essential piece of shop equipment, and for safety, should be fluorescent rather than incandescent. Incandescent light bulbs can scatter or break if gasoline were to be splashed onto the bulb creating a serious fire hazard. Fluorescent light tubes are not as likely to be broken and are usually protected by a clear plastic enclosure. Trouble lights are usually attached to a retractor, which can hold 20 to 50 ft of electrical cord. ● **SEE FIGURE 10–9.**

LED TROUBLE LIGHT **Light-emitting diode (LED)** trouble lights are excellent to use because they are shock resistant, long lasting, and do not represent a fire hazard. Some trouble lights are battery powered and therefore can be used in places where an attached electrical cord could present problems.

BENCH/PEDESTAL GRINDER

A grinder can be mounted on a workbench or on a stand-alone pedestal.

BENCH- OR PEDESTAL-MOUNTED GRINDER These high-powered grinders can be equipped with a wire brush wheel and/or a stone wheel.

- A **wire brush wheel** is used to clean steel or sheet metal parts.
- A **stone wheel** is used to grind metal or to remove the mushroom from the top of punches or chisels. ● **SEE FIGURE 10–10.**

CAUTION: Always wear a face shield when using a wire wheel or a grinder. Also keep the part support ledge (table), also called a throat plate, within 1/16 inch (2 mm) of the stone.



FIGURE 10–10 A typical pedestal grinder with a wire wheel on the left side and a stone wheel on the right side. Even though this machine is equipped with guards, safety glasses or a face shield should always be worn when using a grinder or wire wheel.

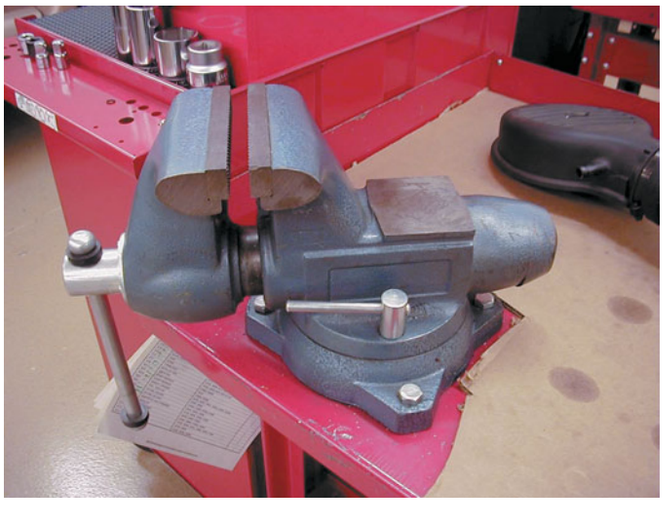


FIGURE 10–11 A typical vise mounted to a workbench.

Most **bench grinders** are equipped with a grinding wheel (stone) on one side and a wire brush wheel on the other side. A bench grinder is a very useful piece of shop equipment and the wire wheel end can be used for the following:

- Cleaning threads of bolts
- Cleaning gaskets from sheet metal parts, such as steel valve covers

CAUTION: Only use a steel wire brush on steel or iron components. If a steel wire brush is used on aluminum or copper-based metal parts, it can remove metal from the part.

The grinding stone end of the bench grinder can be used for the following:

- Sharpening blades and drill bits
- Grinding off the heads of rivets or parts
- Sharpening sheet metal parts for custom fitting

BENCH VISE

A **bench vise** is used to hold components so that work can be performed on the unit. The size of a vise is determined by the width of the jaws. Two common sizes of vises are 4 in. and 6 in. models. The jaws of most vises are serrated and can cause damage to some components unless protected. Many types of protection can be used, including aluminum or copper jaw covers or by simply placing wood between the vise jaws and the component being held. ● **SEE FIGURE 10–11.**

SAFE USE OF VISES. The jaws of vises can cause damage to the part or component being held. Use pieces of wood or other soft material between the steel jaws and the workpiece to help avoid causing damage. Many vises are sold with optional aluminum jaw covers. When finished using a vise, be sure to close the jaws and place the handle straight up and down to help avoid personal injury to anyone walking near the vise.



FIGURE 10–12 A hydraulic press is usually used to press bearings on and off on rear axles and transmissions.

HYDRAULIC PRESSES

Hydraulic presses are hand-operated hydraulic cylinders mounted to a stand and designed to press bearings on or off of shafts, as well as other components. To press off a bearing, a unit called a **bearing splitter** is often required to apply force to the inner race of a bearing. Hydraulic presses use a pressure gauge to show the pressure being applied. Always follow the operating instructions supplied by the manufacturer of the hydraulic press. ● **SEE FIGURE 10–12.**

PORTABLE CRANE AND CHAIN HOIST

A **portable crane** is used to remove and install engines and other heavy vehicle components. Most portable cranes use a hand-operated hydraulic cylinder to raise and lower a boom that is equipped with a nylon strap or steel chain. At the end of the strap or chain is a steel hook that is used to attach around a bracket or auxiliary lifting device. ● **SEE FIGURE 10–13.**

SAFE USE OF PORTABLE CRANES. Always be sure to attach the hook(s) of the portable crane to a secure location on the unit being



FIGURE 10–13 A typical portable crane used to lift and move heavy assemblies, such as engines and transmissions.

TECH TIP

Cover Work While Pressing

Whenever pressing on a bearing or other component, use an old brake drum over the shaft and the bearing. In the event the bearing shatters during the pressing operation, the brake drum will prevent the parts of the bearing from flying outward where they could cause serious personal injury.

lifted. The hook should also be attached to the center of the weight of the object so it can be lifted straight up without tilting.

CAUTION: Always keep feet and other body parts out from underneath the engine or unit being lifted. Always work around a portable crane as if the chain or strap could break at any time.

ENGINE STANDS

An **engine stand** is designed to safely hold an engine and to allow it to be rotated. This allows the technician to easily remove, install, and perform service work to the engine. ● **SEE FIGURE 10–14.**

Most engine stands are constructed of steel and supported by four casters to allow easy movement. There are two basic places where an engine stand attaches to the engine depending on the size of the engine. For most engines and stands, the retaining bolts attach to the same location as the bell housing at the rear of the engine.

On larger engines, such as the 5.9 Cummins inline 6-cylinder diesel engine, the engine mounts to the stand using the engine mounting holes in the block. ● **SEE FIGURE 10–15.**

SAFE OPERATION OF AN ENGINE STAND. When mounting an engine to an engine stand, be sure that the engine is being supported by a portable crane. Be sure the attaching bolts are grade 5 or 8 and the same thread size as the threaded holes in the block. Check that there is at least 1/2 inch (13 mm) of bolt thread engaged in the threaded holes in the engine block. Be sure that all attaching bolts are securely tightened before releasing the weight of the engine from the crane. Use caution when loosening the rotation retaining bolts because the engine could rotate rapidly, causing personal injury.



FIGURE 10–14 Two engines on engine stands. The plastic bags over the engines help keep dirt from getting onto these engines and engine parts.

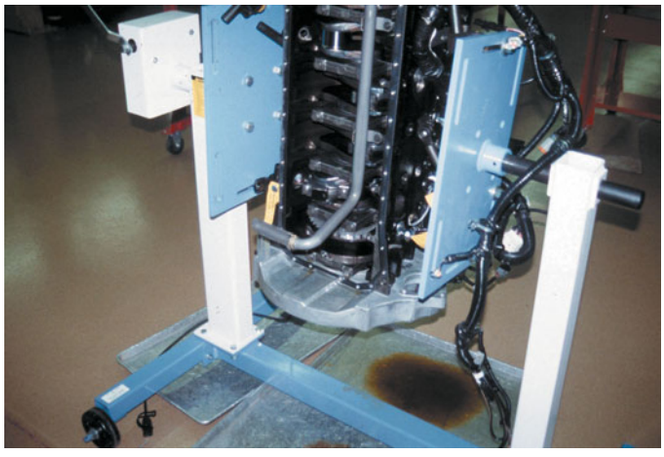


FIGURE 10–15 An engine stand that grasps the engine from the sides rather than the end.

CARE AND MAINTENANCE OF SHOP EQUIPMENT

All shop equipment should be maintained in safe working order. Maintenance of shop equipment usually includes the following operations or procedures.

- **Keep equipment clean.** Dirt and grime can attract and hold moisture, which can lead to rust and corrosion. Oil or grease can attract dirt.
- **Keep equipment lubricated.** While many bearings are sealed and do not require lubrication, always check the instructions for the use of the equipment for suggested lubrication and other service procedures.

CAUTION: Always follow the instructions from the equipment manufacturer regarding proper use and care of the equipment.



1 Inspect the cart and make sure the tanks are chained properly before moving it to the work location.



2 Start by attaching the appropriate work tip to the torch handle. The fitting should only be tightened hand tight. Make sure the valves on the torch handle are closed at this time.



3 Each tank has a regulator assembly with two gauges. The high pressure gauge shows tank pressure, and the low pressure gauge indicates working pressure.



4 Open the oxygen tank valve fully, and open the acetylene tank valve 1/2 turn.



5 Open the oxygen valve on the torch handle 1/4 turn in preparation for adjusting oxygen gas pressure.

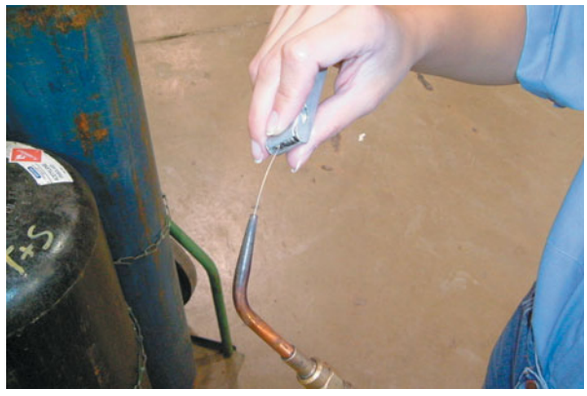


6 Turn the oxygen regulator valve clockwise and adjust oxygen gas pressure to 20 PSI. Close the oxygen valve on the torch handle.

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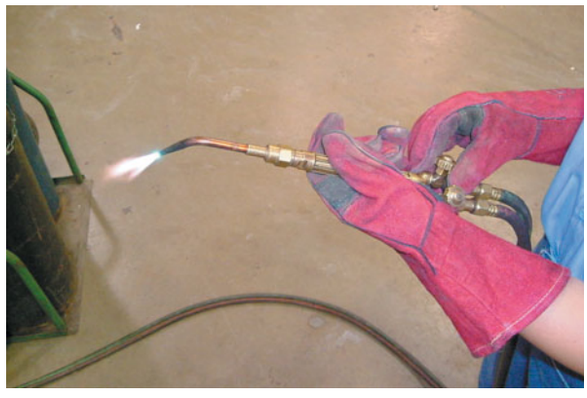
7 Open the acetylene valve on the torch handle 1/4 turn and adjust acetylene gas pressure to 7 PSI. Close the acetylene valve on the torch handle.



8 Open the oxygen valve on the torch handle 1/4 turn and use an appropriate size tip cleaner to clean the tip orifice. Finish by closing the oxygen valve.



9 Put on leather gloves and open the acetylene valve on the torch handle 1/4 turn. Use a flint striker to ignite the acetylene gas exiting the torch tip.



10 Adjust the acetylene valve until the base of the flame just touches the torch tip. Slowly open the oxygen valve on the torch handle and adjust for a neutral flame (blue cone is well-defined).



11 Once work is complete, extinguish the flame by quickly closing the acetylene valve on the torch handle. Be prepared to hear a loud “pop” when the flame goes out. Close the oxygen valve on the torch handle.



12 Close the valves on both tanks and turn the regulator handles CCW until they no longer contact the internal springs. Open the gas valves briefly on the torch handle to release gas pressure from the hoses. Close the gas valves on the torch handle and put away the torch assembly.



1 Heating attachments include ordinary heating tips, middle and right and a “rosebud” (left). Ordinary heating tips work fine for most purposes, but occasionally the rosebud is utilized when a great deal of heat is needed.



2 Note that while acetylene tank pressures are relatively low, the oxygen tank can be filled to over 2,000 PSI. This can represent a serious hazard if precautions are not taken. Be absolutely certain that the tanks are chained properly to the cart before attempting to move it!



3 Any time heating or cutting operations are being performed, be sure that any flammables have been removed from the immediate area. A fire blanket may be placed over floor drains or other objects to prevent fires. A fire extinguisher should be on hand in case of an emergency.



4 Be sure to wear appropriate personal protective equipment during heating and cutting operations.

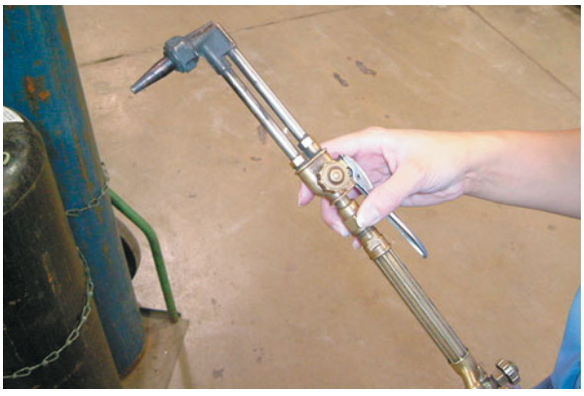


5 Note that heating operations should be performed over steel or firebrick. Never heat or cut steel close to concrete, as it could cause the concrete to explode.



6 When heating steel, move the torch in a circular pattern to prevent melting of the metal. Don’t hold the torch too close to the work as this will cause a “snapping” or “backfire” that can extinguish the flame.

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7 Affix the cutting attachment to the torch handle. Note that the cutting attachment has a cutting handle and a separate oxygen valve.



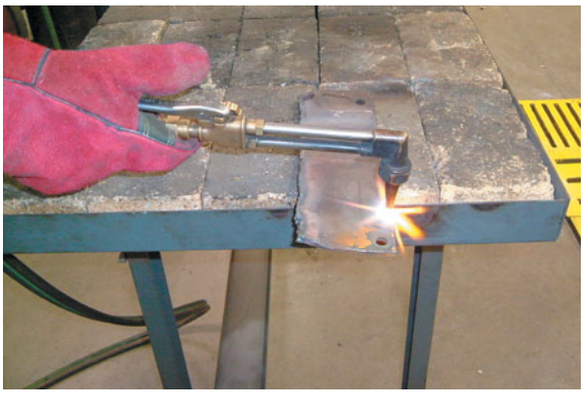
8 Fully open the oxygen valve on the torch handle. Oxygen flow will now be controlled with the valve on the cutting attachment.



9 Oxygen gas pressure should be adjusted to 30 PSI whenever using the cutting attachment. Acetylene pressure is kept at 7 PSI.



10 Open the acetylene valve on the torch handle 1/4 turn and light the torch. Adjust the flame until its base just touches the cutting tip. Slowly open the oxygen valve on the cutting attachment and adjust the flame until the blue cone is well-defined.



11 Direct the flame onto a thin spot or sharp edge of the metal to be cut. This will build the heat quicker in order to get the cut started.



12 When the metal glows red, depress the cutting handle and move the torch to advance the cut. You will need to move the torch faster when cutting thinner pieces of steel. On thicker pieces, point the cutting tip into the direction of the cut.

REVIEW QUESTIONS

1. List the tools used by service technicians that use compressed air.
2. Which trouble light design(s) is (are) the recommended type for maximum safety?
3. What safety precautions should be adhered to when working with a vise?
4. When using a blow gun, what precautions need to be taken?

CHAPTER QUIZ

1. When using compressed air and a blow gun, what is the maximum allowable air pressure?
   a. 10 PSI **c.** 30 PSI
   b. 20 PSI **d.** 40 PSI
2. Which air impact drive size is the most commonly used?
   a. 1/4 in. **c.** 1/2 in.
   b. 3/8 in. **d.** 3/4 in.
3. What type of socket should be used with an air impact wrench?
   a. Black **c.** 12 point
   b. Chrome **d.** Either a or b
4. What can be used to cover the jaws of a vise to help protect the object being held?
   a. Aluminum **c.** Copper
   b. Wood **d.** All of the above
5. Technician A says that impact sockets have thicker walls than conventional sockets. Technician B says that impact sockets have a black oxide finish. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. Two technicians are discussing the use of a typical bench/pedestal-mounted grinder. Technician A says that a wire brush wheel can be used to clean threads. Technician B says that the grinding stone can be used to clean threads. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
7. A hydraulic press is being used to separate a bearing from a shaft. What should be used to cover the bearing during the pressing operation?
   a. Shop cloth **c.** Fender cover
   b. Brake drum **d.** Paper towel
8. Which type of trouble light is recommended for use in the shop?
   a. Incandescent **c.** LED
   b. Fluorescent **d.** Either b or c
9. When mounting an engine to an engine stand, what grade of bolt should be used?
   a. 5 or 8 **c.** 3 or 5
   b. 4 or 7 **d.** 1 or 4
10. Proper care of shop equipment includes _____.
    a. Tuning up every six months
    b. Keeping equipment clean
    c. Keeping equipment lubricated
    d. Both b and c

chapter 11

VEHICLE LIFTING AND HOISTING

OBJECTIVES: After studying Chapter 11, the reader should be able to: • Identify vehicle hoisting and lifting equipment. • Discuss safety procedures related to hoisting or lifting a vehicle. • Describe the proper methods to follow to safely hoist a vehicle.

KEY TERMS: Creeper 92 • Floor jack 91 • Jack stands 91 • Safety stands 91

FLOOR JACK

A **floor jack** is a hand-operated hydraulic device that is used to lift vehicles or components, such as engines, transmissions, and rear axle assemblies. Most floor jacks use four casters, which allow the jack to be easily moved around the shop. ● **SEE FIGURE 11–1.**

SAFE USE OF FLOOR JACKS. Floor jacks are used to lift a vehicle or major vehicle component, but they are not designed to hold a load. Therefore **safety stands,** also called **jack stands** should always be used to support the vehicle. After the floor jack has lifted the vehicle, safety stands should be placed under the vehicle, and then, using the floor jack, lowered onto the safety stands. The floor jack can be lifted in position as another safety device but the load should be removed from the floor jack. If a load is retained on the floor jack,

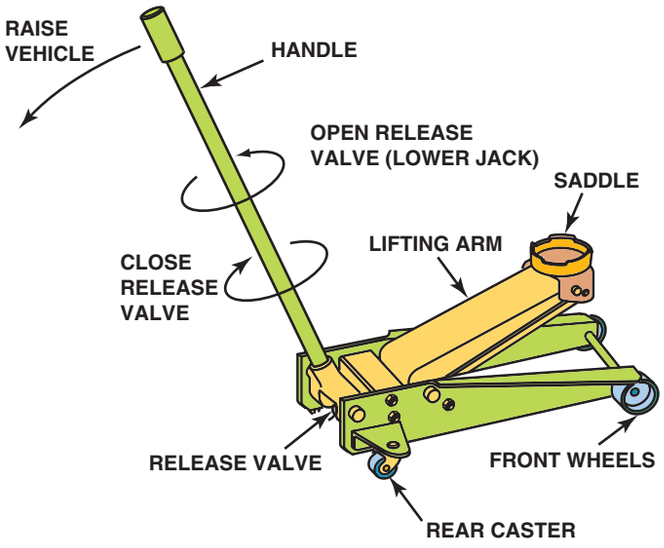


FIGURE 11–1 A hydraulic hand-operated floor jack.



FIGURE 11–2 Safety stands are being used to support the rear of this vehicle. Notice a creeper also.

hydraulic fluid can leak past seals in the hydraulic cylinders, which would lower the vehicle, possibly causing personal injury. ● **SEE FIGURE 11–2.**

CREEPERS

When working underneath a vehicle, most service technicians use a **creeper,** which consists of a flat or concaved surface equipped with low-profile casters. A creeper allows the technician to maneuver under the vehicle easily.

SAFE USE OF CREEPERS Creepers can create a fall hazard if left on the floor. When a creeper is not being used, it should be picked up and placed vertically against a wall or tool box to help prevent accidental falls.

VEHICLE HOISTS

Vehicle hoists include older in-ground pneumatic/hydraulic (air pressure over hydraulic) and above-ground units. Most of the vehicle hoists used today use an electric motor to pressurize hydraulic fluid,

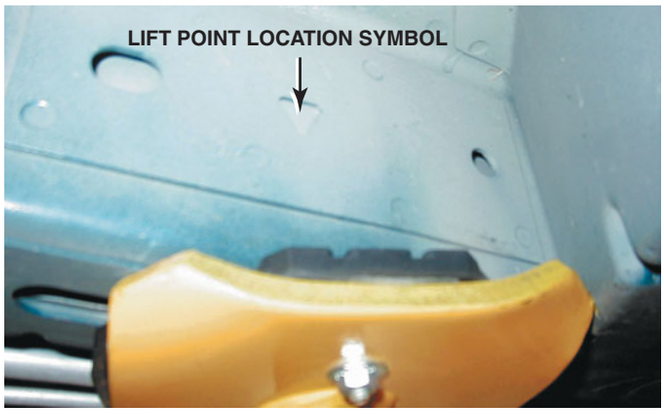


FIGURE 11–3 Most newer vehicles have a triangle symbol indicating the recommended hoisting lift points.

which lifts the vehicle using hydraulic cylinders. Hoists are rated by the maximum weight that they can safely lift, such as 7,000 to 12,000 or more. Hoists can also have equal length arms or can be equipped with different length arms allowing the vehicle to be set so the doors can be opened and not hit the center support column. Many chassis and underbody service procedures require that the vehicle be hoisted or lifted off the ground. The simplest methods involve the use of drive-on ramps or a floor jack and safety (jack) stands, whereas in ground or surface-mounted lifts provide greater access.

SETTING THE PADS IS A CRITICAL PART OF THIS PROCEDURE All automobile and light-truck service manuals include recommended locations to be used when hoisting (lifting) a vehicle. Some vehicles have a decal on the driver's door indicating the recommended lift points. The recommended standards for the lift points and lifting procedures are found in SAE Standard JRP-2184. ● **SEE FIGURE 11–3.**

These recommendations typically include the following points.

1. The vehicle should be centered on the lift or hoist so as not to overload one side or put too much force either forward or rearward. Use tall safety stands if a major component is going to be removed from the vehicle, such as the engine, to help support the vehicle. ● **SEE FIGURE 11–4.**
2. The pads of the lift should be spread as far apart as possible to provide a stable platform.
3. Each pad should be placed under a portion of the vehicle that is strong and capable of supporting the weight of the vehicle.
   a. Pinch welds at the bottom edge of the body are generally considered to be strong.

      CAUTION: Even though pinch weld seams are the recommended location for hoisting many vehicles with unitized bodies (unit-body), care should be taken not to place the pad(s) too far forward or rearward. Incorrect placement of the vehicle on the lift could cause the vehicle to be imbalanced, and the vehicle could fall. This is exactly what happened to the vehicle in ● FIGURE 11–5.

   b. Boxed areas of the body are the best places to position the pads on a vehicle without a frame. Be careful to note whether the arms of the lift might come into contact with other parts of the vehicle before the pad touches the intended location. Commonly damaged areas include the following:
      (1) Rocker panel moldings
      (2) Exhaust system (including catalytic converter)
      (3) Tires or body panels. ● **SEE FIGURES 11–6 AND 11–7.**



(a)



(b)

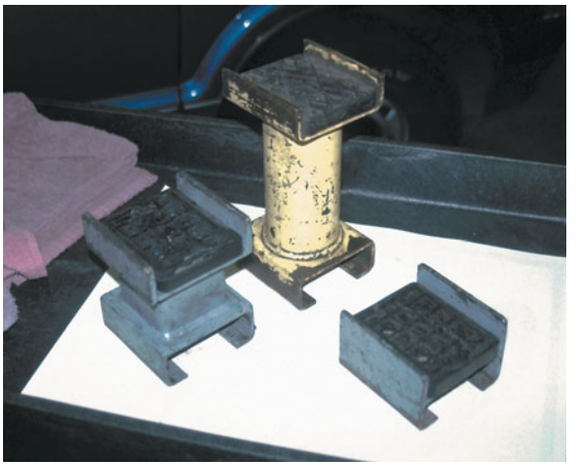
FIGURE 11–4 (a) Tall safety stands can be used to provide additional support for a vehicle while on a hoist. (b) A block of wood should be used to avoid the possibility of doing damage to components supported by the stand.

4. As soon as the pads touch the vehicle, check for proper pad placement. The vehicle should be raised about 1 ft (30 cm) off the floor, then stopped and shaken to check for stability. If the vehicle seems to be stable when checked at a short distance from the floor, continue raising the vehicle and continue to view the vehicle until it has reached the desired height. The hoist should be lowered onto the mechanical locks, and then raised off of the locks before lowering.

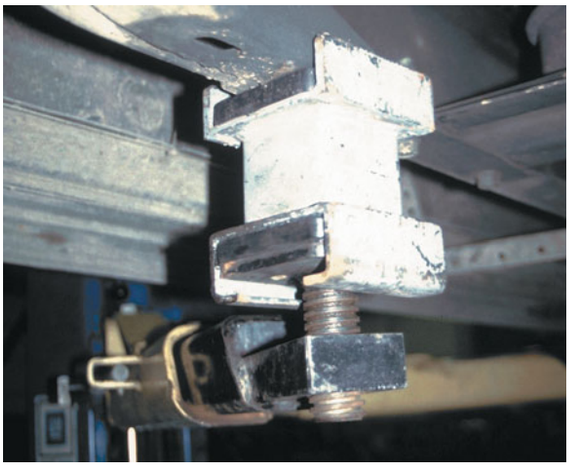
CAUTION: Do not look away from the vehicle while it is being raised (or lowered) on a hoist. Often one side or one end of the hoist can stop or fail, resulting in the vehicle being slanted enough to slip or fall.



FIGURE 11–5 This training vehicle fell from the hoist when the pads were not set correctly. No one was hurt, but the vehicle was damaged.

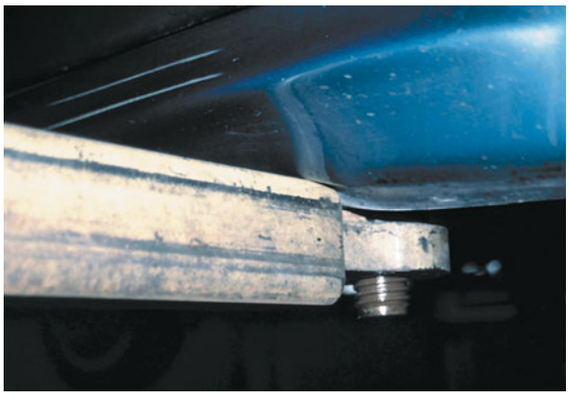


(a)



(b)

FIGURE 11–6 (a) An assortment of hoist pad adapters that are often necessary to safely hoist many pickup trucks, vans, and sport utility vehicles. (b) A view from underneath a Chevrolet pickup truck showing how the pad extensions are used to attach the hoist lifting pad to contact the frame.



(a)



(b)

FIGURE 11–7 (a) In this photo the pad arm is just contacting the rocker panel of the vehicle. (b) This photo shows what can occur if the technician places the pad too far inward underneath the vehicle. The arm of the hoist has dented in the rocket panel.

HINT: Most hoists can be safely placed at any desired height as long as it is high enough for the safety latches to engage. For ease while working, the area in which you are working should be at chest level. When working on brakes or suspension components, it is not necessary to work on them down near the floor or over your head. Raise the hoist so that the components are at chest level.

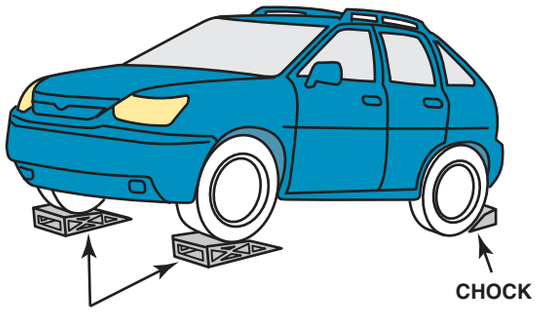


FIGURE 11–8 Drive-on-type ramps. The wheels on the ground level *must* be chocked (blocked) to prevent accidental movement down the ramp.

5. Before lowering the hoist, the safety latch(es) must be released and the direction of the controls reversed. The speed downward is often adjusted to be as slow as possible for additional safety.

DRIVE-ON RAMPS

Ramps are an inexpensive way to raise the front or rear of a vehicle. ● **SEE FIGURE 11–8.** Ramps are easy to store, but they can be dangerous because they can "kick out" when driving the vehicle onto the ramps.

CAUTION: Professional repair shops do not use ramps because they are dangerous to use. Use only with extreme care.



1 The first step in hoisting a vehicle is to properly align the vehicle in the center of the stall.



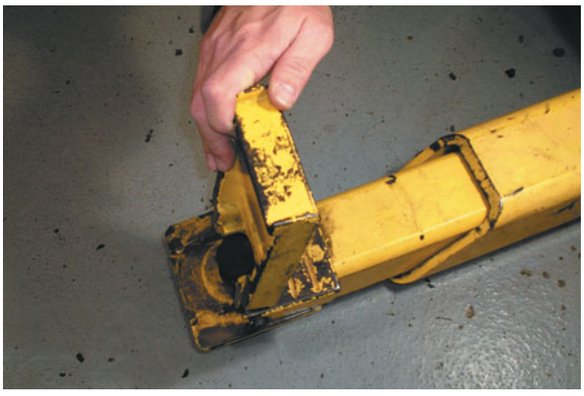
2 Most vehicles will be correctly positioned when the left front tire is centered on the tire pad.



3 The arms can be moved in and out and most pads can be rotated to allow for many different types of vehicle construction.



4 Most lifts are equipped with short pad extensions that are often necessary to use to allow the pad to contact the frame of a vehicle without causing the arm of the lift to hit and damage parts of the body.



5 Tall pad extensions can also be used to gain access to the frame of a vehicle. This position is needed to safely hoist many pickup trucks, vans, and sport utility vehicles.



6 An additional extension may be necessary to hoist a truck or van equipped with running boards to give the necessary clearance.

CONTINUED ▶



7 Position the pads under the vehicle under the recommended locations.



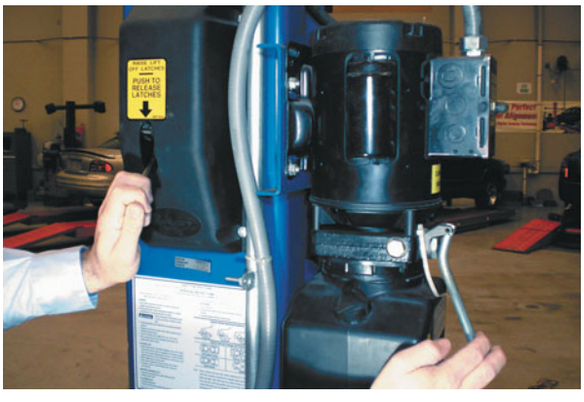
8 After being sure all pads are correctly positioned, use the electromechanical controls to raise the vehicle.



9 With the vehicle raised one foot (30 cm) off the ground, push down on the vehicle to check to see if it is stable on the pads. If the vehicle rocks, lower the vehicle and reset the pads. The vehicle can be raised to any desired working level. Be sure the safety is engaged before working on or under the vehicle.



10 If raising a vehicle without a frame, place the flat pads under the pinch weld seam to spread the load. If additional clearance is necessary, the pads can be raised as shown.



11 When the service work is completed, the hoist should be raised slightly and the safety released before using the hydraulic to lower the vehicle.



12 After lowering the vehicle, be sure all arms of the lift are moved out of the way before driving the vehicle out of the work stall.

REVIEW QUESTIONS

1. Why must safety stands be used after lifting a vehicle with a floor jack?
2. What precautions should be adhered to when storing a creeper?
3. What precautions should be adhered to when hoisting a vehicle?

CHAPTER QUIZ

1. A safety stand is also called a _____.
   a. Jack **c.** Bottle jack
   b. Jack stand **d.** Safety stool
2. A creeper should be stored _____.
   a. Vertically **c.** Flat on the floor
   b. Under a vehicle **d.** Upside down on the floor
3. The SAE standard for hoist location is _____.
   a. J-1980 **c.** JRP-2184
   b. SAE-2009 **d.** J-14302
4. Tall safety stands would be used to _____.
   a. Help support the vehicle when a major component is removed from the vehicle.
   b. Lift a vehicle
   c. Lift a component such as an engine high off the ground
   d. Both b and c
5. Commonly damaged areas of a vehicle during hoisting include _____.
   a. Rocker panels **c.** Tires or body panels
   b. Exhaust systems **d.** All of the above
6. Pad extensions may be needed when hoisting what type of vehicle?
   a. Small cars **c.** Vans
   b. Pickup trucks **d.** Either b or c
7. Technician A says that a hoist can be stopped at any level as long as the safety latch engages. Technician B says that the vehicle should be hoisted to the top of the hoist travel for safety. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
8. Before lowering the vehicle, what should the technician do?
   a. Be sure nothing is underneath the vehicle
   b. Raise the vehicle enough to release the safety latch
   c. Be sure no one will be walking under or near the vehicle
   d. All of the above
9. Technician A says that a creeper should be stored vertically. Technician B says that a creeper should be stored on its casters. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
10. When checking for stability, how high should the vehicle be raised?
    a. About 2 in. (5 cm) **c.** About 1 ft (30 cm)
    b. About 6 in. (15 cm) **d.** About 3 ft (91 cm)

chapter 12 MEASURING SYSTEMS AND TOOLS

OBJECTIVES: **After studying Chapter 12, the reader should be able to:** • Describe how to read a ruler. • Explain how to use a micrometer and vernier dial caliper. • Describe how to use a telescopic gauge and a micrometer to measure cylinder and lifter bores. • Discuss how to measure valve guides using a small-hole gauge. • Explain how to use feeler gauges and dial indicators.

KEY TERMS: Feeler gauge 102 • Sleeve 99 • Small-hole gauge 100 • Spindle 99 • Split-ball gauge 100 • Straightedge 103 • Thickness gauge 102 • Thimble 99

ENGLISH CUSTOMARY MEASURING SYSTEM

The English customary measuring system was established about A.D. 1100 in England during the reign of Henry I. The foot was determined to be 12 inches and was taken from the length of a typical foot. The yard (36 inches) was determined to be the length from King Henry's nose to the end of his outstretched hand. The mile came from Roman days and was originally defined as the distance traveled by a soldier in 1,000 paces or steps. Other English units, such as the pound (weight) and volume (gallon), evolved over the years from Roman and English measurements.

The Fahrenheit temperature scale was created by Gabriel Fahrenheit (1686–1736) and he used 100°F as the temperature of the human body, which he missed by 1.4 degrees (98.6°F is

FREQUENTLY ASKED QUESTION

What Weighs a Gram?

To better understand the metric system measurements, it is often helpful to visualize a certain object and relate it to a metric unit of measure. For example, the following objects weigh about 1 gram.

- A dollar bill
- A small paper clip

considered now to be normal temperature). On the Fahrenheit scale, water freezes at 32°F and water boils at 212°F.

METRIC SYSTEM OF MEASURE

Most of the world uses the metric system of measure. The metric system was created in the late 1700s in France and used the physical world for the basis of the measurements. For example, the meter was defined as being 1/40,000,000 of the circumference of the earth (the distance around the earth at the poles). The Celsius temperature scale developed by Anders Celsius (1701–1744) used the freezing point of water as 0°C (32°F) and the boiling point of water as 100°C (212°F). Other units include a liter of water, which was then used as a standard of weight where 1 liter of water (about 1 quart) weighs 1 kilogram (1,000 grams). Units of measure are then divided or multiplied by 10, 100, and 1,000 to arrive at usable measurements. For example, a kilometer is 1,000 meters and is the most commonly used metric measurement for distance for travel. Other prefixes include:

m = milli = 1/1,000

k = kilo = 1,000

M = mega = 1,000,000

LINEAR METRIC MEASUREMENTS

1 kilometer = 0.62 mile

1 meter = 39.37 inches

1 centimeter (1/100 meter) = 0.39 inch

1 millimeter (1/1,000 meter) = 0.039 inch

VOLUME MEASUREMENT

1 cc (cubic centimeter) = 0.06 cubic inch

1 liter = 0.26 U.S. gallon (about 1 quart)

WEIGHT MEASUREMENT

1 gram = 0.035 ounce

1 kilogram (1,000 grams) = 2.2 pounds

PRESSURE MEASUREMENTS

1 kilopascal (kPa) = 0.14 pound per square inch (6.9 kPa = 1 PSI)

1 bar = 14.5 pounds per square inch

DERIVED UNITS All units of measure, except for the base units, are a combination of units that are referred to as derived units of measure. Some examples of derived units include:

Torque

Velocity

Density

Energy

Power

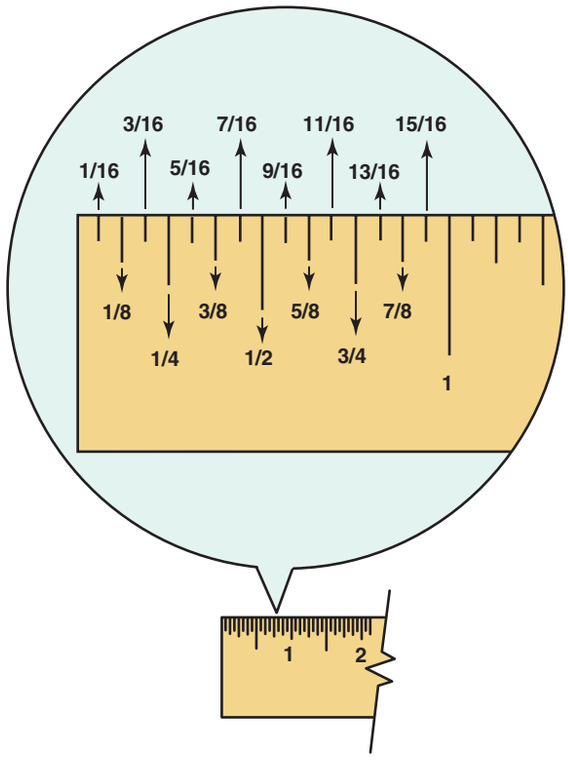


FIGURE 12–1 A rule showing that the larger the division, the longer the line.

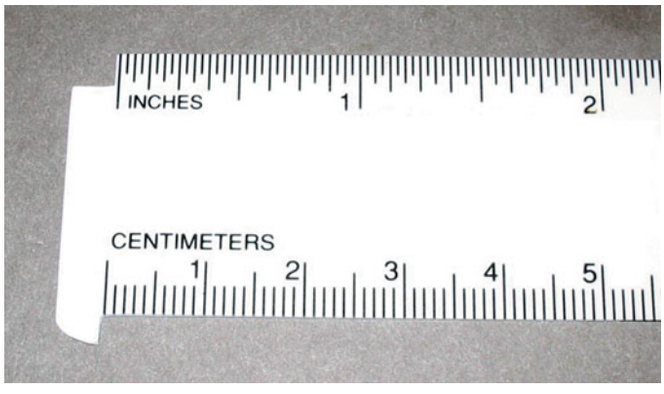


FIGURE 12–2 A plastic rule that has both inches and centimeters. Each line between the numbers on the centimeters represents 1 millimeter because there are 10 millimeters in 1 centimeter.

LINEAR MEASUREMENTS (TAPE MEASURE/RULE)

A tape measure or machinist rule divides inches into smaller units. Each smaller unit is drawn with a line shorter than the longer unit. The units of measure starting with the largest include:

1 inch

1/2 inch

1/4 inch

1/8 inch

1/16 inch

Some rules show 1/32 of an inch. ● **SEE FIGURE 12–1.**

A metric scale is also included on many tape measures and machinists rules. ● **SEE FIGURE 12–2.**

MICROMETER

A micrometer is the most used measuring instrument in engine service and repair. ● **SEE FIGURE 12–3.**

The **thimble** rotates over the **sleeve** on a screw that has 40 threads per inch. Every revolution of the thimble moves the **spindle** 0.025 in. The thimble is graduated into 25 equally spaced lines; therefore, each line represents 0.001 in. Every micrometer should be checked for calibration on a regular basis. ● **SEE FIGURES 12–4 THROUGH 12–6.**

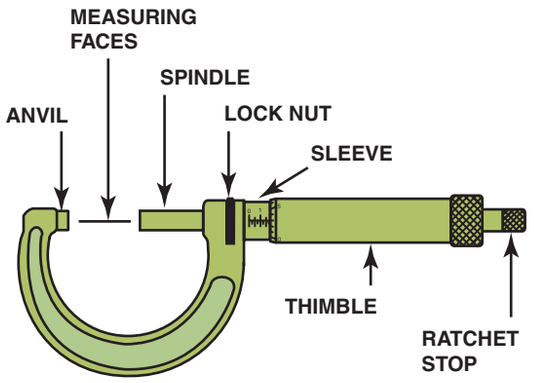


FIGURE 12–3 A typical micrometer showing the names of the parts. The sleeve may also be called the *barrel* or *stock.*

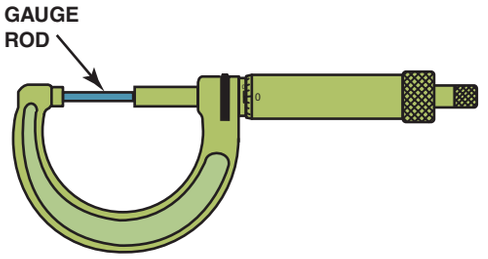


FIGURE 12–4 All micrometers should be checked and calibrated as needed using a gauge rod.

CRANKSHAFT MEASUREMENT Even though the connecting rod journals and the main bearing journals are usually different sizes, they both can and should be measured for out-of-round and taper. ● **SEE FIGURE 12–7.**

OUT-OF-ROUND. A journal should be measured in at least two positions across the diameter and every 120 degrees around the journal, as shown in ● **FIGURE 12–8,** for an example of the six readings. Calculate the out-of-round measurement by subtracting the lowest reading from the highest reading for both A and B positions.

Position A: 2.0000 − 1.9995 = 0.0005 in.

Position B: 2.0000 − 1.9989 = 0.0011 in.

The maximum out-of-round measurement occurs in position B (0.0011 in.), which is the measurement that should be used to compare against factory specifications to determine if any machining will be necessary.

TAPER. To determine the taper of the journal, compare the readings in the same place between A and B positions and subtract the lower reading from the higher reading.

For example:

Position A		Position B	
2.0000	–	2.0000	= 0.0000
1.9999	–	1.9999	= 0.0000
1.9995	–	1.9989	= 0.0006

Use 0.0006 in. as the taper for the journal and compare with factory specifications.

CAMSHAFT MEASUREMENT The journal of the camshaft(s) can also be measured using a micrometer and compared with factory specifications for taper and out-of-round. ● **SEE FIGURE 12–9.**

NOTE: On overhead valve (pushrod) engines, the camshaft journal diameter often decreases slightly toward the rear of the engine. Overhead camshaft engines usually have the same journal diameter.

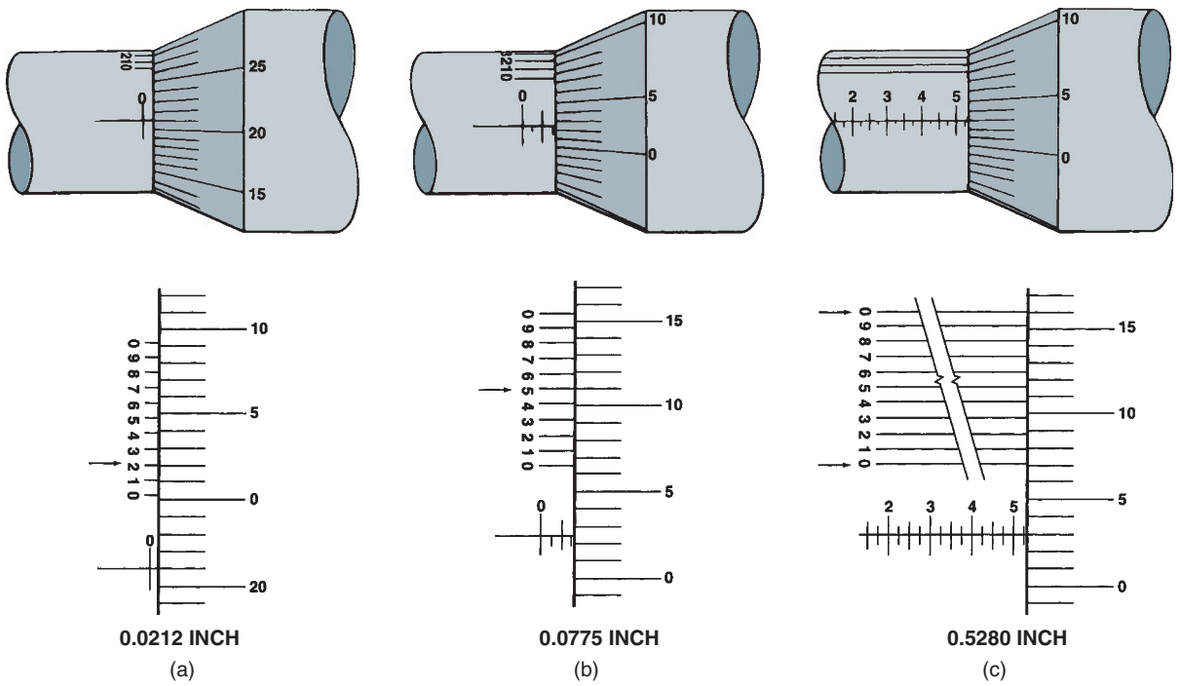


FIGURE 12–5 The three micrometer readings are (a) 0.0212 in.; (b) 0.0775 in.; (c) 0.5280 in. These measurements used the vernier scale on the sleeve to arrive at the ten-thousandth measurement. The number that is aligned represents the digit in the ten-thousandth place.

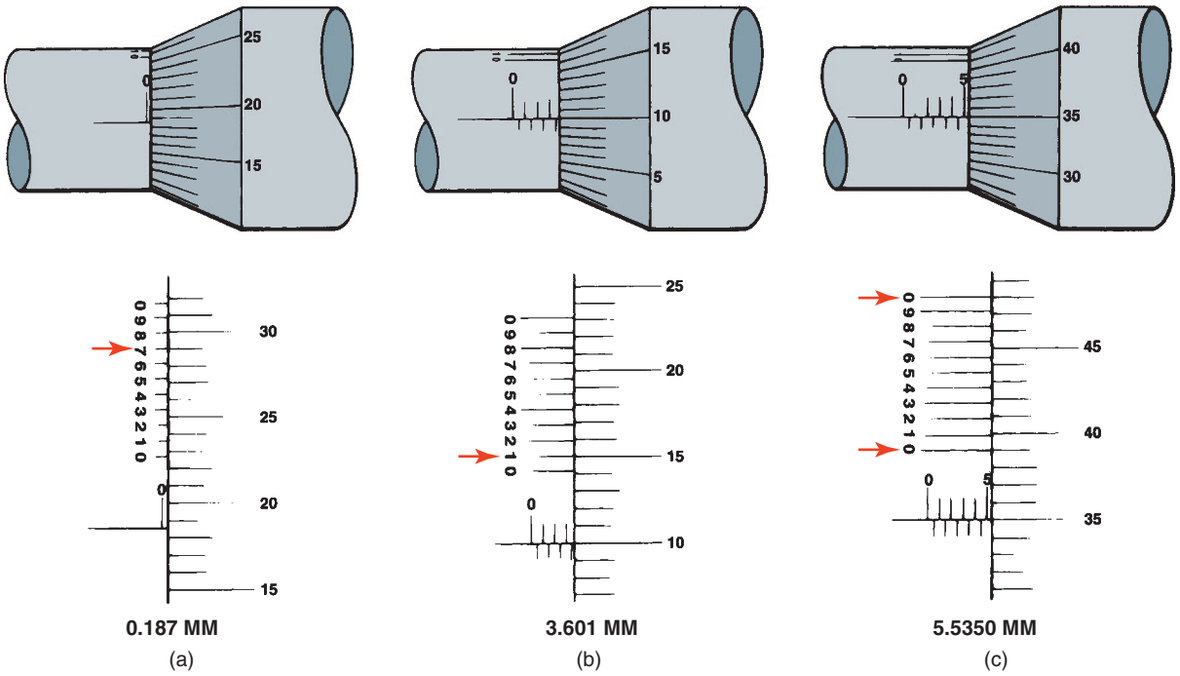


FIGURE 12–6 Metric micrometer readings that use the vernier scale on the sleeve to read to the nearest 0.001 millimeter. The arrows point to the final reading for each of the three examples.

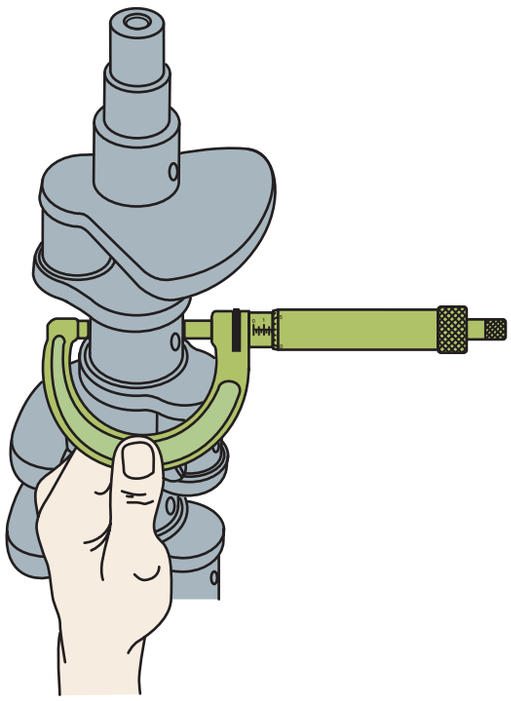


FIGURE 12–7 Using a micrometer to measure the connecting rod journal for out-of-round and taper.

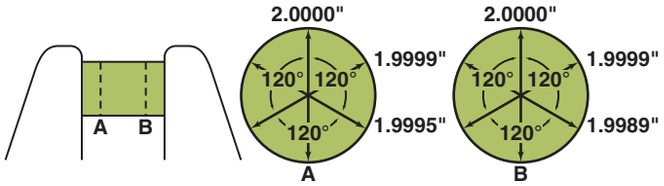


FIGURE 12–8 Crankshaft journal measurements. Each journal should be measured in at least six locations, but also in position A and position B and at 120-degree intervals around the journal.

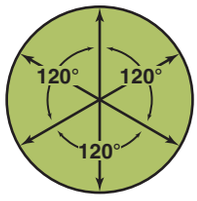


FIGURE 12–9 Camshaft journals should be measured in three locations, 120 degrees apart, to check for out-of-round.

The cam lift can also be measured with a micrometer and compared with factory specifications, as shown in ● **FIGURE 12–10.**

TELESCOPIC GAUGE

A telescopic gauge is used with a micrometer to measure the inside diameter of a hole or bore.

The cylinder bore can be measured by inserting a telescopic gauge into the bore and rotating the handle lock to allow the arms of the gauge to contact the inside bore of the cylinder. Tighten the handle lock and remove the gauge from the cylinder. Use a micrometer to measure the telescopic gauge. ● **SEE FIGURE 12–11.**

A telescopic gauge can also be used to measure the following:

- Camshaft bearing (● **SEE FIGURE 12–12.**)
- Main bearing bore (housing bore) measurement
- Connecting rod bore measurement

SMALL-HOLE GAUGE

A **small-hole gauge** (also called a **split-ball gauge**) is used with a micrometer to measure the inside diameter of small holes such as a valve guide in a cylinder head. ● **SEE FIGURES 12–13 AND 12–14.**

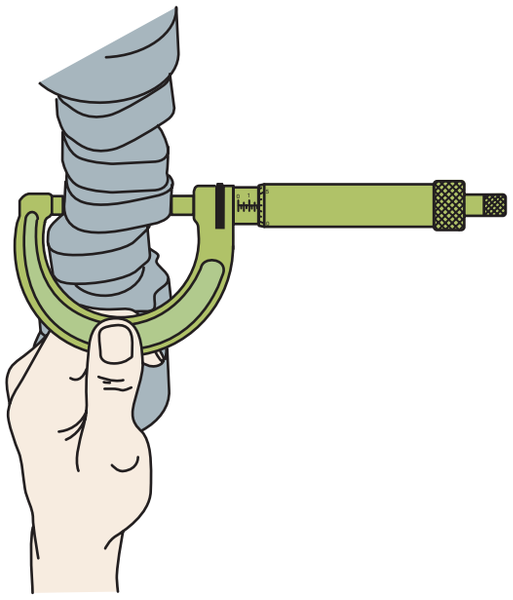
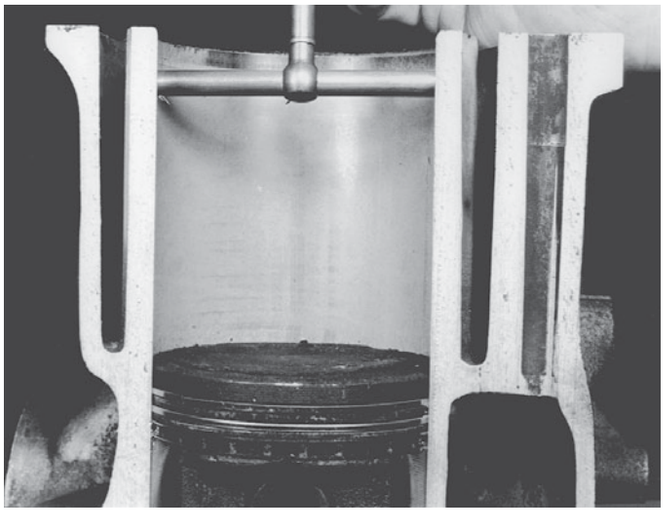
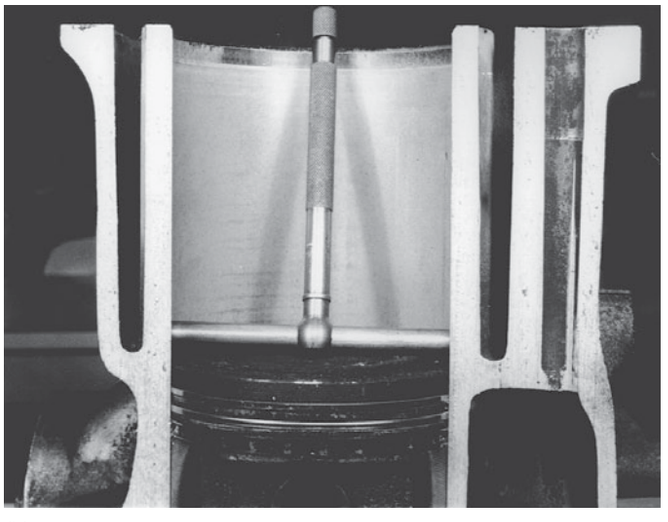


FIGURE 12–10 Checking a camshaft for wear by measuring the lobe height with a micrometer.

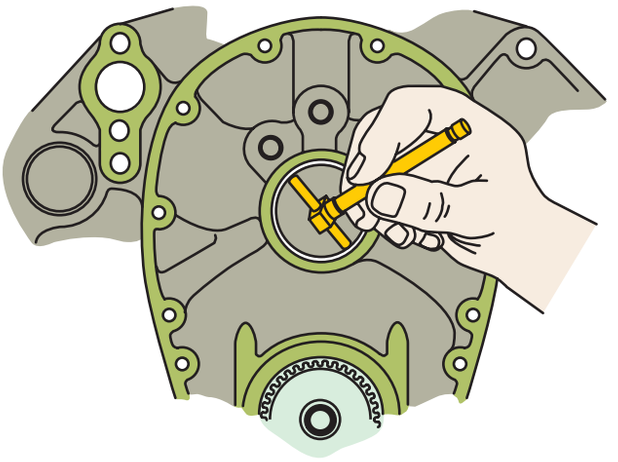


(a)

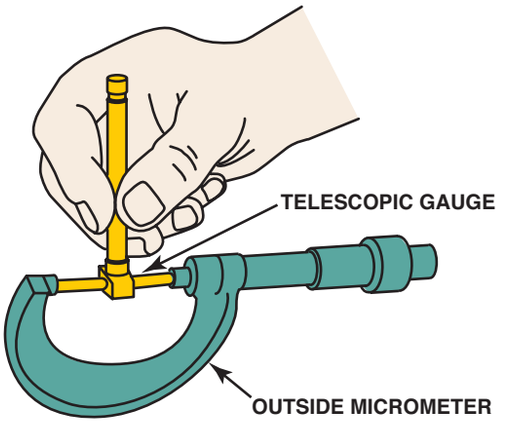


(b)

FIGURE 12–11 When the head is first removed, the cylinder taper and out-of-round should be checked below the ridge (a) and above the piston when it is at the bottom of the stroke (b).



(a)



(b)

FIGURE 12–12 (a) A telescopic gauge being used to measure the inside diameter (ID) of a camshaft bearing. (b) An outside micrometer used to measure the telescopic gauge.

FREQUENTLY ASKED QUESTION

What Is the Difference Between the Word *Gage* and *Gauge?*

The word *gauge* means "measurement or dimension to a standard of reference." The word *gauge* can also be spelled *gage.* Therefore, in most cases, the words mean the same.

INTERESTING NOTE: One vehicle manufacturing representative told me that *gage* was used rather than *gauge* because even though it is the second acceptable spelling of the word, it is correct and it saved the company a lot of money in printing costs because the word *gage* has one less letter! One letter multiplied by millions of vehicles with gauges on the dash and the word *gauge* used in service manuals adds up to a big savings to the manufacturer.

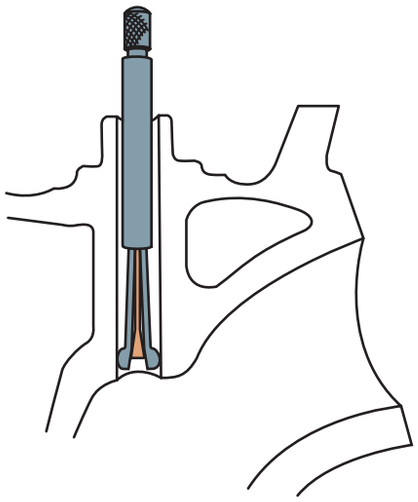


FIGURE 12–13 Cutaway of a valve guide with a hole gauge adjusted to the hole diameter.

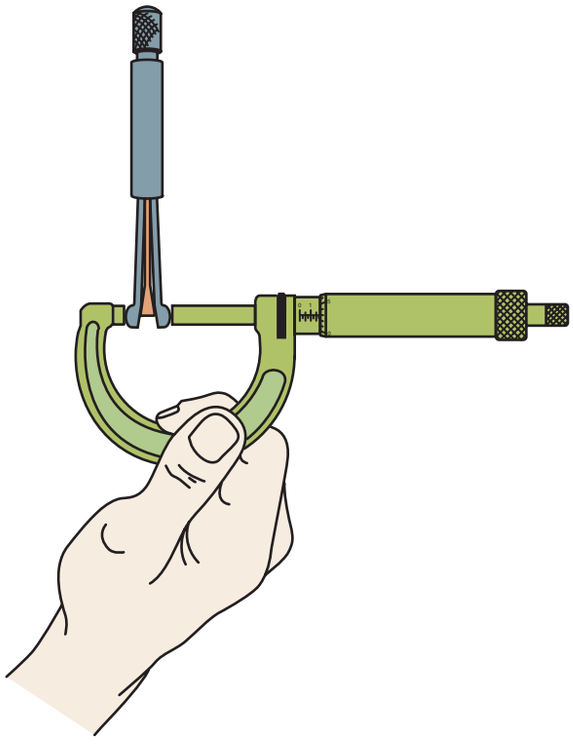


FIGURE 12–14 The outside of a hole gauge being measured with a micrometer.

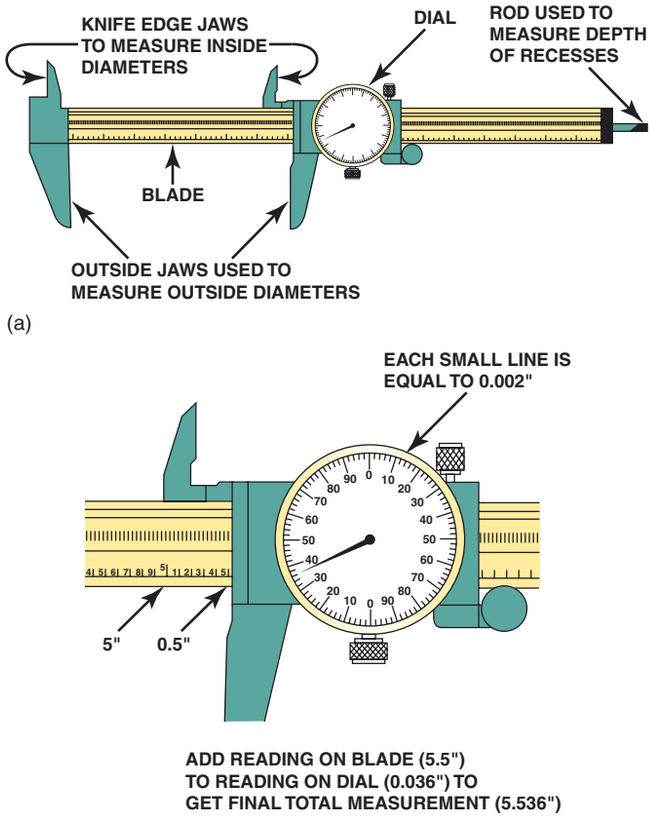


FIGURE 12–15 (a) A typical vernier dial caliper. This is a very useful measuring tool for automotive engine work because it is capable of measuring inside, outside, and depth measurements. (b) To read a vernier dial caliper, simply add the reading on the blade to the reading on the dial.

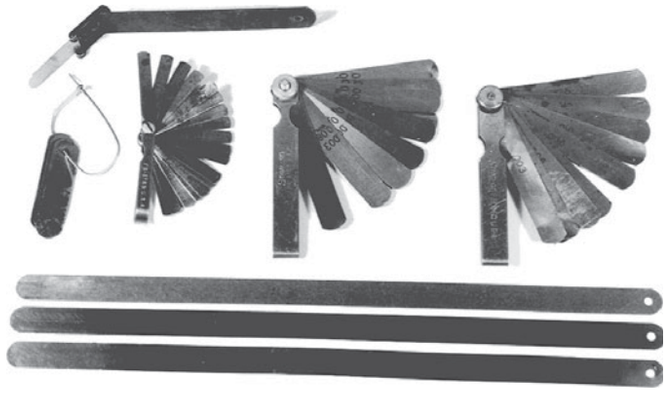


FIGURE 12–16 A group of feeler gauges (also known as thickness gauges), used to measure between two parts. The long gauges on the bottom are used to measure the piston-to-cylinder wall clearance.

VERNIER DIAL CALIPER

A vernier dial caliper is normally used to measure length, inside and outside diameters, and depth. ● **SEE FIGURE 12–15.**

FEELER GAUGE

A **feeler gauge** (also known as a **thickness gauge**) is an accurately manufactured strip of metal that is used to determine the gap or clearance between two components. ● **SEE FIGURE 12–16.**

A feeler gauge can be used to check the following:

- Piston ring gap (● **SEE FIGURE 12–17.**)
- Piston ring side clearance
- Connecting rod side clearance
- Piston-to-wall clearance

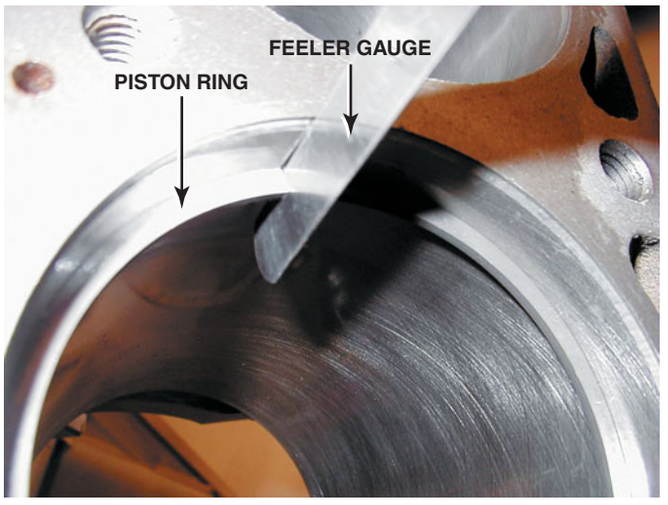


FIGURE 12–17 A feeler gauge, also called a thickness gauge, is used to measure the small clearances such as the end gap of a piston ring.

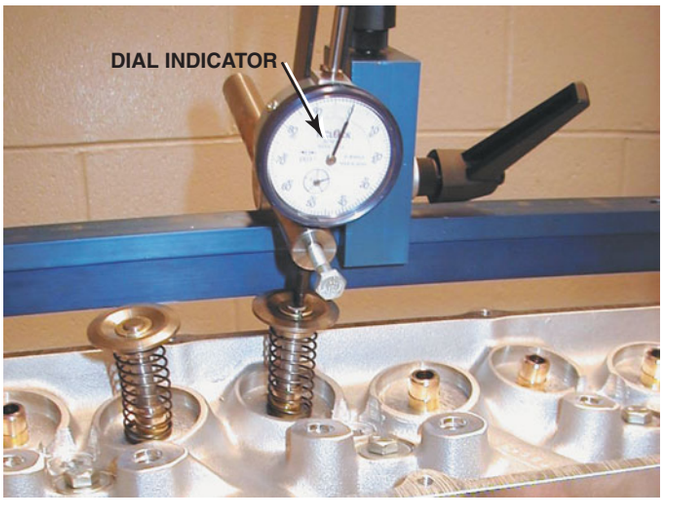


FIGURE 12–19 A dial indicator is used to measure valve lift during flow testing of a high-performance cylinder head.

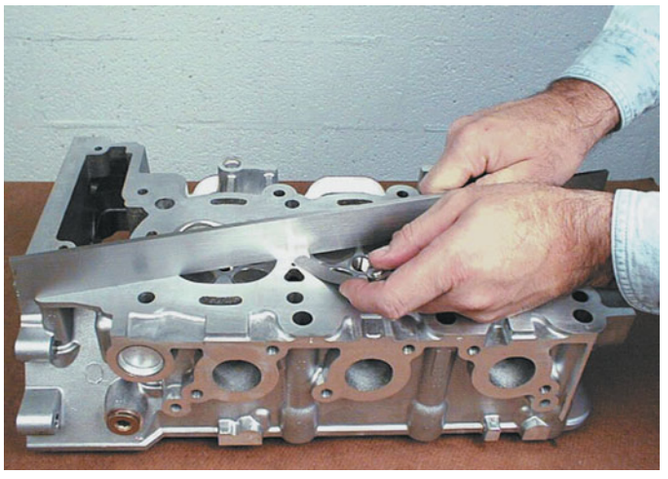


FIGURE 12–18 A straightedge is used with a feeler gauge to determine if a cylinder head is warped or twisted.

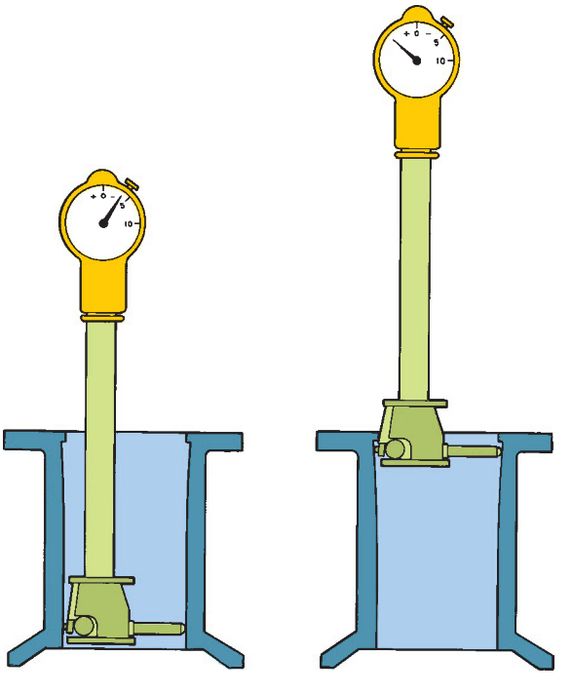


FIGURE 12–20 A dial bore gauge is used to measure cylinders and other engine parts for out-of-round and taper conditions.

STRAIGHTEDGE

A **straightedge** is a precision ground metal measuring gauge that is used to check the flatness of engine components when used with a feeler gauge. A straightedge is used to check the flatness of the following:

- Cylinder heads (● **SEE FIGURE 12–18.**)
- Cylinder block deck
- Straightness of the main bearing bores (saddles)

DIAL INDICATOR

A dial indicator is a precision measuring instrument used to measure crankshaft end play, crankshaft runout, and valve guide wear. A dial indicator can be mounted three ways, including:

- **Magnetic mount.** This is a very useful method because a dial indicator can be attached to any steel or cast iron part.
- **Clamp mount.** A clamp-mounted dial indicator is used in many places where a mount could be clamped.
- **Threaded rod.** Using a threaded rod allows the dial indicator to be securely mounted, such as shown in ● **FIGURE 12–19.**

DIAL BORE GAUGE

A dial bore gauge is an expensive, but important, gauge used to measure cylinder taper and out-of-round as well as main bearing (block housing) bore for taper and out-of-round. ● **SEE FIGURE 12–20.** A dial bore gauge has to be adjusted to a dimension, such as the factory specifications. The reading on the dial bore gauge then indicates plus (+) or minus (−) readings from the predetermined dimension. This is

why a dial bore is best used to measure taper and out-of-round because it shows the difference in cylinder or bore rather than an actual measurement.

DEPTH MICROMETER

A depth micrometer is similar to a conventional micrometer except that it is designed to measure the depth from a flat surface. ● **SEE FIGURE 12–21.**

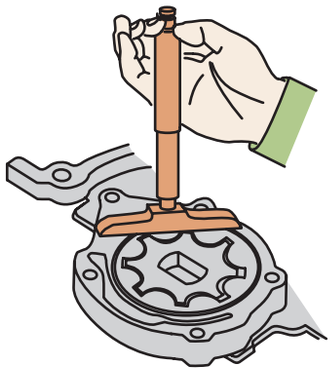


FIGURE 12–21 A depth micrometer being used to measure the height of the rotor of an oil pump from the surface of the housing.

REVIEW QUESTIONS

1. Explain how a micrometer is read.
2. Describe how to check a crankshaft journal for out-of-round and taper.
3. List engine components that can be measured with the help of a telescopic gauge.
4. List the gaps or clearances that can be measured using a feeler (thickness) gauge.
5. Explain why a dial bore gauge has to be set to a dimension before using.

CHAPTER QUIZ

1. The threaded movable part that rotates on a micrometer is called the _____.
   a. Sleeve
   b. Thimble
   c. Spindle
   d. Anvil
2. To check a crankshaft journal for taper, the journal should be measured in at least how many locations?
   a. One
   b. Two
   c. Four
   d. Six
3. To check a crankshaft journal for out-of-round, the journal should be measured in at least how many locations?
   a. Two
   b. Four
   c. Six
   d. Eight
4. A telescopic gauge can be used to measure a cylinder bore if what other measuring device is used to measure the telescopic gauge?
   a. Micrometer
   b. Feeler gauge
   c. Straightedge
   d. Dial indicator
5. To directly measure the diameter of a valve guide in a cylinder head, use a micrometer and a _____.
   a. Telescopic gauge
   b. Feeler gauge
   c. Small-hole gauge
   d. Dial indicator
6. Which of the following *cannot* be measured using a feeler gauge?
   a. Valve guide clearance
   b. Piston-ring gap
   c. Piston-ring side clearance
   d. Connecting rod side clearance
7. Which of the following *cannot* be measured using a straightedge and a feeler gauge?
   a. Cylinder head flatness
   b. Block deck flatness
   c. Straightness of the main bearing bores
   d. Straightness of the cylinder bore
8. Which measuring gauge needs to be set up (adjusted) to a fixed dimension before use?
   a. Dial indicator
   b. Dial bore gauge
   c. Vernier dial gauge
   d. Micrometer
9. The freezing point of water is _____.
   a. 0°C
   b. 32°F
   c. 0°F
   d. Both a and b
10. Which metric unit of measure is used for volume measurement?
    a. Meter
    b. cc
    c. Centimeter
    d. Millimeter

SECTION IV

Principles, Math, and Calculations

13 Scientific Principles and Materials

14 Math, Charts, and Calculations

chapter 13

SCIENTIFIC PRINCIPLES AND MATERIALS

OBJECTIVES: After studying Chapter 13, the reader will be able to: • Describe Newton's Laws of Motion. • Explain kinetic energy and why it is so important to brake design. • Discuss mechanical advantage and how it is used in a vehicle. • Define torque and horsepower. • Describe sound and acoustics. • Explain bases and acids. • Discuss the gas laws. • Explain the coefficient of friction. • Describe the difference between heat and temperature. • Describe the methods used to identify plastic, iron, steel, and aluminum.

KEY TERMS: Acid material 111 • Alkaline 111 • Brake 108 • Brake horsepower (bhp) 108 • BTU (British Thermal Unit) 110 • Caustic material 111 • Celsius (centigrade) 110 • Conduction 110 • Conductor 110 • Convection 110 • Dynamometer (dyno or dyn) 107 • Energy 106 • Fahrenheit 111 • First-class lever 109 • Force 106 • Fulcrum 109 • Horsepower 107 • Hypothesis 105 • Inertia 109 • Insulator 110 • Kinetic energy 106 • Leverage 109 • Mass 109 • Mechanical advantage 110 • Newton's laws of motion 108 • Pedal ratio 110 • PH 111 • Potential energy 106 • Power 107 • Propagation 112 • Radiation 110 • Root cause 105 • Scientific method 105 • Second-class lever 109 • Third-class lever 109 • Torque 106 • Weight 109 • Work 106 • Wrought alloys 113

SCIENTIFIC METHOD

The **scientific method** is a series of steps taken to solve a problem. These steps help eliminate errors and to achieve an accurate result. The scientific method is the foundation of automotive diagnosis. A scientific method involves the following steps:

STEP 1 Observe the conditions or problem and define or describe the problem.

STEP 2 Formulate an explanation that could be the cause of the problem.

STEP 3 Use the explanation (**hypothesis**) to test to see if it matches the existing problem. If not, then return to step 2 to formulate another explanation.

STEP 4 After the explanation has proved to be a possible solution to a problem, additional tests should be performed to verify that the method works all of the time.

USING THE SCIENTIFIC METHOD

While a service technician will not perform research, using a scientific approach to problem solving is very important.

This means that every fault should be investigated to determine the root cause rather than solving what at first is thought to be the problem or fault. The **root cause** is the true cause of a failure, which may not be noticed at first. Many service technicians ask themselves "why" when they discover a fault. Often this leads to another possible problem and then the technician should ask another "why." This scientific method of finding the root cause of an automotive problem is often called the "five whys." By the time the technician has asked "why" five times, the root cause is usually discovered.

EXAMPLES OF THE FIVE WHYS

As an example of using a scientific method approach to automotive faults, an owner may state that the vehicle does not start and the battery appears to be dead. Therefore, applying the five whys (scientific approach) first ask why:

- First why—What caused the battery to become discharged? To answer this question requires observation and the creating

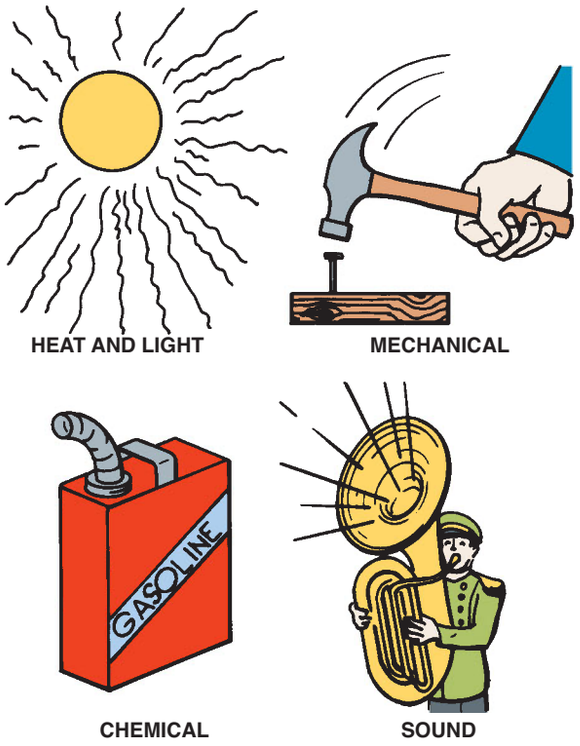


FIGURE 13–1 Energy, which is the ability to perform work, exists in many forms.

of a hypothesis, such as "is the battery defective" or "did the customer leave the lights on?" This requires questioning the owner and testing the battery.

- Second why—Assume that the battery was in good condition but discharged. Now the technician should ask the second why. "Why did the battery become discharged?" This means that a battery ignition off drain test needs to be performed as well as testing of the charging system. Assume the battery drain test was okay, but that the charging system was not working properly.
- Third why—The charging system was found to be not working correctly. A visual inspection found that the alternator drive belt was not tight enough to properly operate the alternator. The technician needs to ask the third why, "Why is the accessory drive belt still loose?"
- Fourth why—"Why was the accessory drive belt loose?" The cause could be a defective tensioner. If the tensioner itself was not a problem, then another "why" needs to be asked.
- Fifth why—If the accessory belt and belt tensioner were okay, then further investigation would be needed to find the root cause. For example, "Is one of the tensioner retaining bolts loose, maybe from a previous repair?" This could be the root cause.

ENERGY PRINCIPLES

Energy is the ability or the capacity to do work. There are many forms of energy, but chemical, mechanical, and electrical energy are the most familiar kinds involved in the operation of an automobile. ● **SEE FIGURE 13–1.** Energy in the form of a moving object is called **kinetic energy.** An example of kinetic energy is a moving vehicle. Energy is called **potential energy** if it is capable of being changed

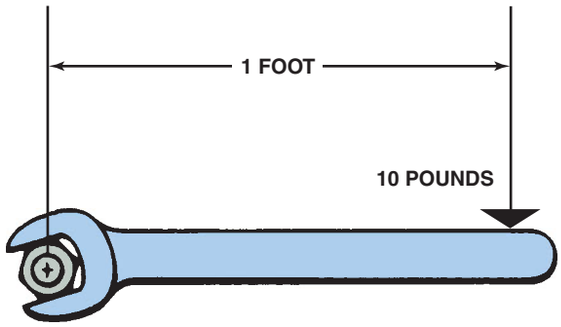


FIGURE 13–2 Torque is a twisting force equal to the distance from the pivot point times the force applied expressed in units called pound-feet (lb-ft) or Newton-meters (N-m).

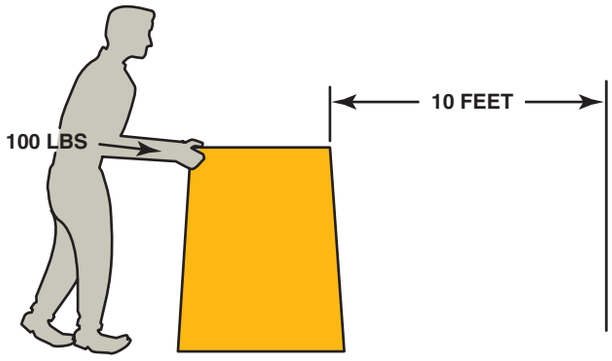


FIGURE 13–3 Work is calculated by multiplying force times distance. If you push 100 pounds 10 feet, you have done 1,000 foot-pounds of work.

to useful energy, such as the potential energy stored in a battery or a vehicle at the top of a hill. In both of these cases, there is no energy being released but if the battery were connected to an electrical load, such as a light bulb, or the vehicle starts moving down the hill, the energy is being released.

TORQUE

Torque is the term used to describe a rotating force that may or may not result in motion. Torque is measured as the amount of **force** multiplied by the length of the lever through which it acts. If a one-foot-long wrench is used to apply 10 pounds of force to the end of the wrench to turn a bolt, then 10 pound-feet of torque is being applied. ● **SEE FIGURE 13–2.** The metric unit for torque is Newton-meters because Newton is the metric unit for force and the distance is expressed in meters.

1 pound-foot = 1.3558 Newton-meters

1 Newton-meter = 0.7376 pound-foot

WORK

Work is defined as actually accomplishing movement when force (torque) is applied to an object. A service technician can apply torque to a bolt in an attempt to loosen it, yet no work is done until the bolt actually moves. Work is calculated by multiplying the applied force (in pounds) by the distance the object moves (in feet). If you applied 100 pounds of force to move an object 10 feet, then you accomplished 1,000 foot-pounds of work (100 pounds × 10 feet = 1,000 foot pounds). ● **SEE FIGURE 13–3.**

Newton-Meters to Pound-Feet Conversion Chart (1 N-m = 0.074 lb-ft)							
N-m	Lb-ft	N-m	Lb-ft	N-m	Lb-ft	N-m	Lb-ft
1	0.74	26	19.2	51	37.7	76	56.2
2	1.5	27	20.0	52	38.5	77	57.0
3	2.2	28	20.7	53	39.2	78	57.7
4	3.0	29	21.5	54	40.0	79	58.5
5	3.7	30	22.2	55	40.7	80	59.2
6	4.4	31	22.9	56	41.4	81	59.9
7	5.2	32	23.7	57	42.2	82	60.7
8	5.9	33	24.4	58	42.9	83	61.4
9	6.7	34	25.2	59	43.7	84	62.2
10	7.4	35	25.9	60	44.4	85	62.9
11	8.1	36	26.6	61	45.1	86	63.6
12	8.9	37	27.4	62	45.9	87	64.4
13	9.6	38	28.1	63	46.6	88	65.1
14	10.4	39	28.9	64	47.4	89	65.9
15	11.1	40	29.6	65	48.1	90	66.6
16	11.8	41	30.3	66	48.8	91	67.3
17	12.6	42	31.1	67	49.6	92	68.1
18	13.3	43	31.8	68	50.3	93	68.8
19	14.1	44	32.6	69	51.0	94	69.6
20	14.8	45	33.3	70	51.8	95	70.3
21	15.5	46	34.0	71	52.5	96	71.0
22	16.3	47	34.8	72	53.3	97	71.8
23	17.0	48	35.5	73	54.0	98	72.5
24	17.8	49	36.3	74	54.8	99	73.3
25	18.5	50	37.0	75	55.5	100	74.0

Pound-Feet to Newton-Meters Conversion Chart (1 lb-ft = 1.4 N-m)							
Lb-ft	N-m	Lb-ft	N-m	Lb-ft	N-m	Lb-ft	N-m
1	1.4	26	36.4	51	71.4	76	106.4
2	2.8	27	37.8	52	72.8	77	107.8
3	4.2	28	39.2	53	74.2	78	109.2
4	5.6	29	40.6	54	75.6	79	110.6
5	7.0	30	42.0	55	77.0	80	112.0
6	8.4	31	43.4	56	78.4	81	113.4
7	9.8	32	44.8	57	79.8	82	114.8
8	11.2	33	46.2	58	81.2	83	116.2
9	12.6	34	47.6	59	82.6	84	117.6
10	14.0	35	49.0	60	84.0	85	119.0
11	15.4	36	50.4	61	85.4	86	120.4
12	16.8	37	51.8	62	86.8	87	121.8
13	18.2	38	53.2	63	88.2	88	123.2
14	19.6	39	54.6	64	89.6	89	124.6
15	21.0	40	56.0	65	91.0	90	126.0
16	22.4	41	57.4	66	92.4	91	127.4
17	23.8	42	58.8	67	93.8	92	128.8
18	25.2	43	60.2	68	95.2	93	130.2
19	26.6	44	61.6	69	96.6	94	131.6
20	28.0	45	63.0	70	98.0	95	133.0
21	29.4	46	64.4	71	99.4	96	134.4
22	30.8	47	65.8	72	100.8	97	135.8
23	32.2	48	67.2	73	102.2	98	137.2
24	33.6	49	68.6	74	103.6	99	138.6
25	35.0	50	70.0	75	105.0	100	140.0

FREQUENTLY ASKED QUESTION

What Is the Difference between Torque and Work?

The designations for torque and work are often confusing. Torque is expressed in pound-feet because it represents a force exerted a certain distance from the object and acts as a lever. Work, however, is expressed in foot-pounds because work is the movement over a certain distance (feet) multiplied by the force applied (pounds). Engines produce torque and service technicians exert torque represented by the unit pound-feet.

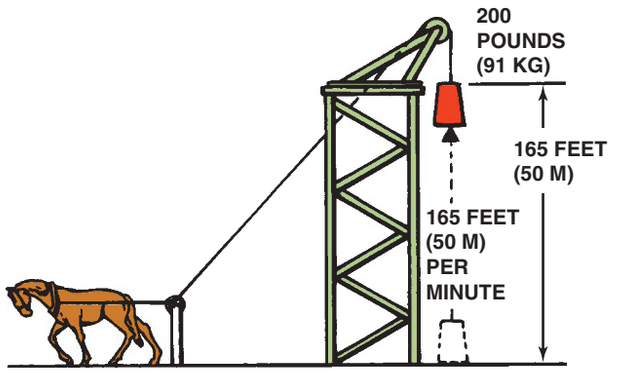


FIGURE 13–4 One horsepower is equal to 33,000 foot-pounds (200 lbs × 165 ft) of work per minute.

POWER

The term **power** means the rate of doing work. Power equals work divided by time. Work is achieved when a certain amount of mass (weight) is moved a certain distance by a force. If the object is moved in 10 seconds or 10 minutes does not make a difference in the amount of work accomplished, but it does affect the amount of power needed. Power is expressed in units of foot-pounds per minute.

HORSEPOWER

The power an engine produces is called horsepower (hp). One **horsepower** is the power required to move 550 pounds one foot in one second, or 33,000 pounds one foot in one minute (550 lb × 60 sec = 33,000 lb). This is expressed as 500 foot-pounds (ft-lb) per second or 33,000 foot-pounds per minute. ● **SEE FIGURE 13–4.**

The actual horsepower produced by an engine is measured with a **dynamometer.** A dynamometer (often abbreviated as **dyno**

or **dyn**) places a load on the engine and measures the amount of twisting force the engine crankshaft places against the load. The load holds the engine speed, so it is called a **brake.** The horsepower derived from a dynamometer is called **brake horsepower (bhp).** The dynamometer actually measures the torque output of the engine. Torque is a rotating force that may or may not cause movement. The horsepower is calculated from the torque readings at various engine speeds (in revolutions per minute or RPM).

Horsepower is torque times RPM divided by 5252.

$$\text{Horsepower} = \frac{\text{Torque} \times \text{RPM}}{5252}$$

Torque is what the driver "feels" as the vehicle is being accelerated. A small engine operating at a high RPM may have the same horsepower as a large engine operating at a low RPM.

NOTE: As can be seen by the formula for horsepower, the higher the engine speed for a given amount of torque, the greater the horsepower.

NEWTON'S LAWS OF MOTION

Sir Isaac Newton (1643–1727) was an English physicist and mathematician who developed many theories of science, including three laws of motion.

1. **Newton's first law of motion** states that an object at rest tends to stay at rest and an object in motion tends to stay in motion unless acted on by an outside force. For example, it requires a large force to get a vehicle that is stopped into motion. It also requires that a force be applied to slow and stop a vehicle that is in motion.
2. Newton's second law of motion states that the force needed to move an object is proportional to the mass of the object multiplied by the acceleration rate of the object. This means that it requires a great deal more force to accelerate a heavy sport utility vehicle (SUV) than a small economy vehicle. The rate of acceleration also depends on the amount of force that is applied.
3. Newton's third law of motion states that for every action, there is an opposite and equal reaction. For example, when the air-fuel mixture is ignited in an engine, the force is exerted on the piston, which is forced downward, which causes the crankshaft of the engine to rotate. The opposite action is applied to the cylinder head of the engine and applies the same force although this part is designed not to move.

KINETIC ENERGY

Kinetic energy is a fundamental form of mechanical energy. It is the energy of mass in motion. Every moving object possesses kinetic energy, and the amount of that energy is determined by the object's mass and speed. The greater the mass of an object and the faster it moves, the more kinetic energy it possesses. Even at low speeds, a moving vehicle has enough kinetic energy to cause serious injury and damage. The job of the brake system is to dispose of that energy in a safe and controlled manner.

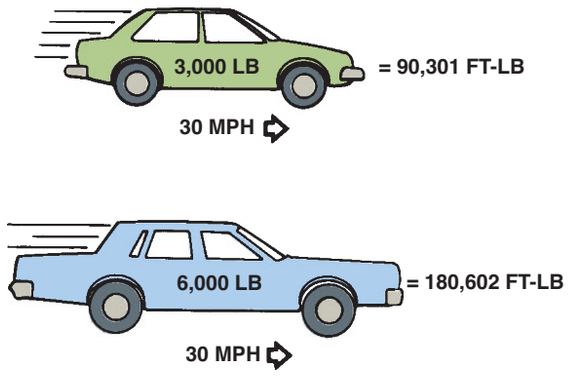


FIGURE 13–5 Kinetic energy increases in direct proportion to the weight of the vehicle.

Engineers calculate kinetic energy using the following formula:

$$\frac{mv^2}{29.9} = E_k$$

where:

m = mass or weight of the vehicle in pounds
v = velocity of the vehicle in miles per hour
E_k = kinetic energy in foot-pounds (ft-lb)

Another way to express this equation is as follows.

$$\frac{\text{weight} \times \text{speed}^2}{29.9} = \text{kinetic energy}$$

If a 3,000-pound vehicle traveling at 30 mph is compared to a 6,000-pound vehicle also traveling at 30 mph as shown in ● **FIGURE 13–5,** the equations for computing their respective kinetic energies look like this:

$$\frac{3{,}000 \text{ lb} \times 30^2 \text{ mph}}{29.9} = 90{,}301 \text{ ft-lb}$$

$$\frac{6{,}000 \text{ lb} \times 30^2 \text{ mph}}{29.9} = 180{,}602 \text{ ft-lb}$$

The results show that when the weight of a vehicle is doubled from 3,000 to 6,000 pounds, its kinetic energy is also doubled from 90,301 foot-pounds to 180,602 foot-pounds. In mathematical terms, kinetic energy increases *proportionally* as weight increases. In other words, if the weight of a moving object doubles, its kinetic energy also doubles. If the weight quadruples, the kinetic energy becomes four times as great.

If a 3,000-pound vehicle traveling at 30 mph is compared to the same vehicle traveling at 60 mph (● **FIGURE 13–6**), the equations for computing their respective kinetic energies look like this:

$$\frac{3{,}000 \text{ lb} \times 30^2 \text{ mph}}{29.9} = 90{,}301 \text{ ft-lb}$$

$$\frac{3{,}000 \text{ lb} \times 60^2 \text{ mph}}{29.9} = 361{,}204 \text{ ft-lb}$$

The results show that the vehicle traveling at 30 mph has over 90,000 foot-pounds of kinetic energy, but at 60 mph the figure increases to over 350,000 foot-pounds. In fact, at twice the speed, the vehicle has exactly four times as much kinetic energy. If the speed were doubled again to 120 mph, the amount of kinetic energy

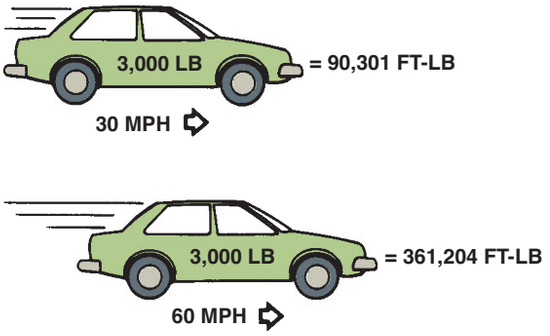


FIGURE 13–6 Kinetic energy increases as the square of any increase in vehicle speed.

FREQUENTLY ASKED QUESTION

What Is the Difference Between Mass and Weight?

Mass is the amount of matter in an object. One of the properties of mass is inertia. Inertia is the resistance to being put in motion and the tendency to remain in motion once it is set in motion.

The **weight** of an object is the force of gravity on the object and may be defined as the mass times the acceleration of gravity.

Therefore, mass means the property of an object and weight is a force.

TECH TIP

Brakes Cannot Overcome the Laws of Physics

No vehicle can stop on a dime. The energy required to slow or stop a vehicle must be absorbed by the braking system. All drivers should be aware of this fact and drive at a reasonable speed for the road and traffic conditions.

would grow to almost 1,500,000 foot-pounds! In mathematical terms, kinetic energy increases as the *square of its speed.* In other words, if the speed of a moving object doubles (2), the kinetic energy becomes four times as great ($2^2 = 4$). And if the speed quadruples (4), say from 15 to 60 mph, the kinetic energy becomes 16 times as great ($4^2 = 16$). This is the reason speed has such an impact on kinetic energy.

KINETIC ENERGY AND BRAKE DESIGN The relationships between weight, speed, and kinetic energy have significant practical consequences for the brake system engineer. If vehicle A weighs twice as much as vehicle B, it needs a brake system that is twice as powerful. But if vehicle C has twice the speed potential of vehicle D, it needs brakes that are, not twice, but four times more powerful.

INERTIA

Although brake engineers take both weight and speed capability into account when designing a brake system, these are not the only factors involved. Another physical property, inertia, also affects the braking process and the selection of brake components. **Inertia** is defined by Isaac Newton's first law of motion, which states that a body at rest tends to remain at rest, and a body in motion tends to remain in motion in a straight line unless acted upon by an outside force.

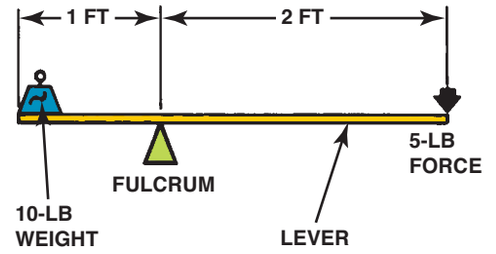


FIGURE 13–7 A first-class lever increases force and changes the direction of the force.

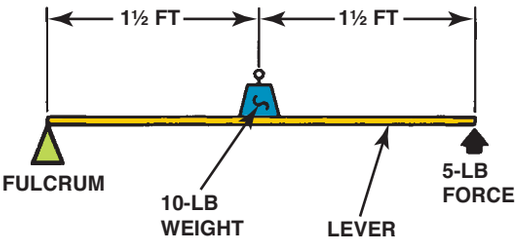


FIGURE 13–8 A second-class lever increases force in the same direction as it is applied.

MECHANICAL PRINCIPLES

The primary mechanical principle used to increase application force in every brake system is **leverage.** In the science of mechanics, a lever is a simple machine that consists of a rigid object, typically a metal bar that pivots about a fixed point called a **fulcrum.** There are three basic types of levers, but the job of all three is to change a quantity of energy into a more useful form.

A **first-class lever** increases the force applied to it and also changes the direction of the force. ● **SEE FIGURE 13–7.**

With a first-class lever, the weight is placed at one end while the lifting force is applied to the other. The fulcrum is positioned at some point in between. If the fulcrum is placed twice as far from the long end of the lever as from the short end, a 10-pound weight on the short end can be lifted by only a 5-pound force at the long end. However, the short end of the lever will travel only half as far as the long end. Moving the fulcrum closer to the weight will further reduce the force required to lift it, but it will also decrease the distance the weight is moved.

A **second-class lever** increases the force applied to it and passes it along in the same direction. ● **SEE FIGURE 13–8.**

With a second-class lever, the fulcrum is located at one end while the lifting force is applied at the other. The weight is positioned at some point in between. If a 10-pound weight is placed at the center of the lever, it can be lifted by only a 5-pound force at the end of the lever. However, the weight will only travel half the distance the end of the lever does. As the weight is moved closer to the fulcrum, the force required to lift it, and the distance it travels, are both reduced.

A **third-class lever** actually reduces the force applied to it, but the resulting force moves farther and faster. ● **SEE FIGURE 13–9.**

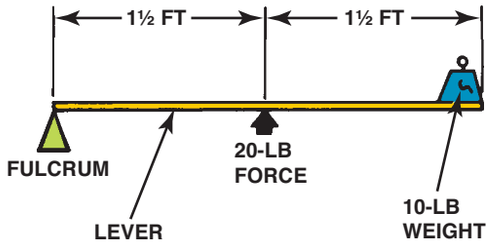


FIGURE 13–9 A third-class lever reduces force but increases the speed and travel of the resulting work.

With a third-class lever, the fulcrum is located at one end and the weight is placed at the other. The lifting force is applied at some point in between. If a 10-pound weight is placed at the end of the lever, it can be lifted by a 20-pound force applied at the middle of the lever. Although the force required to move the weight has doubled, the weight is moved twice as far and twice as fast as the point on the lever where the force was applied. The closer to the fulcrum the lifting force is applied, the greater the force required by the weight and the farther and faster the weight will move.

The levers in brake systems are used to increase force, so they are either first- or second-class. Second-class levers are the most common, and the service brake pedal is a good example. In a typical suspended brake pedal, the pedal arm is the lever, the pivot point is the fulcrum, and the force is applied at the foot pedal pad. ● **SEE FIGURE 13–10.** The force applied to the master cylinder by the pedal pushrod attached to the pivot is much greater than the force applied at the pedal pad, but the pushrod does not travel nearly as far.

Leverage creates a **mechanical advantage** that, at the brake pedal, is called the **pedal ratio.** For example, a pedal ratio of 5 to 1 is common for manual brakes, which means that a force of 10 pounds at the brake pedal will result in a force of 50 pounds at the pedal pushrod. In practice, leverage is used at many points in both the service and parking brake systems to increase braking force while making it easier for the driver to control the amount of force applied.

HEAT AND TEMPERATURE

Heat and temperature are related but are not the same. Temperature is the intensity of the heat source, whereas heat is the quantity of heat. For example, the heat from a match and a large fire may measure the same temperature, but the amount of heat generated by the fire is far greater than the amount of heat generated by a single match.

HEAT Heat is measured in units called **British Thermal Units,** abbreviated **BTUs.** One BTU is the amount of heat needed to raise the temperature of one pound of water one degree Fahrenheit. For example, room heaters and air conditioners are rated in how many BTUs per hour can be added (heater) or removed (air conditioner) from a space in one hour.

Heat energy can be transferred by three ways, including:

- **Conduction**—Conduction is the process of the heat traveling from a hotter part to a colder part of the same object or by direct contact. For example, if one end of a steel bar is heated, then the heat will travel by conduction toward the colder areas of the bar. Also, if the metal were touched, heat would travel from the steel bar to the finger. Metals are good conductors of heat, whereas plastic, rubber, and ceramics are poor conductors of heat and are called **insulators.**

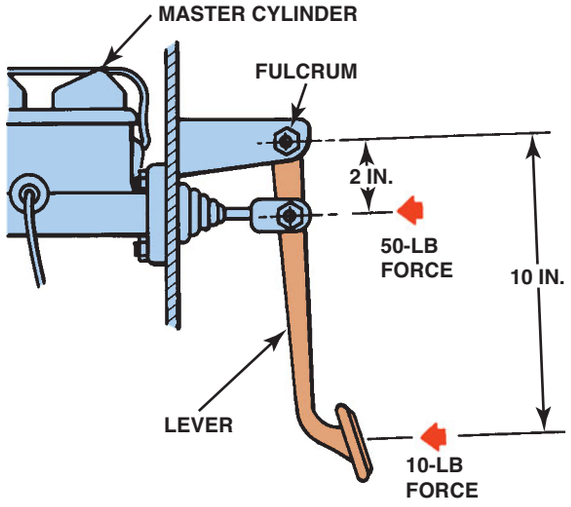


FIGURE 13–10 This brake pedal assembly provides a 5:1 mechanical advantage because a 10-lb force input results in a 50-lb force into the master cylinder.

TECH TIP

Conductors and Insulators

If a material is a good conductor of heat, it is also a good conductor of electricity. Most **conductors** are metals, such as steel, copper, aluminum, and brass. Most insulators are nonmetals, such as plastic and rubber. Therefore, if a material does not conduct heat, it usually will not conduct electricity.

FREQUENTLY ASKED QUESTION

How Does a Coat Keep You Warm?

A coat is worn in cold weather to keep warm. Does it keep the cold out or the heat in? Actually, both, but because heat travels from a warm object (human body) to a colder object (outside cold air), the primary purpose of a coat is to keep the body heat from escaping into the cold air.

- **Convection**—Convection is the transfer of heat through a liquid or a gas, which causes it to rise while the cooler liquid or gas falls within a container. A hot air balloon is an example where hot gas in the balloon causes it to rise above the surrounding cooler air.
- **Radiation**—Radiation is a method of energy transfer where heat is transmitted through the air. Heat from the sun is transmitted through the atmosphere where it heats the ground. Heat can be felt above a hot stove.

TEMPERATURE Temperature is the measurement of the ability to give up or absorb heat from another body. Heat always flows from a warmer object to a colder object.

Temperature is measured using two scales:

1. **Celsius** (also called **centigrade**). The Celsius scale was devised by taking the freezing point and the boiling point of water and dividing it into 100 equal parts.

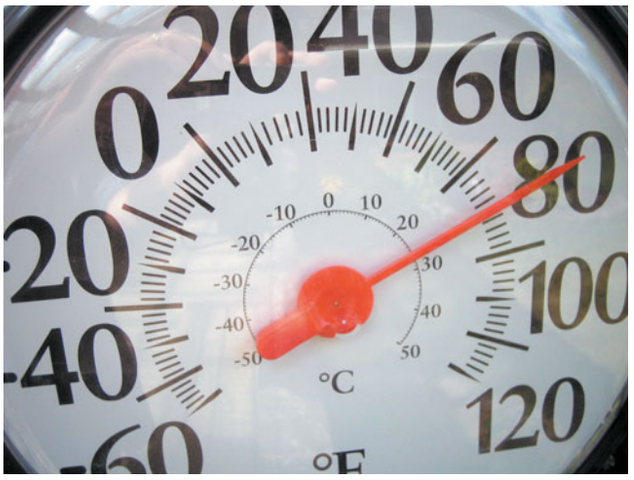


FIGURE 13–11 A typical outdoor thermometer which is used to measure temperature, not heat.

TECH TIP

Quick and Easy Temperature Conversion

Many service information and scan tool data are expressed in degrees Celsius, which is often confusing to those used to temperature expressed in Fahrenheit degrees. A quick and easy way to get an *approximate* conversion is to take the degrees in Celsius, double it, and add 25.

For example,

Celsius × 2 + 25 = approximate Fahrenheit degrees:

0°C × 2 = 0 + 25 = 25°F (actual = 32°F)
10°C × 2 = 20 + 25 = 45°F (actual = 50°F)
15°C × 2 = 30 + 25 = 55°F (actual = 59°F)
20°C × 2 = 40 + 25 = 65°F (actual = 68°F)
25°C × 2 = 50 + 25 = 75°F (actual = 77°F)
30°C × 2 = 60 + 25 = 85°F (actual = 86°F)
35°C × 2 = 70 + 25 = 95°F (actual = 95°F)
40°C × 2 = 80 + 25 = 105°F (actual = 104°F)
45°C × 2 = 90 + 25 = 115°F (actual = 113°F)
50°C × 2 = 100 + 25 = 125°F (actual = 122°F)

2. **Fahrenheit.** The Fahrenheit scale was developed by Gabriel Fahrenheit (1686–1736), a German physicist who proposed the scale in 1724. He wanted to avoid using negative numbers, so the scale used had zero degrees representing the coldest outside air temperature he had ever measured and used his own body temperature to represent 100 degrees. Later, more accurate measurements indicate that average human body temperature to be 98.6 degrees so he was off by 1.4 degrees. Also, negative outside air temperatures can occur. ● **SEE FIGURE 13–11** and the comparison chart.

Temperature Symbol	Degree Celsius °C	Degree Fahrenheit °F
Boiling point of water	100.0	212.0
Average human body temperature	37.0	98.6
Average room temperature	20.0 to 25.0	68.0 to 77.0
Melting point of ice	0.0	32.0

FREQUENTLY ASKED QUESTION

What Is Thermodynamics?

Thermodynamics is the study of the relationship among temperature, pressure, and volume changes. The laws of thermodynamics help engineers design and develop engines with higher efficiency. Thermodynamics is therefore used in the design of the cooling system, as well as in the engine, because the more heat created by the burning of fuel in the engine, the more power the engine can develop using the same or less amount of fuel.

FREQUENTLY ASKED QUESTION

Can Water and Acid Be Mixed Together?

Acids have a very strong affinity for water and as a result, if water is poured into acid, the resulting reaction would be extremely violent and acid would be forced outward in all directions. Always pour acid into water, never water into acid.

Technicians seldom need to work with acids because even battery electrolytes from the water and acid are premixed to help prevent the possibility of a technician creating a harmful reaction.

ACIDS AND BASES

ACIDS Acids are substances that can corrode metals and some can cause severe burns to the skin. Common household acids that are not harmful and taste sour include vinegar and lemon juice (citric acid). Stronger acids include:

- Hydrochloric acid
- Nitric acid
- Battery acid

BASES A base is a substance that can also burn the skin if strong enough and is also referred to as **alkaline.** Common household bases are generally not harmful unless eaten and have a bitter taste, including baking soda, soap, and antacid, such as Milk of Magnesia®. Stronger bases, which can burn the skin include:

- Lye (sodium hydroxide)
- Bleach
- Drain cleaner

pH SCALE Most chemical cleaners used for cleaning carbon-type deposits are a strong soap, or **caustic material.** A value called **pH,** measured on a scale from 1 to 14, is used to indicate the amount of chemical activity. The term *pH* is from the French word *pouvoir hydrogine,* meaning "hydrogen power." Pure water is neutral. On the pH scale, water is pH 7. Caustic materials have pH numbers from 8 through 14. The higher the number, the stronger the caustic action will be. **Acid materials** have pH numbers from 6 through 1. The lower the number, the stronger the acid action will be. Caustic materials and acid materials neutralize each other, such as when baking soda (a caustic) is used to clean the outside of the battery

(an acid surface). The caustic baking soda neutralizes any sulfuric acid that has been spilled or splashed on the outside of the battery.

CAUTION: Whenever working with chemicals, eye protection must be used.

GAS LAWS

Gas laws are a set of characteristics that describe how gases act and the relationship between their temperature, pressure, and volume. Gas laws have application in most systems of the vehicle, including tires, air-conditioning systems, and anywhere else gases are present.

BOYLE'S LAW Boyle's law was first written in 1662 by Robert Boyle (1627–1691) and describes the relationship between volume and pressure of a gas in a closed container. Boyle's law states that the volume of a gas varies inversely (opposite) with the pressure exerted against it in a closed container. Therefore, if a closed container is compressed, the volume of the gas inside is reduced but the pressure is increased.

CHARLES'S LAW Charles's Law was first formulated about 1787 by a French scientist, Jacque Charles (1746–1823). According to Charles's law when the temperature of a gas increases, the volume increases. When the temperature of a gas decreases, the volume decreases.

SOUND AND ACOUSTICS

Sound is the movement of air which the ear interprets as sound. Sound travels through the air, which is called **propagation.** Propagation of sound is normally thought to be only transmitted through air, but liquids can also transmit sound waves. Sound has two properties:

- **Frequency.** This is also called the pitch of the sound and is measured in Hertz or cycles per second. Normal hearing frequency ranges from as low as 20 Hertz to 20,000 Hertz. Very low frequencies, such as the heart beat, of one or two Hertz cannot be heard. High frequencies over 20,000 Hertz also cannot be detected by humans.
- **Intensity.** The intensity of sound, which is also called loudness, is measured in decibels (dB) named for Alexander Graham Bell (1847–1922), the inventor of the telephone. Relative intensity (loudness), using the decibel scale, includes the following examples:
  - Whisper 10–20 dB
  - Normal conversation 60 dB
  - Thunder 110 dB
  - Threshold of pain 120 dB

ACOUSTICS Acoustics is the study of sound and how it is generated and transmitted. Acoustic engineers are employed by vehicle manufacturers to help reduce noise and designing methods to reduce or stop the noise from being transmitted into the passenger compartment. For example, according to acoustic engineers, about 80% of the noise created by the movement of the tires on the road is transmitted through the chassis and body of the vehicle. Only about 20% of the sound is transferred to the passenger compartment through the air.

TECH TIP

Wear Hearing Protection

According to audiologists (hearing and speech doctors), a person should wear ear protection if the level of sound requires that your voice be raised in order to be heard. Any level that exceeds 90 dB requires the use of ear protection to avoid hearing loss. This means that ear protection should be worn when using a power mower or using an air tool, such as an air impact wrench or air ratchet.

PLASTICS

There are two basic types of plastic.

THERMOSET PLASTIC This type of plastic is changed chemically when cured and shaped and cannot be reheated or reformed. Rubber is an example of a thermoset plastic material that cannot be remelted and reformed after curing. Other examples of thermoset plastics include:

- Bakelite (phenol formaldehyde resin)
- Polyester resin
- Epoxy resin

THERMOPLASTIC This type of plastic is flexible at room temperature. Thermoplastic can be recycled by grinding it into pieces and remolding it into another shape. Examples of thermoplastics include:

- Polyethylene (PE)
- Polyvinyl chloride (PVC)
- Polystyrene (PS)
- ABS (acrylonitrile butadiene styrene)
- PA nylon (polyamides)

PLASTIC IDENTIFICATION While it is not important for the average service technician to determine what kind of plastic is being used for what application, it is important to know when restoring a part or refinishing a plastic part. For example, interior plastic parts can be made from the following plastic material:

- Polypropylene plastic (PP)
- Polyethylene (PE) (● **SEE FIGURE 13–12**)
- ABS plastic
- ABS/PVC plastic
- Vinyl (PVC) plastic

Most large plastic pieces are labeled on the inside with letters, such as PP or PE. However, if no marking is visible, it is still possible to identify the type of plastic using a simple basic test. A painter will need to know the type of plastic if refinishing these parts. Often replacement plastic parts are available in only one color and must be painted to match the original when being replaced. A burn test is used to test if the plastic part is polypropylene or ABS plastic by performing the following steps:

STEP 1 Remove a small piece from a hidden back side of the plastic part being tested.

STEP 2 Hold the small piece of plastic with tweezers and ignite the plastic.

STEP 3 Observe the burning of the plastic:
- No visible smoke means that the plastic is polypropylene.
- Visible black smoke means that the plastic is ABS.



FIGURE 13–12 This interior plastic part is labeled PE-HD, which means polyethylene-high density.

STEP 4 To determine if a part to be painted is polyvinyl chloride, a copper wire test needs to be performed by heating a copper wire and then touching the heated wire to a hidden back side surface of the part being tested. After melting some plastic onto the copper wire, return the wire to the flame and observe the color of the flame. If the color of the flame is green/blue or turquoise, then the plastic is polyvinyl chloride (vinyl).

After the type of plastic has been identified, then check with service information and paint literature to determine the proper paint and preparations needed to refinish the plastic part.

IRON AND STEEL

Iron is a chemical element with a symbol of Fe. It is one of the most commonly available elements on earth and is refined from iron ore. Steel is made from iron after further refining. The main difference between iron and steel is the amount of carbon. The amount of carbon is critical to the strength and characteristics of iron and steel.

CAST IRON Cast iron contains 2% to 4% carbon and this carbon is usually in the shape of flakes of graphite 0.001 to 0.004 inches long. Cast iron is used in many automotive applications, including engine blocks, rear axle assemblies, and some suspension components.

DUCTILE CAST IRON In ductile iron, the carbon in the alloy with silicon are small ball-shapes called spherloidols. Ductile iron is also called malleable iron and is used to make crankshafts.

GRAY CAST IRON Gray cast iron is cast iron that has another element, silicon, in the alloy giving the metal a gray color. Gray cast iron is used for engine blocks.

NOTE: Cast iron contains graphite, which acts as a lubricant when being machined. As a result, cooling oil or water is not needed when making cast iron brake rotors or brake drums.

SAE STEEL DESIGNATIONS

Steels are designed by a system established by the Society of Automotive Engineers and includes numbers to indicate the main element used in the alloy, plus the "points of carbon." One part of carbon is 0.01%. In other words, 100 points of carbon is equal to 1%. The percentage of carbon in steel has a huge input on the strength and characteristics of the steel. For example,

- **Mild (low carbon) steel** has less than 20 points of carbon (0.02%). Mild steel is soft and easily formed but is not very strong. Common usage of low carbon steel is in tables and chairs and vehicle body parts where strength is not an issue.
- **Medium carbon steel** usually has between 25 and 50 points of carbon (0.25% and 0.50%). This type of steel can be heat treated to create steel that is ductile (flexible) and yet has good strength. This type of steel is usually used in forgings and machined components.
- **High carbon steel** usually has between 60 and 100 points (0.60% and 1.00%) of carbon and is very strong. It is commonly used in vehicle springs and can be hardened.

CAUTION: Both medium carbon and high carbon steel can be hardened by heating and then cooling, using water or oil to rapidly cool the metal. Therefore, if heating any metal, always allow it to cool slowly to avoid changing the hardness of the steel.

The SAE numbering designation usually includes four numbers:

- The first two numbers indicate the type of alloy which could include several alloy elements.
- The last two numbers designate the points of carbon.

1xxx = plain carbon steels
2xxx = nickel steels
3xxx = nickel-chromium steels
4xxx = molybdenum steels
5xxx = chromium steels
6xxx = chromium-vanadium steels
7xxx = tungsten-chromium steels
9xxx = silicon-manganese steels

A commonly used alloy for forged crankshafts is SAE 4340. The analysis of this designation is: 4340 = An alloy that contains 1.82% nickel, 0.5% to 0.8% chromium, and 0.25% molybdenum with 40 points of carbon.

ALUMINUM AND ALUMINUM ALLOYS

Aluminum is a lightweight metal that is used in many automotive applications, including suspension components, engine blocks, and cylinder heads. Aluminum is almost always combined with small quantities of other metals to form an alloy, using copper, manganese, zinc, or silicon. Aluminum and aluminum alloys that are mechanical shaped are called **wrought alloys** and are labeled according to the International Alloy Designation system. The system uses a four-digit number, which identifies the alloying elements, followed by a dash (-) and then a letter identifying the type of heat treatment. This is followed by a number identifying the specific hardness or temper of the finished alloy. A typical example would be 6061-T6. The 6061 is a 6000 series alloy with magnesium and silicon. The "61" further identifies other elements and their percentages. The numbering system for cast aluminum alloy is similar but is designed by standards of the Aluminum Association (AA).

REVIEW QUESTIONS

1. What is kinetic energy?
2. How is mechanical advantage used in the braking system?
3. What is the difference between torque and power?
4. How can a burn test help identify the type of plastic used?
5. What is the pH of acids and bases?

CHAPTER QUIZ

1. All of the following are correct statements about braking *except:*
   a. Kinetic energy must be absorbed by the braking system.
   b. Kinetic energy of a vehicle doubles when the speed doubles.
   c. The heavier the vehicle, the greater the kinetic energy when moving.
   d. If the vehicle weight is doubled, the kinetic energy of a moving vehicle is doubled.
2. The brake pedal assembly uses a mechanical lever to _____.
   a. Increase the driver's force on the brake pedal applied to the master cylinder.
   b. Decrease the distance the brake pedal needs to be depressed by the driver.
   c. Decrease the driver's force on the brake pedal applied to the master cylinder.
   d. Allow for clearance between the brake pedal and the floor when the brakes are applied.
3. Technician A says that work is being performed if a force is being applied, yet the object does not move. Technician B says that torque is a twisting force that may or may not result in motion. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
4. Two technicians are discussing engine horsepower and torque figures. Technician A says that torque is measured on a dynamometer. Technician B says that horsepower is measured on a dynamometer. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
5. An example of a lever and mechanical advantage used on a vehicle is the _____.
   a. Radio volume control **c.** Fuel tank
   b. Brake pedal **d.** Battery
6. Two technicians are discussing temperature and heat. Technician A says that temperature is the intensity of the heat source. Technician B says that heat is the amount of heat. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
7. Heat can move or travel by _____.
   a. Conduction **c.** Radiation
   b. Convection **d.** All of the above
8. Technician A says that zero degrees Celsius is the freezing temperature of water. Technician B says that 100 degrees Celsius is the boiling temperature of water. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
9. Technician A says that pure (distilled) water has a pH of 7. Technician B says that the pH of acids is less than 7. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
10. Technician A says that the kinetic energy of a vehicle is proportional to its weight. Technician B says that the kinetic energy of a moving vehicle is directly proportional to its speed. Which technician is correct?
    a. Technician A only **c.** Both Technicians A and B
    b. Technician B only **d.** Neither Technician A nor B

chapter 14

MATH, CHARTS, AND CALCULATIONS

OBJECTIVES: After studying Chapter 14, the reader will be able to: • Add and subtract decimal numbers. • Read a chart and graph. • Calculate percentages. • Explain how to work with fractions. • Demonstrate how to multiply and divide. • Discuss ratios. • Calculate fuel economy.

KEY TERMS: Chart 118 • Decimal point 115 • Diagram 118 • Direct drive 117 • Drive gear 117 • Driven gear 117 • Fractions 116 • Gear reduction 117 • Graph 117 • Overdrive 117 • Percentage 115 • Scientific notation 115 • Variable 117

DECIMALS

Decimals are commonly used by service technicians. The placement of the decimal point indicates the value of the number. The naming of decimals includes tenths, hundredths, thousandths, and higher. Decimals are used to represent fractions of a unit by using a dot called a **decimal point** to indicate that the number is a decimal.

TENTHS A decimal with one number to the right of the decimal point indicates an accuracy of 1/10 or 0.1. For example, 0.7 is the same as 7/10 and is pronounced "seven tenths" or "zero point seven." A decimal can also include numbers larger than zero, but has a resolution or accuracy measured in tenths, such as in 14.7.

HUNDREDTH Decimals with two numbers to the right of the decimal point indicate an accuracy to 1/100 or 0.01. For example, 0.47 is pronounced "forty-seven hundredth" or "zero point four seven."

THOUSANDTH A decimal with three numbers to the right of the decimal point indicates an accuracy to 1/1000 or 0.001. For example, 0.867 is pronounced "eight hundred sixty-seven thousandth" or "zero point eight six seven."

ADDING AND SUBTRACTING DECIMALS When adding or subtracting decimals, the decimal point has to be aligned. This ensures that the numbers are placed into the correct position of tenth, hundredth, and thousandth. For example:

$$\begin{array}{r} 0.147 \\ +\ 0.02 \\ \hline 0.167 \end{array}$$

Notice that the top number is expressed in thousandths and the lower number is expressed in hundredths. The final figure is also shown in thousandths.

NOTE: If these numbers were measurements, the first result cannot be more accurate than the least accurate measurement. This means that the final result should be expressed in hundredths instead of thousandths.

When subtracting or multiplying decimals, keep the decimal points aligned or use a calculator making certain to include the decimal point.

PERCENTAGE

Percentage is the relationship of a value or number out of 100. Using money as an example, three quarters (25 cents each) equals 75 cents ($0.75) or 75% of a dollar ($1.00). Many examples are not that easy, for example, 70 is what percentage of 120? To determine the percentage, divide the first number (70) by the second number (120).

$$70 \div 120 = 0.58$$

To convert this number to a percentage, multiply the number by 100 or move the decimal point two places to the right (58) and then add a percentage symbol to indicate that the number is a percentage (58%).

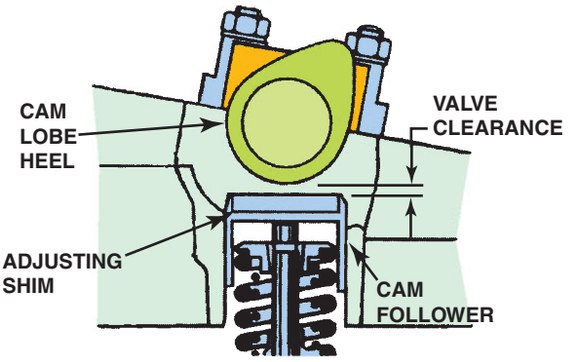


FIGURE 14–1 Valve clearance allows the metal parts to expand and maintain proper operation, both when the engine is cold or at normal operating temperature. Adjustment is achieved by changing the thickness of the adjusting shim.

SCIENTIFIC NOTATION

Very large and very small decimal numbers are frequently expressed using scientific notation. **Scientific notation** is written as a number multiplied by the number of zeros to the right or left of the decimal point. For example, 68,000 could be written as 6.8×10^4, indicating that the number shown has 3 zeros plus the 8 to the right of the decimal point. Small numbers, such as 0.00068, would use a negative sign beside the number over the 10 to represent that the decimal point needs to be moved toward the left (6.8×10^{-4}).

ADDING AND SUBTRACTING

Technicians are often required to add or subtract measurements when working on vehicles. For example, adding and subtracting is needed to select shims (thin pieces of steel) for adjusting valve clearance or differential preload measurements.

For example, if the valve clearance specification is 0.012 in. and the clearance is actually 0.016 in., and the shim that is in place between the camshaft lobe and the valve bucket is 0.080 in. thick, what size (thickness) of shim needs to be installed to achieve the correct valve clearance?

Solution: The shim thickness of 0.080 in. results in a valve clearance of 0.016 in. The specification requires that the shim needs to be thicker to reduce the valve clearance. ● **SEE FIGURE 14–1.**

To determine the thickness of a shim, the amount of clearance needed to be corrected needs to be calculated. The original clearance is 0.016 in. and the specification is 0.012 in. The difference is determined by subtracting the actual clearance from the specified clearance:

$$0.016 - 0.012 = 0.004 \text{ in.}$$

The result (0.004 in.) then needs to be added to the thickness of the existing shim to determine the thickness of the replacement shim needed to achieve the correct valve clearance.

$$\begin{array}{rl} \textbf{Existing shim thickness} = & \textbf{0.080 in.} \\ \textbf{Additional thickness needed} = + & \textbf{0.004 in.} \\ \textbf{Thickness of new shim} = & \textbf{0.084 in.} \end{array}$$

FRACTIONS

Fractions, such as 1/2, 1/4, or 5/8 are commonly found in specifications for hose inside diameter measurements. A tape measure or machinists rule can be used to measure the fitting or the original part. Sometimes, fractions need to be converted to decimal units if the replacement parts are offered by that measurement method. When comparing fractions to decimal units, think about the number of cents in a dollar.

1/2 dollar = 50 cents

Quarter = 25 cents

1/10 (dime) = 10 cents

1/20 (nickel) = 5 cents

Other fractions, such as 3/8, 5/8, and 5/16 are harder to determine. If a chart is not available, divide the bottom number, called the denominator into the top number, called the numerator.

3/8 = 3 divided by 8 = 0.375

5/8 = 5 divided by 8 = 0.625

5/16 = 5 divided by 16 = 0.3125

MULTIPLYING AND DIVIDING

Multiplying by a service technician is usually done to determine gear ratios and to determine the total of many of the same items. For example, the final overall gear ratio is determined by multiplying the transmission gear ratio by the final drive ratio and is covered later in this chapter.

Dividing is commonly done when calculating total resistance of many resistances connected in parallel. In this situation, the value of the resistance is divided by the number of equal resistances. For example, if four bulbs with a resistance of 0.4 ohm were connected in parallel, the total resistance would be just 0.1 ohm (0.4 ÷ 4 = 0.1).

MATHEMATICAL FORMULAS

A formula uses letters to represent values or measurements and indicates how these numbers are to be multiplied, divided, added, or subtracted. To use a formula, the technician needs to replace the letters with the actual number and perform the indicated math functions.

For example, a formula used to determine engine speed in revolutions per minute (RPM) and is represented by the following formula:

$$\text{RPM} = \frac{\text{mph} \times \text{gear ratio} \times 336}{\text{tire diameter (inches)}}$$

This formula is used to determine the speed of the engine compared to the gear ratio and tire size. Sometimes, wheel and tire sizes are changed and knowing this is helpful.

To calculate the engine speed, the actual information needs to be placed into the formula.

Mph = 70 mph
Gear ratio = 2:41:1
Tire diameter = 26 inches

? FREQUENTLY ASKED QUESTION

How Is Metric Fuel Economy Measured?

In the United States fuel economy is expressed in miles per gallon. Outside of the United States, fuel economy is measured in the number of liters of fuel needed to travel 100 kilometers (62 miles), abbreviated L/100 km. This means that as the number increases, the fuel economy decreases. For example:

MPG	L/100 km
5	47.0
10	23.5
15	15.7
20	11.8
25	9.4
30	7.8
35	6.7
40	5.9
45	5.2
50	4.7

In the metric system, the fuel is measured; in the United States, the miles are measured.

Replacing the terms with the actual numbers results in the following:

$$\text{RPM} = \frac{70 \times 2.41 \times 336}{26} = \frac{5668}{26} = 2180 \text{ RPM}$$

FUEL ECONOMY CALCULATOR

To calculate fuel economy in miles per gallons, two factors must be known:

1. How far was the vehicle driven.
2. How many gallons of fuel were needed.

This calculation requires that the fuel tank be filled two times; first at the start of the test and then at the end of the test distance. For example:

STEP 1 Fill the tank until the nozzle clicks off.

NOTE: Try to use the same station and pump, if possible, to achieve the most accurate results.

STEP 2 Drive a reasonable distance. For the example, 220 miles were traveled.

STEP 3 Fill the fuel tank and record the number of gallons used. For this example, exactly 10.0 gallons were needed to refill the tank.

STEP 4 Calculate fuel economy: MPG = Miles driven divided by the number of gallons used.

MPG = 220 divided by 10.0 = 22.0 miles per gallon

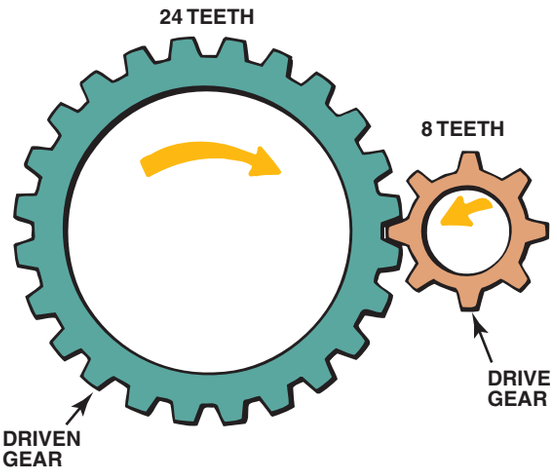


FIGURE 14–2 The drive gear is attached or is closer to the power source and rotates or drives the driven gear.

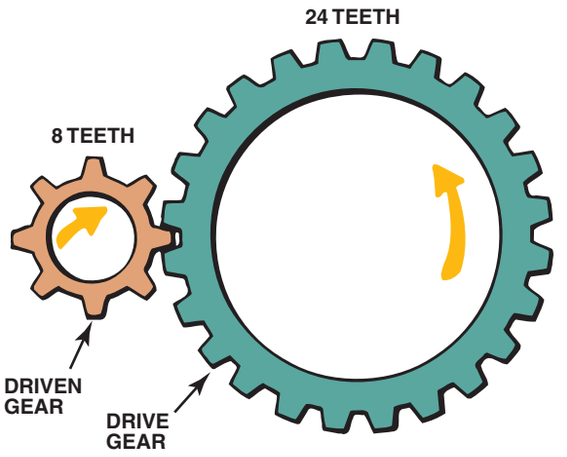


FIGURE 14–3 If the driven gear is rotating faster than the drive gear, it is called an overdrive ratio.

GEAR RATIOS

When one gear turns another, the speed that the two gears turn in relation to each other is the gear ratio. Gear ratio is expressed as the number of rotations the **drive gear** must make in order to rotate the **driven gear** through one revolution. To obtain a gear ratio, simply divide the number of teeth on the driven gear by the number of teeth on the drive gear. Gear ratios, which are expressed relative to the number one, fall into three categories:

- Direct drive
- Gear reduction
- Overdrive

DIRECT DRIVE

If two meshed gears are the same size and have the same number of teeth, they will turn at the same speed. Since the drive gear turns once for each revolution of the driven gear, the gear ratio is 1:1; this is called a **direct drive.** When a transmission is in direct drive, the engine and transmission turn at the same speed.

GEAR REDUCTION

If one gear drives a second gear that has three times the number of teeth, the smaller drive gear must travel three complete revolutions in order to drive the larger gear through one rotation. ● **SEE FIGURE 14–2.** Divide the number of teeth on the driven gear by the number of teeth on the drive gear and you get a 3:1 gear ratio (pronounced three to one). This type of gear arrangement, where driven gear speed is slower than drive gear speed, provides **gear reduction.** Gear reduction may also be called underdrive as drive speed is less than, or under, driven speed. Both terms mean the same thing and use is a matter of preference.

Gear reduction is used for the lower gears in a transmission. First gear in a transmission is called "low" gear because output speed, not gear ratio, is low. Low gears have numerically high gear ratios. That is, a 3:1 gear ratio is a lower gear than those with a 2:1 or 1:1 gear ratio. These three ratios taken in order represent a typical upshift pattern from low gear (3:1), to second gear (2:1), to third gear (1:1).

OVERDRIVE

Overdrive is the opposite of a gear reduction condition and occurs when a driven gear turns faster than its drive gear. For the gears shown in **FIGURE 14–3,** the driven gear turns three times for each turn of the drive gear. The driven gear is said to overdrive the drive gear. For this example, the gear ratio is 0.33:1.

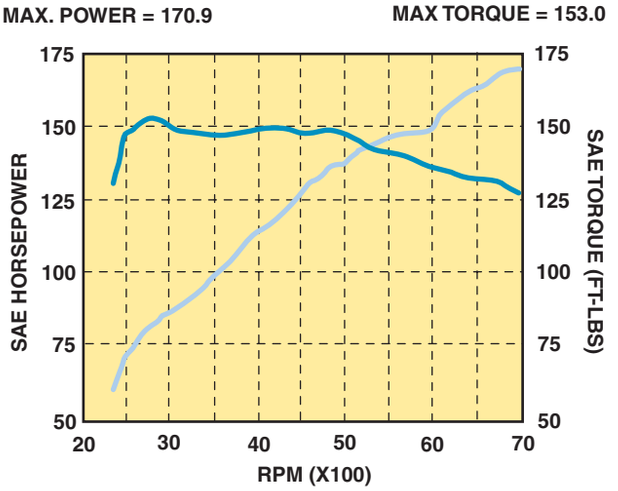


FIGURE 14–4 A graph showing horsepower and torque. Notice that the curves cross at 5252 RPM or a little bit to the right of the 50, which is expressed as the graph number multiplied by 100. Example is 52 multiplied by 100 equals 5200 RPM. The torque and horsepower curves cross at 5252 RPM because torque is measured by a dynamometer and then horsepower is calculated using a formula which causes both values to be the same at that one engine speed.

Overdrive ratios of 0.65:1 and 0.70:1 are typical of those used in automotive applications.

NOTE: Ratios always end in 1 with a colon in between. Therefore, the first number is less than 1 if it is an overdrive ratio and greater than 1 if it is a gear reduction ratio.

GRAPHS, CHARTS, AND DIAGRAMS

GRAPH READING

A **graph** is a visual display of information. Graphs are commonly used in the automotive service industry to illustrate trends or specifications along with time or some other variable. A **variable** is a measurement of something that changes, such as engine speed or time. A graph has two variables displayed. One variable changes from left to right on the horizontal axis. This is called the X axis. The other variable is displayed on the vertical axis, called the Y axis.

A graph is created by making a series of dots at various locations and then connecting the dots with a line. ● **SEE FIGURE 14–4.**

RANGE	GEAR	2–4 BAND	REVERSE INPUT CLUTCH	OVERRUN CLUTCH	FORWARD CLUTCH	FORWARD SPRAG CL. ASSEMBLY	3–4 CLUTCH	LO-ROLLER CLUTCH	LO-REV. CLUTCH
PARK-NEUTRAL									
OVERDRIVE	FIRST GEAR				APPLIED	HOLDING		HOLDING	
	SECOND GEAR	APPLIED			APPLIED	HOLDING			
	THIRD GEAR				APPLIED	HOLDING	APPLIED		
	FOURTH GEAR	APPLIED			APPLIED		APPLIED		
DRIVE	FIRST GEAR			APPLIED	APPLIED	HOLDING		HOLDING	
	SECOND GEAR	APPLIED		APPLIED	APPLIED	HOLDING			
	THIRD GEAR			APPLIED	APPLIED	HOLDING	APPLIED		
MANUAL 2ND	FIRST GEAR			APPLIED	APPLIED	HOLDING		HOLDING	
	SECOND GEAR	APPLIED		APPLIED	APPLIED	HOLDING			
MANUAL 1ST	FIRST GEAR			APPLIED		HOLDING		HOLDING	APPLIED
REVERSE	REVERSE		APPLIED						APPLIED

FIGURE 14–5 A typical chart showing what is applied in what gear in an automatic transmission.

INTERPRETING A GRAPH. To interpret a graph, select a point along the horizontal axis (X axis) and then look directly above the point where the line appears. Mark this spot and then look directly to the left along the vertical axis (Y axis) to see what value is represented by the points on the graph.

CHART READING

A **chart** is used to represent data, such as numbers or specifications, along with another variable, such as model or year of vehicle. A chart is very useful for showing many different specifications or other facts in an easy-to-read format. ● **SEE FIGURE 14–5** for an example of a transmission specifications chart, which shows the transmission parts listed along the horizontal axis (X axis) and gear of the automatic transmission along the vertical or Y axis.

INTERPRETING A CHART. A chart can look complicated but if studied, it is easy to interpret. Start by looking along the horizontal or vertical axis for the information, such as the range of the transmission down the left column. Then look to the right to find which device is being used to achieve that transmission drive range.

DIAGRAM READING

A **diagram** is a graphic design that explains or shows the arrangement of parts. Diagrams are commonly used in the automotive service industry to show how a component is assembled and in which order the parts are placed together. ● **SEE FIGURE 14–6** for an example.

INTERPRETING A DIAGRAM A diagram usually shows the relationship of many parts. Lines are used to show the centerline of the part and the identity of the part is often shown as a number or letter. A separate chart or area of the diagram needs to be looked at to determine the name of the part. Diagrams are most helpful when disassembling or assembling a component, such as a transmission.

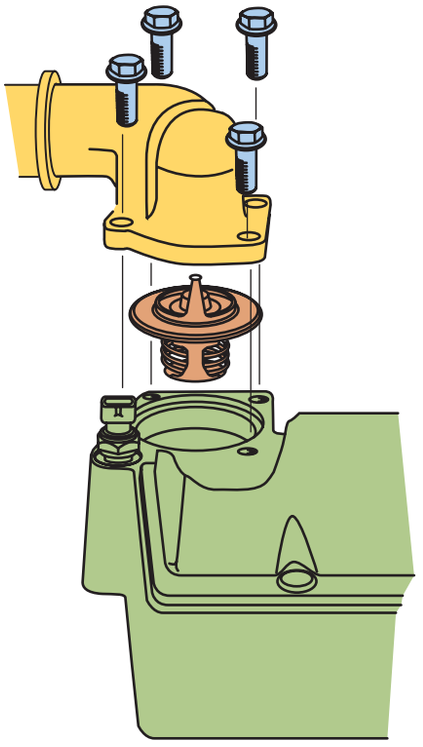


FIGURE 14–6 An exploded view showing how the thermostat is placed in the engine.

For best results, use electronic information and print out the diagram so it can be written on and can be thrown away when the repair has been completed. This process also helps prevent getting grease on the pages of a service manual.

REVIEW QUESTIONS

1. What is the formula for determining fuel economy?
2. Why are the torque and horsepower of an engine equal at 5252 RPM?
3. What service operation may require the technician to add and subtract?
4. What service operation may require the technician to multiply or divide?
5. How is fuel economy expressed in the metric system?
6. What math function is needed to calculate the overall gear ratio if the transmission and differential ratios are both known?

CHAPTER QUIZ

1. Ten of 30 vehicles checked during a safety inspection had at least one tire that was under inflated. This represents what percentage of the vehicles?
   a. 25% **c.** 43%
   b. 33% **d.** 67%
2. Which of the following shows the relationship of parts?
   a. Chart **c.** Diagram
   b. Graph **d.** Schematic
3. Add 0.102 in. and 0.080 inch. The answer is _____.
   a. 0.182 inch **c.** 0.0082 inch
   b. 0.1082 inch **d.** 0.8200 inch
4. Which is the largest?
   a. 1/10 **c.** .375
   b. .25 **d.** 1/50
5. What is 26 out of 87 in percentage?
   a. 33.5% **c.** 29.89%
   b. 11.3% **d.** 61.0%
6. What number is being represented by the scientific notation 6.28×10^3?
   a. 6.28 **c.** 6,280
   b. 628 **d.** 62,800
7. 3/16 is what number in decimal form?
   a. 0.1875 **c.** 0.5333
   b. 1.875 **d.** 5.333
8. How is 0.183 pronounced?
   a. One hundred eighty-three thousandth
   b. One thousand eighty-three
   c. Zero dot one hundred and eighty-three hundredths
   d. One tenth and 83 hundredths
9. Metric fuel economy is measured in what units?
   a. Miles per gallon
   b. Miles per kilometer
   c. Liters per 100 kilometers
   d. Kilometers per liter
10. Which is the smallest?
    a. 1/16 **c.** 3/8
    b. .25 **d.** .33

SECTION V Vehicle Service Information, Identification, and Routine Maintenance

15 Service Information
16 Vehicle Identification and Emission Ratings
17 Preventative Maintenance and Service Procedures

chapter 15 SERVICE INFORMATION

OBJECTIVES: After studying Chapter 15, the reader should be able to: • Discuss the importance of vehicle history. • Retrieve vehicle service information. • Read and interpret service manuals and electronic service information. • Describe the use of the vehicle owner's manual.

KEY TERMS: Julian date 123 • Labor guides 122 • Service information 120 • Technical service bulletin (TSB) 122



FIGURE 15–1 The owner's manual has a lot of information pertaining to the operation as well as the maintenance and resetting procedures that technicians often need.

VEHICLE SERVICE HISTORY RECORDS

Whenever service work is performed, a record of what was done is usually kept on file by the shop or service department for a number of years. The wise service technician will check the vehicle service history if working on a vehicle with an unusual problem. Often, a previous repair may indicate the reason for the current problem or it could be related to the same circuit or components. For example, a collision could have caused hidden damage that can affect the operation of the vehicle. Knowing that a collision had been recently repaired may be helpful to the technician.

OWNER'S MANUALS

It has been said by many automotive professional technicians and service advisors that the owner's manual is not read by many vehicle owners. Most owner's manuals contain all or most of the following information.

1. How to reset the maintenance reminder light
2. Specifications, including viscosity of oil needed and number of quarts (liters)
3. Tire pressures and standard as well as optional tire sizes
4. Maintenance schedule for all fluids, including coolant, brake fluid, automatic transmission fluid, and differential fluid
5. How to program the remote control as well as the power windows and door locks
6. How to reset the tire pressure monitoring system after a tire rotation

● **SEE FIGURE 15–1**

LUBRICATION GUIDES

Lubrication guides, such as those published by Chek-Chart and Chilton, include all specifications for lubrication-related service including:

- Hoisting location
- Lubrication points
- Grease and oil specifications
- Capacities for engine oil, transmission fluid, coolant and differential fluid

REAL WORLD FIX

Owner's Manual Is the Key to Proper Operation

A customer purchased a used Pontiac Vibe and complained to a shop that the cruise control would disengage and had to be reset if driven below 25 mph (40 km/h). The service technician was able to verify that in fact this occurred, but did not know if this feature was normal or not. The technician checked the owner's manual and discovered that this vehicle was designed to operate this way. Unlike other cruise control systems, those systems on Toyota-based vehicles are designed to shut off below 25 mph, requiring the driver to reset the desired speed. The customer was informed that nothing could be done to correct this concern and the technician also learned something. Vehicles that use the Toyota cruise control system include all Toyotas, plus Lexus, Pontiac Vibe, and Chevrolet Prism.

HINT: Some vehicle manufacturers offer owner's manuals on their website for a free download.

SERVICE MANUALS

Factory and aftermarket service manuals, also called shop manuals, contain specifications and service procedures. While factory service manuals cover just one year and one or more models of the same vehicle, most aftermarket service manuals cover multiple years and/or models in one manual.

Included in most service manuals are the following:

- Capacities and recommended specifications for all fluids
- Specifications including engine and routine maintenance items
- Testing procedures
- Service procedures including the use of special tools when needed
- Component location information

While some factory service manuals are printed in one volume, most factory **service information** is printed in several volumes due to the amount and depth of information presented. The typical factory service manual is divided into sections.

GENERAL INFORMATION General information includes topics such as:

- Warnings and cautions
- Vehicle identification numbers on engine, transmission/transaxle, and body parts
- Lock cylinder coding
- Fastener information
- Decimal and metric equivalents
- Abbreviations and standard nomenclature used
- Service parts identification label and process code information

TECH TIP

Exploded Views

Exploded views of components such as engines and transmissions are available in shop manuals and electronic service information, as well as in parts and labor time guides. These views, showing all of the parts as if the assembly was blown apart, give the service technician a clear view of the various parts and their relationship to other parts in the assembly.

TECH TIP

Print It Out

It is often a benefit to have the written instructions or schematics (wiring diagrams) at the vehicle while diagnosing or performing a repair. One advantage of a hard copy service manual is that it can be taken to the vehicle and used as needed. However, dirty hands can often cause pages to become unreadable. The advantage of electronic format service information is that the material can be printed out and taken to the vehicle for easy access. This also allows the service technician to write or draw on the printed copy, which can be a big help when performing tests such as electrical system measurements. These notes can then be used to document the test results on the work order.

MAINTENANCE AND LUBRICATION INFORMATION

Maintenance and lubrication information includes topics such as:

- Schedule for "normal" as well as "severe" usage time and mileage charts
- Specified oil and other lubricant specifications
- Chassis lubrication points
- Tire rotation methods
- Periodic vehicle inspection services (items to check and time/mileage intervals)
- Maintenance item part numbers, such as oil and air filter numbers, and specifications, such as oil capacity and tire pressures

ENGINES

- Engine electrical diagnosis (battery, charging, cranking, ignition, and wiring)
- Engine mechanical diagnosis
- Specific engine information for each engine that may be used in the vehicle(s) covered by the service manual, including:
  - Engine identification
  - On-vehicle service procedures
  - Description of the engine and the operation of the lubrication system
  - Exploded views showing all parts of the engine
  - Disassembly procedures
  - Inspection procedures and specifications of the parts and subsystems
  - Assembly procedures
  - Torque specifications for all fasteners, including the torque sequence

AUTOMATIC TRANSMISSION/TRANSAXLE

- General information (identification and specifications)
- Diagnosis procedures, including preliminary checks and fluid level procedures
- General service, including leak detection and correction
- Cooler flushing procedures
- Unit removal procedures
- Unit disassembly procedures and precautions
- Unit assembly procedures and torque specifications

ELECTRICAL SYSTEMS

- Symbols used
- Troubleshooting procedures
- Repair procedures (wire repair, connectors, and terminals)
- Power distribution
- Ground distribution
- Component location views
- Harness routing views
- Individual electrical circuits, including circuit operation and schematics

HEATING, VENTILATION, AND AIR CONDITIONING

- Heater system
  - General description
  - Heater control assembly
  - Diagnosis, including heater electrical wiring and vacuum system
  - Blower motor and fan assembly diagnosis and servicing procedures
  - Air distribution values
  - Fastener torque specifications
- Air-conditioning system
  - General description and system components
  - Air-conditioning system diagnosis, including leak detection
  - Air-conditioning and heater function tests
  - Air-conditioning service procedures
  - Refrigerant recovery, recycling, adding oil, evacuating procedures, and charging procedures
  - Troubleshooting guide

ENGINE PERFORMANCE (DRIVEABILITY AND EMISSIONS)

- Vehicle emission control information (VECI) label, visual/physical underhood inspection
- On-board diagnostic system
- Scan tool values
- Wiring harness service
- Symptom charts
- Diagnostic trouble code (DTC) information

TECH TIP

Look for Severe Service Times

Many time guides provide additional time for vehicles that may be excessively rusted due to climate conditions or have been subjected to abuse. Be sure to quote the higher rate if any of these conditions are present on the customer's vehicle.

ADVANTAGES OF HARD COPY VERSUS ELECTRONIC SERVICE INFORMATION

All forms of service information have some advantages, including:

Hard Copy	Electronic Service Information
• Easy to use—no hardware or expensive computers needed • Can be taken to the vehicle for reference • Can view several pages easily for reference	• Information can be printed out and taken to the vehicle • Has a search function for information • Internet or network access allows use at several locations in the shop

DISADVANTGES OF HARD COPY VERSUS ELECTRONIC SERVICE INFORMATION

All forms of service information have some disadvantages, including:

Hard Copy	Electronic Service Information
• Can be lost or left in the vehicle • Cost is high for each manual • Can get dirty and unreadable	• Requires a computer and printer • Internet or network access can be a challenge • Cost can be high

LABOR GUIDE MANUALS

Labor guides, also called flat-rate manuals, list vehicle service procedures and the time it should take an average technician to complete the task. This flat-rate time is then the basis for estimates and pay for technicians. Some manuals also include a parts list, including the price of the part to help service advisors create complete estimates for both labor and parts. These manuals are usually called "parts and time guides." Some guides include labor time only. ● **SEE FIGURE 15–2.**

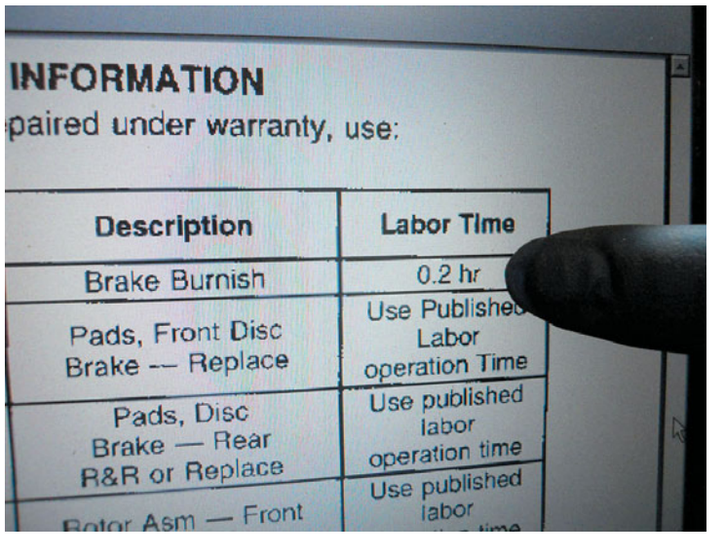


FIGURE 15–2 Some technical service bulletins also include the designated flat-rate time when specifying a repair procedure.

ELECTRONIC SERVICE INFORMATION

There are many programs available that will provide electronic service information for the automotive industry. Sometimes the vehicle makers make information available on CDs or DVDs, but mostly it is available online. Most electronic service information has technical service bulletins (TSBs), wiring diagrams and a main menu that includes the major components of the vehicle as a starting point. ● **SEE FIGURE 15–3.** ALLDATA and Mitchell On-Demand are commonly used software programs that include service information for many vehicles.

Service information and testing procedures should be closely followed including any symptom charts or flow charts. A sample of a symptom information chart is shown ● **CHART 15–1.**

HOME SCREEN The Home screen is the first screen displayed when you start. It displays buttons that represent the major sections of the program. Access to the Home screen is available from anywhere within the program by clicking the Home button on the toolbar.

TOOLBARS A main toolbar is displayed on most screens, providing quick access to certain functions. This toolbar varies somewhat, depending upon what information is being accessed.

ELECTRONIC SERVICE INFORMATION Electronic service information is available mostly by subscription and provides access to an Internet site where service manual–type information is available. Most vehicle manufacturers also offer electronic service information to their dealers and to most schools and colleges that offer corporate training programs.

TECHNICAL SERVICE BULLETINS **Technical service bulletins,** often abbreviated TSBs, are issued by the vehicle manufacturer to notify service technicians of a problem and include the necessary corrective action. Technical service bulletins are designed for dealership technicians but are republished by aftermarket companies and made available along with other service information to shops and vehicle repair facilities.

INTERNET The Internet has opened the field for information exchange and access to technical advice. One of the most useful websites is the International Automotive Technician's network at **www.iatn.net**. This is a free site but service technicians need to register to join. For a small monthly sponsor fee, the shop or service technician can gain access to the archives, which include thousands of successful repairs in the searchable database.

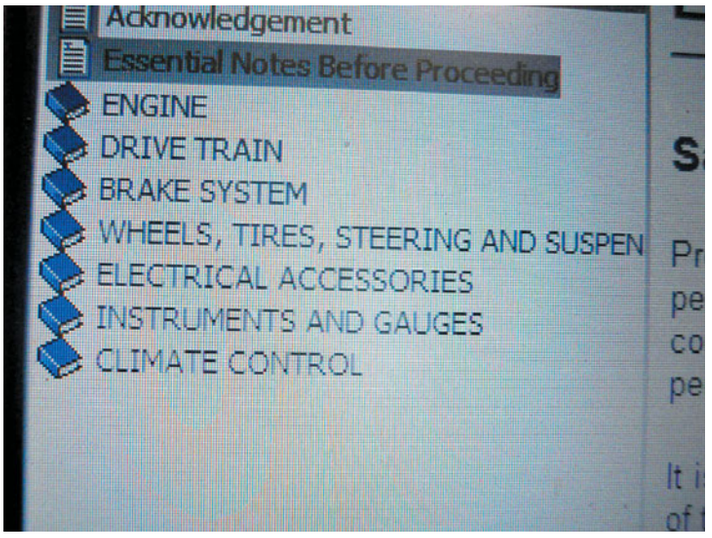


FIGURE 15–3 A main menu showing the major systems of the vehicle. Clicking on one of these major topics opens up another menu showing more detailed information.

RECALLS AND CAMPAIGNS A recall or campaign is issued by a vehicle manufacturer and a notice is sent to all owners in the event of a safety- or emission-related fault or concern. While these faults may be repaired by independent shops, it is generally handled by a local dealer. Items that have created recalls in the past have included potential fuel system leakage problems, exhaust leakage, or electrical malfunctions that could cause a possible fire or the engine to stall. Unlike technical service bulletins whose cost is only covered when the vehicle is within the warranty period, a recall or campaign is always done at no cost to the vehicle owner.

? FREQUENTLY ASKED QUESTION

What Is the Julian Date?

The **Julian date** (abbreviated JD) is the number of the day of the year. January 1 is day 001. The Julian date is named for Julius Caesar, who developed the current calendar. The Julian date is often mentioned in technical service bulletin where changes need to be made to certain component if the date of manufactured falls within the specified Julian dates.

POSSIBLE CAUSE	REASON
Throttle-position (TP) sensor	• The TP sensor should be within the specified range at idle. If too high or too low, the computer may not provide a strong enough extra pulse to prevent a hesitation. • An open or short in the TP sensor can result in hesitation because the computer would not be receiving correct information regarding the position of the throttle.
Throttle-plate deposit buildup	An airflow restriction at the throttle plates creates not only less air reaching the engine but also swirling air due to the deposits. This swirling or uneven airflow can cause an uneven air-fuel mixture being supplied to the engine, causing poor idle quality and a sag or hesitation during acceleration.
Manifold absolute pressure (MAP) sensor fault	The MAP sensor detects changes in engine load and signals to the computer to increase the amount of fuel needed for proper operation. Check the vacuum hose and the sensor itself for proper operation.
Check the throttle linkage for binding	A kinked throttle cable or cruise (speed) control cable can cause the accelerator pedal to bind.
Contaminated fuel	Fuel contaminated with excessive amounts of alcohol or water can cause a hesitation or sag during acceleration. **HINT: To easily check for the presence of alcohol in gasoline, simply get a sample of the fuel and place it in a clean container. Add some water and shake. If no alcohol is in the gasoline, the water will settle to the bottom and be clear. If there is alcohol in the gasoline, the alcohol will absorb the water. The alcohol-water combination will settle to the bottom of the container, but will be cloudy rather than clear.**
Clogged, shorted, or leaking fuel injectors	Any injector problem that results in less than an ideal amount of fuel being delivered to the cylinders can result in a hesitation, a sag, or stumble during acceleration.
Spark plugs or spark plug wires	Any fault in the ignition system such as a defective spark plug wire or cracked spark plug can cause hesitation, a sag, or stumble during acceleration. At higher engine speeds, a defective spark plug wire is not as noticeable as it is at lower speeds, especially in vehicles equipped with a V-8 engine.
EGR valve operation	Hesitation, a sag, or stumble can occur if the EGR valve opens too soon or is stuck partially open.
False air	A loose or cracked intake hose between the mass airflow (MAF) sensor and the throttle plate can be the cause of hesitation.

CHART 15–1

A chart showing symptoms for hesitation while accelerating. These charts help the technician diagnose faults that do not set a diagnostic trouble code (DTC).

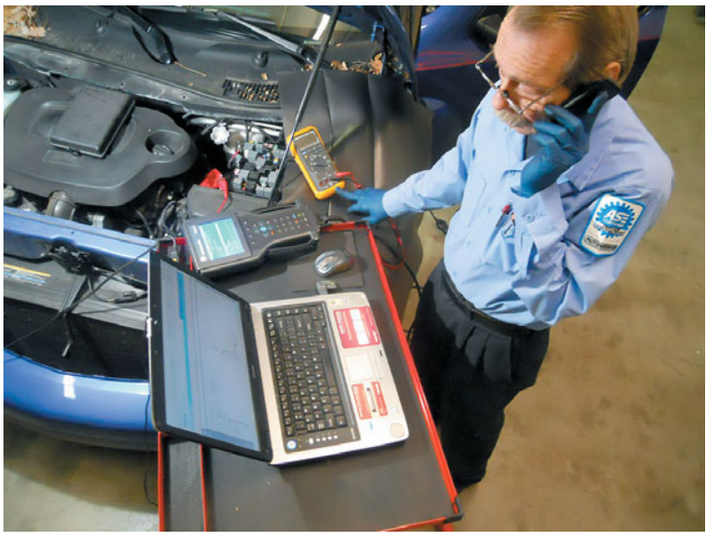


FIGURE 15–4 Whenever calling a hot line service be sure that you have all of the vehicle information ready and are prepared to give answers regarding voltage readings or scan tool data when talking to the vehicle specialist.

HOTLINE SERVICES

A hotline service provider is a subscription-based helpline to assist service technicians solve technical problems. While services vary, most charge a monthly fee for a certain amount of time each month to talk to an experienced service technician who has a large amount of resource materials available for reference. Often, the technician hired by the hotline services specializes in one vehicle make and is familiar with many of the pattern failures that are seen by other technicians in the field. Hotline services are an efficient way to get information on an as-needed basis.

Some examples of hotline automotive service providers include:

- Identifix
- Autohotlineusa
- Taylor Automotive Tech-Line
- Aspire

SEE FIGURE 15–4

TECH TIP

Use a Bluetooth Hands-Free Telephone

When talking to a hotline service provider, it is wise to be looking at the vehicle during the call to be able to provide information about the vehicle and perform the suggested tests. This makes the job of troubleshooting easier and faster for both the technician and the service provider, resulting in shorter length calls. Using a Bluetooth hands-free telephone should help shorten the length of calls, which means the cost will be less for the help service.

SPECIALITY REPAIR MANUALS

Examples of specialty repair manuals include unit repair for assembled components, such as automatic transmission/transaxle, manual transmission/transaxle, differentials, and engines. Some specialty repair manuals cover older or antique vehicles, which may include unit repair sections.

AFTERMARKET SUPPLIES GUIDES AND CATALOGS

Aftermarket supplies guides and catalogs are usually free and often include expanded views of assembled parts along with helpful hints and advice. Sometimes the only place where this information is available is at trade shows associated with automotive training conferences and expos. Go to the following websites for examples of training conferences with trade shows.

- **www.CARSevent.com**
- **www.avtechexpo.com**
- **www.visionkc.com** (Vision Expo)

REVIEW QUESTIONS

1. What is included in the vehicle owner's manual that could be helpful for a service technician?
2. Lubrication service guides include what type of information?
3. Explain why factory service manuals or factory electronic service information are the most detailed of all service information.
4. Explain how flat-rate and parts guides are useful to customers.
5. List additional types of service manuals that are available.
6. Describe how hotline services and Internet sites assist service technicians.

CHAPTER QUIZ

1. What type of information is commonly included in the owner's manual that would be a benefit to service technicians?
   a. Maintenance reminder light reset procedures
   b. Tire pressure monitoring system reset procedures
   c. Maintenance items specifications
   d. All of the above
2. Two technicians are discussing the need for the history of the vehicle. Technician A says that an accident could cause faults due to hidden damage. Technician B says that some faults could be related to a previous repair. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

3. The viscosity of engine oil is found where?
   a. Owner's manual
   b. Factory service manual or service information
   c. Lubrication guide
   d. All of the above
4. Wiring diagrams are usually found where?
   a. Owner's manuals **c.** Unit repair manuals
   b. Factory service manuals **d.** Lubrication guides
5. What type of manual includes time needed to perform service procedures?
   a. Flat-rate manuals **c.** Factory service manuals
   b. Owner's manuals **d.** Parts guide
6. Component location can be found in _____.
   a. Factory service manuals
   b. Owner's manuals
   c. Component location manuals
   d. Both a and c
7. Aftermarket service information is available in what format?
   a. Manuals **c.** Internet
   b. CDs or DVDs **d.** All of the above
8. Hotline services are _____.
   a. Free
   b. Available for a service fee
   c. Available on CD or DVD format
   d. Accessed by the Internet
9. Aftermarket parts catalogs can be a useful source of information and they are usually _____.
   a. Free
   b. Available by paid subscription
   c. Available on CD or DVD
   d. Available for a fee on a secured Internet site
10. Which type of manual or service information includes the flat-rate time and the cost of parts?
    a. Parts and time guides
    b. Factory service manuals
    c. Component location guides
    d. Free Internet sites

chapter 16

VEHICLE IDENTIFICATION AND EMISSION RATINGS

OBJECTIVES: After studying Chapter 16, the reader should be able to: • Identify a vehicle. • Interpret vehicle identification numbers and placard information. • Interpret vehicle emissions and emission control information. • Read and interpret casting numbers. • Locate calibration codes.

KEY TERMS: Bin number 127 • Calendar year (CY) 126 • Calibration codes 128 • California Air Resources Board (CARB) 127 • Casting numbers 128 • Country of origin 126 • Environmental Protection Agency (EPA) 127 • Gross axle weight rating (GAWR) 126 • Gross vehicle weight rating (GVWR) 126 • Model year (MY) 126 • Tier 1 127 • Tier 2 127 • Vehicle emissions control information (VECI) 126 • Vehicle identification number (VIN) 126

PARTS OF A VEHICLE

The names of the parts of a vehicle are based on the location and purpose of the component.

LEFT SIDE OF THE VEHICLE—RIGHT SIDE OF THE VEHICLE Both of these terms refer to the left and right as if the driver is sitting behind the steering wheel. Therefore, the left side (including components under the hood) is on the driver's side.

FRONT AND REAR The proper term for the back portion of any vehicle is rear (for example, left rear tire).

FRONT-WHEEL DRIVE VERSUS REAR-WHEEL DRIVE

Front-wheel drive (FWD) means that the front wheels are being driven by the engine, as well as turned by the steering wheel. Rear-wheel drive (RWD) means that the rear wheels are driven by the engine. If the engine is in the front, it can be either front- or rear-wheel drive. In many cases, a front engine vehicle can also drive all four wheels called four-wheel drive (4WD) or all-wheel drive (AWD). If the engine is located at the rear of the vehicle, it can be rear-wheel drive or four-wheel (AWD) drive.



FIGURE 16–1 Typical vehicle identification number (VIN) as viewed through the windshield.



FIGURE 16–2 A VECI label on a 2008 Ford.

1 = United States	9 = Brazil	U = Romania
2 = Canada	J = Japan	V = France
3 = Mexico	K = Korea	W = Germany
4 = United States	L = China	X = Russia
5 = United States	R = Taiwan	Y = Sweden
6 = Australia	S = England	Z = Italy
8 = Argentina	T = Czechoslovakia	

CHART 16–1

A = 1980/2010	L = 1990/2020	Y = 2000/2030
B = 1981/2011	M = 1991/2021	1 = 2001/2031
C = 1982/2012	N = 1992/2022	2 = 2002/2032
D = 1983/2013	P = 1993/2023	3 = 2003/2033
E = 1984/2014	R = 1994/2024	4 = 2004/2034
F = 1985/2015	S = 1995/2025	5 = 2005/2035
G = 1986/2016	T = 1996/2026	6 = 2006/2036
H = 1987/2017	V = 1997/2027	7 = 2007/2037
J = 1988/2018	W = 1998/2028	8 = 2008/2038
K = 1989/2019	X = 1999/2029	9 = 2009/2039

CHART 16–2

VIN Year Chart *(The Pattern Repeats Every 30 Years)*

VEHICLE IDENTIFICATION

All service work requires that the vehicle, including the engine and accessories, be properly identified. The most common identification is the make, model, and year of the vehicle.

Make: e.g., Chevrolet

Model: e.g., Impala

Year: e.g., 2007

The year of the vehicle is often difficult to determine exactly. A model may be introduced as the next year's model as soon as January of the previous year. Typically, a new **model year** (abbreviated **MY**) starts in September or October of the year prior to the actual new year, but not always. This is why the **vehicle identification number,** usually abbreviated **VIN,** is so important. ● **SEE FIGURE 16–1.**

Since 1981, all vehicle manufacturers have used a VIN that is 17 characters long. Although every vehicle manufacturer assigns various letters or numbers within these 17 characters, there are some constants, including:

- The first number or letter designates the **country of origin.** ● **SEE CHART 16–1.**
- The model of the vehicle is commonly the fourth and/or fifth character.
- The eighth character is often the engine code. (Some engines cannot be determined by the VIN number.)
- The tenth character represents the **calendar year** (abbreviated **CY**) on all vehicles. ● **SEE CHART 16–2.**

VEHICLE SAFETY CERTIFICATION LABEL

A vehicle safety certification label is attached to the left side pillar post on the rearward-facing section of the left front door. This label indicates the month and year of manufacture as well as the **gross vehicle weight rating (GVWR),** the **gross axle weight rating (GAWR),** and the vehicle identification number (VIN).

VECI LABEL

The **vehicle emissions control information (VECI)** label under the hood of the vehicle shows informative settings and emission hose routing information. ● **SEE FIGURE 16–2.**

The VECI label (sticker) can be located on the bottom side of the hood, the radiator fan shroud, the radiator core support, or the strut towers. The VECI label usually includes the following information.

- Engine identification
- Emissions standard that the vehicle meets
- Vacuum hose routing diagram
- Base ignition timing (if adjustable)
- Spark plug type and gap
- Valve lash
- Emission calibration code



FIGURE 16–3 The underhood decal showing that this Lexus RX-330 meets both national (Tier 2; BIN 5) and California LEV-II (ULEV) regulation standards.

EMISSION STANDARDS IN THE UNITED STATES

In the United States, emissions standards are managed by the **Environmental Protection Agency (EPA)** as well as some U.S. state governments. Some of the strictest standards in the world are formulated in California by the **California Air Resources Board (CARB).**

TIER 1 AND TIER 2

Federal emission standards are set by the Clean Air Act Amendments (CAAA) of 1990 grouped by **tier.** All vehicles sold in the United States must meet **Tier 1** standards that went into effect in 1994 and are the least stringent. Additional **Tier 2** standards have been optional since 2001, and were completely adopted in 2009. The current Tier 1 standards are different between automobiles and light trucks (SUVs, pickup trucks, and minivans), but Tier 2 standards are the same for both types.

There are several ratings that can be given to vehicles, and a certain percentage of a manufacturer's vehicles must meet different levels in order for the company to sell its products in affected regions. Beyond Tier 1, and in order by stringency, are the following levels.

- **TLEV—Transitional Low-Emission Vehicle.** More stringent for HC than Tier 1.
- **LEV—(also known as LEV I)—Low-Emission Vehicle.** An intermediate California standard about twice as stringent as Tier 1 for HC and NO_x.
- **ULEV—(also known as ULEV I).** Ultra-Low-Emission Vehicle. A stronger California standard emphasizing very low HC emissions.
- **ULEV II—Ultra-Low-Emission Vehicle.** A cleaner-than-average vehicle certified under the Phase II LEV standard. Hydrocarbon and carbon monoxide emissions levels are nearly 50% lower than those of a LEV II-certified vehicle. ● **SEE FIGURE 16–3.**
- **SULEV—Super-Ultra-Low-Emission Vehicle.** A California standard even tighter than ULEV, including much lower HC and NO_x emissions; roughly equivalent to Tier 2 Bin 2 vehicles.
- **ZEV—Zero-Emission Vehicle.** A California standard prohibiting any tailpipe emissions. The ZEV category is largely restricted to electric vehicles and hydrogen-fueled vehicles. In these cases, any emissions that are created are produced at another site, such as a power plant or hydrogen reforming center, unless such sites run on renewable energy.

NOTE: A battery-powered electric vehicle charged from the power grid will still be up to 10 times cleaner than even the cleanest gasoline vehicles over their respective lifetimes.

The current California ZEV regulation allows manufacturers a choice of two options for meeting the ZEV requirements.

1. Vehicle manufacturers can meet the ZEV obligations by meeting standards that are similar to the ZEV rule as it existed in 2001. This means using a formula allowing a vehicle mix of 2% pure ZEVs, 2% AT-PZEVs (vehicles earning advanced technology partial ZEV credits), and 6% PZEVs (extremely clean conventional vehicles). The ZEV obligation is based on the number of passenger cars and small trucks a manufacturer sells in California.
2. Manufacturers may also choose a new alternative ZEV compliance strategy of meeting part of the ZEV requirement by producing the sales-weighted market share of approximately 250 fuel-cell vehicles. The remainder of the ZEV requirements could be achieved by producing 4% AT-PZEVs and 6% PZEVs. The required number of fuel-cell vehicles will increase to 2,500 from 2009 to 2011, 25,000 from 2012 through 2020, and 50,000 from 2015 through 2017. Manufacturers can substitute battery electric vehicles for up to 50% of the fuel-cell vehicle requirements.
   - **PZEV—Partial-Zero-Emission Vehicle.** Compliant with the SULEV standard; additionally has near-zero evaporative emissions and a 15-year/150,000-mile warranty on its emission control equipment.

Tier 2 standards are even more stringent. Tier 2 variations are appended with "II," such as LEV II or SULEV II. Other categories have also been created.

- **ILEV—Inherently Low-Emission Vehicle.**
- **AT-PZEV—Advanced Technology Partial-Zero-Emission Vehicle.** If a vehicle meets the PZEV standards and is using high-technology features, such as an electric motor or high-pressure gaseous fuel tanks for compressed natural gas, it qualifies as an AT-PZEV. Hybrid electric vehicles such as the Toyota Prius can qualify, as can internal combustion engine vehicles that run on natural gas (CNG), such as the Honda Civic GX. These vehicles are classified as "partial" ZEV because they receive partial credit for the number of ZEV vehicles that automakers would otherwise be required to sell in California.
- **NLEV—National Low-Emission Vehicle.** All vehicles nationwide must meet this standard, which started in 2001. ● **SEE CHARTS 16–3 AND 16–4.**

FEDERAL EPA BIN NUMBER

The higher the tier number, the newer the regulation; the lower the **bin number,** the cleaner the vehicle. The 2004 Toyota Prius is a very clean Bin 3, while the Hummer H2 is a dirty Bin 11. Examples include:

- Tier 1: The former federal standard; carried over to model year 2004 for those vehicles not yet subject to the phase-in.
- Tier 2, Bin 1: The cleanest federal Tier 2 standard; a zero-emission vehicle (ZEV).
- Tier 2, Bins 4–2: Cleaner than the average standard.

		NMOG GRAMS (MILE)	CO GRAMS (MILE)	NO_x GRAMS (MILE)
LEV I (Cars)	TLEV	0.125 (0.156)	3.4 (4.2)	0.4 (0.6)
	LEV	0.075 (0.090)	3.4 (4.2)	0.2 (0.3)
	ULEV	0.040 (0.055)	1.7 (2.1)	0.2 (0.3)
LEV II (Cars and Trucks less than 8,500 lbs)	LEV	0.075 (0.090)	3.4 (4.2)	0.05 (0.07)
	ULEV	0.040 (0.055)	1.7 (2.1)	0.05 (0.07)
	SULEV	−(0.010)	−(1.0)	−(0.02)

CHART 16–3

LEV Standard Categories
NOTE: Numbers in parentheses are 100,000-mile standards for LEV I, and 120,000-mile standards for LEV II. NMOG means non-methane organic gases, which includes alcohol. CO means carbon monoxide. NO_x means oxides of nitrogen. Data compiled from California Environmental Protection Agency—Air Resource Board (CARB) documents.

CERTIFICATION LEVEL	NMOG (g/ml)	CO (g/ml)	NO_x (g/ml)
LEV II	0.090	4.2	0.07
ULEV II	0.055	2.1	0.07
SULEV II	0.010	1.0	0.02

CHART 16–4

California LEV II 120,000-Mile Tailpipe Emissions Limits
NOTE: Numbers in parentheses are 100,000-mile standards for LEV I, and 120,000-mile standards for LEV II. NMOG means non-methane organic gases, which includes alcohol. CO means carbon monoxide. NO_x means oxides of nitrogen. The specification is in grams per mile (g/ml). Data compiled from California Environmental Protection Agency—Air Resources Board (CARB) documents.

- Tier 2, Bin 5: "Average" of new Tier 2 standards, roughly equivalent to a LEV II vehicle.
- Tier 2, Bins 6–9: Not as clean as the average requirement for a Tier 2 vehicle.
- Tier 2, Bin 10: Least-clean Tier 2 bin applicable to passenger vehicles. ● **SEE CHARTS 16–5 AND 16–6.**

CALIBRATION CODES

Calibration codes are usually located on powertrain control modules (PCMs) or other controllers. Some calibration codes are only accessible with a scan tool. Whenever diagnosing an engine operating fault, it is often necessary to know the calibration code to be sure that the vehicle is the subject of a technical service bulletin or other service procedure. ● **SEE FIGURE 16–4.**

CASTING NUMBERS

Whenever an engine part such as a block is cast, a number is put into the mold to identify the casting. ● **SEE FIGURE 16–5.** These **casting numbers** can be used to check dimensions such as the cubic inch displacement and other information. Sometimes changes are made to the mold, yet the casting number is not changed. Most often the casting number is the best piece of identifying information that the service technician can use for identifying an engine.

CERTIFICATION LEVEL	NMOG (g/ml)	CO (g/ml)	NO_x (g/ml)
Bin 1	0.0	0.0	0.0
Bin 2	0.010	2.1	0.02
Bin 3	0.055	2.1	0.03
Bin 4	0.070	2.1	0.04
Bin 5	0.090	4.2	0.07
Bin 6	0.090	4.2	0.10
Bin 7	0.090	4.2	0.15
Bin 8a	0.125	4.2	0.20
Bin 8b	0.156	4.2	0.20
Bin 9a	0.090	4.2	0.30
Bin 9b	0.130	4.2	0.30
Bin 9c	0.180	4.2	0.30
Bin 10a	0.156	4.2	0.60
Bin 10b	0.230	6.4	0.60
Bin 10c	0.230	6.4	0.60
Bin 11	0.230	7.3	0.90

CHART 16–5

EPA Tier 2—120,000-Mile Tailpipe Emission Limits
NOTE: The bin number is determined by the type and weight of the vehicle. The highest bin allowed for vehicles built after January 1, 2007, is Bin 8. Data compiled from the Environmental Protection Agency (EPA).

U.S. EPA VEHICLE INFORMATION PROGRAM (THE HIGHER THE SCORE, THE LOWER THE EMISSIONS)	
SELECTED EMISSIONS STANDARDS	SCORE
Bin 1 and ZEV	10
PZEV	9.5
Bin 2	9
Bin 3	8
Bin 4	7
Bin 5 and LEV II cars	6
Bin 6	5
Bin 7	4
Bin 8	3
Bin 9a and LEV I cars	2
Bin 9b	2
Bin 10a	1
Bin 10b and Tier 1 cars	1
Bin 11	0

CHART 16–6

Air Pollution Score
Courtesy of the Environmental Protection Agency (EPA).



FIGURE 16–4 A typical computer calibration sticker on the case of the controller. The information on the sticker is often needed when ordering parts or a replacement controller.



FIGURE 16–5 Engine block identification number cast into the block is used for identification.

REVIEW QUESTIONS

1. From what position are the terms left and right determined?
2. What are the major pieces of information that are included in the vehicle identification number (VIN)?
3. What information is included on the VECI label under the hood?
4. What does Tier 2 Bin 5 mean?

CHAPTER QUIZ

1. The passenger side is called the _____.
   a. Right side
   b. Left side
   c. Either right or left side, depending on how the vehicle is viewed
   d. Both a and b
2. A vehicle with the engine in the front can be _____.
   a. Front-wheel drive **c.** Four-wheel drive
   b. Rear-wheel drive **d.** All of the above
3. The vehicle identification number (VIN) is how many characters long?
   a. 10 **c.** 17
   b. 12 **d.** 21
4. The tenth character represents the year of the vehicle. If the tenth character is a "Y," what year is the vehicle?
   a. 1998 **c.** 2002
   b. 2000 **d.** 2004
5. The first character of the vehicle identification number is the country of origin. Where was the vehicle built that has a "5" as the first character?
   a. United States **c.** Mexico
   b. Canada **d.** Japan
6. The VECI label includes all *except* _____.
   a. Engine identification
   b. Horsepower and torque rating of the engine
   c. Spark plug type and gap
   d. Valve lash
7. The vehicle safety certification label includes all *except* _____.
   a. VIN
   b. GVWR
   c. Tire pressure recommendation
   d. GAWR
8. What are the characters that are embedded in most engine blocks and are used for identification?
   a. VIN **c.** Bin number
   b. Calibration codes **d.** Casting number
9. If the first character of the VIN is an "S," where was the vehicle made?
   a. United States **c.** Canada
   b. Mexico **d.** England
10. Technician A says that the lower the bin number is, the cleaner. Technician B says that SULEV has cleaner standards than ULEV. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

chapter 17

PREVENTATIVE MAINTENANCE AND SERVICE PROCEDURES

OBJECTIVES: **After studying Chapter 17, the reader should be able to:** • Prepare for ASE Engine Repair (A1) certification test content area "A" (General Engine Diagnosis) and content area "D" (Lubrication and Cooling Systems Diagnosis and Repair). • Perform routine fluid and service checks. • Explain how to rotate tires. • Describe how to install wheels and tighten lug nuts using a torque wrench and the proper sequence. • Describe chassis system lubrication and under-vehicle inspection.

KEY TERMS: Air filter 132 • Alemite fittings 143 • Algorithm 135 • American Petroleum Institute (API) 144 • American Society for Testing Materials (ASTM) 143 • Automatic transmission fluid (ATF) 138 • Brake fluid 133 • Cabin filter 132 • Dipstick 134 • DOT 3 133 • DOT 4 133 • DOT 5 133 • DOT 5.1 134 • National Lubricating Grease Institute (NLGI) 143 • Penetration test 143 • Polyglycol 133 • Preventative maintenance (PM) 130 • Serpentine (Poly V) 139 • Silicone brake fluid 133 • Synchromesh transmission fluid (STF) 144 • Zerk fittings 143

PREVENTATIVE MAINTENANCE

PURPOSE

Preventative maintenance (PM) means periodic service work performed on a vehicle that will help keep it functioning correctly for a long time. All vehicle manufacturers publish a list of service work to be performed on a regular basis. Preventative maintenance is also called *routine maintenance* because it is usually performed on a set scheduled routine. The interval specified for preventative maintenance is often expressed in time and miles (km) such as:

- Every six months (could be longer for many vehicles)
- Every 5,000 to 10,000 miles (8,000 to 16,000 km) depending on the vehicle and how it is being operated
- Either of the above, whichever occurs first

ITEMS REQUIRING MAINTENANCE

The items or systems that require routine maintenance include:

1. Engine oil and oil filter replacement
2. Air and cabin filter replacement
3. Tire inflation pressure check, inspection, and rotation
4. Brake and suspension system inspection
5. Underhood inspection and fluid checks
6. Under-vehicle inspection and fluid checks
7. Air-conditioning system inspection and service
8. Safety inspection, such as all lights and windshield wiper blades
9. Routine cleaning of vehicle both inside and out

GETTING READY FOR SERVICE

PRE-SERVICE INSPECTION

Prior to any service work, it is wise to check the vehicle for damage and document the work order if any damage is found. In most dealerships and shops, this is the responsibility of the following personnel.

- Service adviser (service writer) or
- Shop foreman or
- Shop owner

The designated person should check the vehicle for the following:

1. Body damage
2. Missing wheel covers
3. Glass damage such as a cracked windshield
4. Any faults in the paint or trim
5. Valid license plates

PROTECT THE VEHICLE

Before most service work is done, protect the inside of the vehicle by using commercially available plastic or paper protective coverings for the following areas.

- Seats
- Floor
- Steering wheel

SEE FIGURE 17–1

PROTECT THE TECHNICIAN

Before starting routine preventative maintenance on a vehicle be sure to perform the following:

1. Open the hood (engine compartment cover). Often the struts that hold a hood open are weak or defective. Therefore, before



FIGURE 17–1 Before service begins, be sure to cover the seats, floor, and steering wheel with protective coverings.

starting to work under the hood, always make sure that the hood is securely held open.

2. Connect an exhaust system hose to the tailpipe(s) before work is started that will involve operating the engine. ● **SEE FIGURE 17–2.**
3. Wear personal protective equipment (PPE) including:
   - Safety glasses
   - Hearing protection if around air tools or other loud noises
   - Gloves if handling hot objects or chemicals such as used engine oil
4. On hybrid vehicles, make sure that the technician has possession of the key transmitter and that the vehicle is *not* in the ready mode before starting any inspection or service procedures.

SAFETY INSPECTION

A safety inspection is usually recommended to be performed anytime the vehicle is in the shop for service or repair.

These inspections should include all of the following:

1. Exterior lights, including:
   a. Headlights (high and low beam)
   b. Tail lights
   c. Turn signals
   d. License plate light
   e. Parking lights
2. Horn
3. Windshield wiper operation
4. Mirrors
5. Defroster fan operation
6. Steering for excessive looseness or leaks



FIGURE 17–2 An exhaust system hose should be connected to the tailpipe(s) whenever the engine is being run indoors.

TECH TIP

Do No Harm

As stated in the Hippocratic oath, a doctor agrees first to do no harm to the patient during treatment. Service technicians should also try to do no harm to the vehicle while it is being serviced.

Always ask, "Am I going to do any harm if I do this?" before you do it.

7. Shock absorbers that allow excessive body sway
8. Tire condition, tread depth, and proper inflation pressure
9. Parking brake operation
10. Exhaust system for excessive noise or leaks

WINDSHIELD WIPER AND WASHER FLUID SERVICE

WINDSHIELD WIPERS Windshield wiper blades are constructed of rubber and tend to become brittle due to age. Wiper blades should be cleaned whenever the vehicle is cleaned using water and a soft cloth. Wiper blade or wiper blade insert replacement includes the following steps.

- Turn the ignition switch to on (run).
- Turn the wiper switch on and operate the wipers.
- When the wipers are located in an easy-to-reach location, turn the ignition switch off. The wipers should stop.
- Remove the insert or the entire blade as per service information and/or the instructions on the replacement windshield wiper blade package.
- After double-checking that the wiper is securely attached, turn the ignition switch on (run).
- Turn the wiper switch off and allow the wipers to reach the park position. Check for proper operation.

● **SEE FIGURE 17–3.**

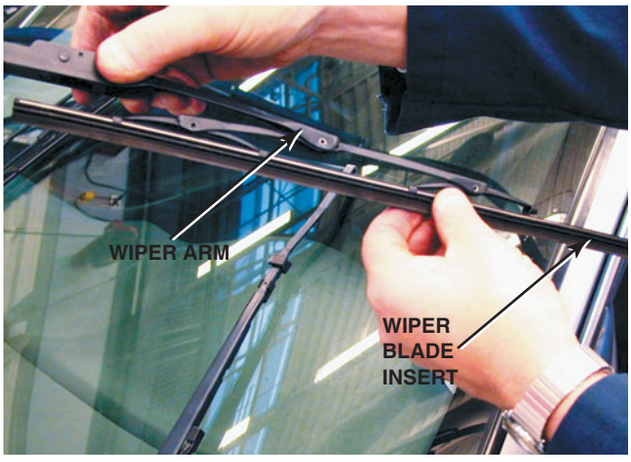


FIGURE 17–3 Installing a wiper blade insert into a wiper arm.



(a)



(b)

FIGURE 17–4 (a) The windshield wiper fluid reservoir cap is usually labeled with a symbol showing a windshield washer. (b) Use only the recommended washer fluid. Never use antifreeze in the windshield washer reservoir.

WINDSHIELD WASHER FLUID Windshield washer fluid level should be checked regularly and refilled as necessary. Use only the fluid that is recommended for use in vehicle windshield washer systems. ● **SEE FIGURE 17–4.**

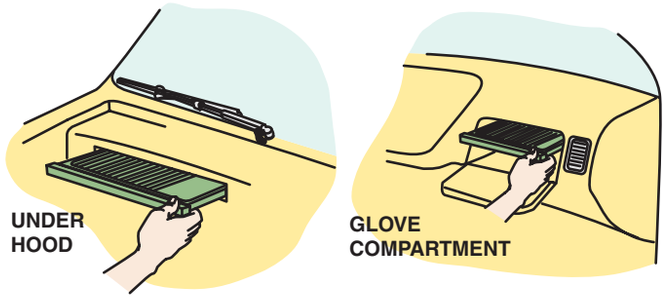


FIGURE 17–5 A cabin filter can be accessed either through the glove compartment or under the hood on most vehicles.

Most windshield washer fluid looks like blue water. It is actually water with an alcohol (methanol) additive to prevent freezing and to help clean the windshield by dissolving bugs. Be careful not to spill any washer fluid when filling the reservoir because the corrosiveness can harm wiring and electronic components.

CAUTION: Some mixed fluids are for summer use only and do not contain antifreeze protection. Read the label carefully!

WARNING

Windshield washer fluid usually contains methanol, a poisonous chemical that can cause blindness if ingested.

CABIN FILTER REPLACEMENT

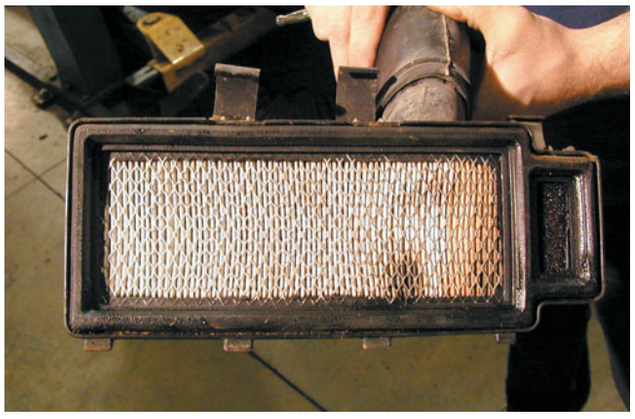
A **cabin filter** is used in the heating, ventilation, and air-conditioning (HVAC) system to filter the outside air drawn into the passenger compartment. Some filters contain activated charcoal to help eliminate odors. The cabin air filter should be replaced often—every year or every 12,000 miles (19,000 km). The cabin air filter can be accessed from:

- Under the hood at the cowl (bulkhead) or
- Under the dash, usually behind the glove (instrument panel) compartment (Check service information for the exact location and servicing procedures for the vehicle being serviced.)

● **SEE FIGURE 17–5.**

AIR FILTER INSPECTION/ REPLACEMENT

An **air filter** filters dirt from the air before it enters the intake system of the engine. The air filter should be replaced according to vehicle manufacturer's recommendations. Over time, the filter will start to get clogged and decrease the engine's efficiency. Many vehicle manufacturers recommend replacing the air filter every 30,000 miles (50,000 km), or more frequently under dusty conditions. Many service



(a)



(b)

FIGURE 17–6 (a) A typical dirty air filter. (b) Always check the inlet passage leading to the air filter for debris that can reduce airflow to the engine.

technicians recommend replacing the air filter every year. ● **SEE FIGURE 17–6**.

BRAKE FLUID INSPECTION

BRAKE FLUID LEVEL

Brake fluid is used to transmit the force of the driver's foot on the brake pedal, called the service brake, to each individual wheel brake. The brake fluid should be checked at the same time the engine oil is changed, or every six months, whichever occurs first. It is normal for the brake fluid level to drop as the disc brake pads wear. Therefore, when the fluid level is low, check for two possible causes.

CAUSE 1 Normal disc brake pad wear (Inspect the brakes if the fluid level is low.)

CAUSE 2 A leak somewhere in the hydraulic brake system (Carefully inspect the entire brake system for leaks if the brakes are not worn and the brake fluid level is low.)

There are two types of brake master cylinders.

- **Transparent reservoir.** This type allows viewing of the brake fluid (and hydraulic clutch master cylinder if so equipped) without having to remove the cover of the reservoir. The proper level should be between the MIN (minimum) level indicated and the MAX (maximum) level indicated on the clear plastic reservoir. ● **SEE FIGURE 17–7**.



FIGURE 17–7 A master cylinder with a transparent reservoir. The brake fluid level should be between the MAX and the MIN levels as marked on the reservoir.

- **Metal or nontransparent plastic reservoir.** This type of reservoir used on older vehicles requires that the cover be removed to check the level of the brake fluid. The proper level of brake fluid should be 0.25 inch (6 mm) from the top.

CAUTION: Do not overfill a brake master cylinder. The brake fluid gets hotter as the brakes are used and there must be room in the master cylinder reservoir for the brake fluid to expand.

BRAKE FLUID TYPES

Brake fluid is made from a combination of various types of glycol, a non-petroleum-based fluid. Brake fluid is a polyalkylene-glycol-ether mixture, called **polyglycol** for short. *All polyglycol brake fluid is clear to amber in color.*

CAUTION: DOT 3 brake fluid is a very strong solvent and can remove paint! Care is required when working with this type brake fluid to avoid contact with the vehicle's painted surfaces. It also takes the color out of leather shoes.

All automotive brake fluid must meet Federal Motor Vehicle Safety Standard 116. The Society of Automotive Engineers (SAE) and the Department of Transportation (DOT) have established brake fluid specification standards.

- **DOT 3.** The **DOT 3** brake fluid is most often used. It absorbs moisture and, according to SAE, can absorb 2% of its volume in water per year. Moisture is absorbed by the brake fluid through microscopic seams in the brake system and around seals. Over time, the water will corrode the system and thicken the brake fluid. Moisture can cause a spongy brake pedal because the increased concentration of water within the fluid boils at lower temperatures and can result in vapor lock. DOT 3 must be used from a sealed (capped) container. If allowed to remain open for any length of time, DOT 3 will absorb moisture from the surrounding air. ● **SEE FIGURE 17–8**.
- **DOT 4.** The **DOT 4** brake fluid is formulated for use by all vehicles, imported or domestic. It is commonly called low moisture absorption (LMA) because it does not absorb water as fast as DOT 3. It is still affected by moisture, however, and should be used only from a sealed container. The cost of DOT 4 is approximately double the cost of DOT 3.
- **DOT 5.** The **DOT 5** type is commonly called **silicone brake fluid.** It is made from polydimethylsiloxanes. Because it does

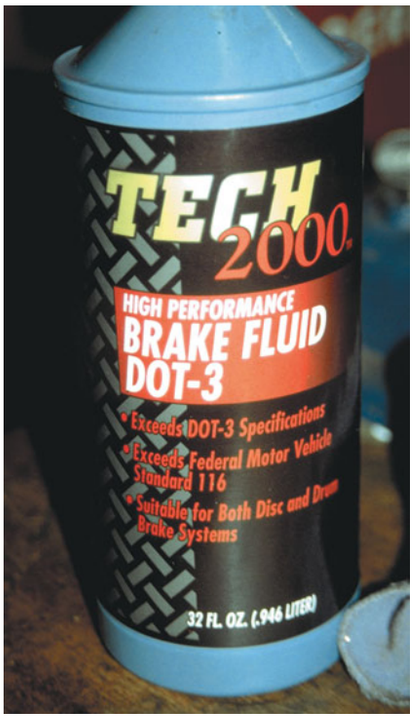


FIGURE 17–8 DOT 3 brake fluid. Always use fluid from a sealed container because brake fluid absorbs moisture from the air.

not absorb water, it is called nonhygroscopic. DOT 5 brake fluid does not mix with and should not be used with DOT 3 or DOT 4 brake fluid.

NOTE: Even though DOT 5 does not normally absorb water, it is still tested using standardized SAE procedures in a humidity chamber. After a fixed amount of time, the brake fluid is measured for boiling point. Because it has had a *chance* to absorb moisture, the boiling point after this sequence is called the minimum wet boiling point.

DOT 5 brake fluid is purple (violet), to distinguish it from DOT 3 or DOT 4 brake fluid.

- **DOT 5.1.** The **DOT 5.1** brake fluid is a non-silicone-based polyglycol fluid that is clear to amber in color. This severe-duty fluid has a boiling point of over 500°F,(260°C) equal to the boiling point of silicone-based DOT 5 fluid. Unlike DOT 5, the DOT 5.1 fluid can be mixed with either DOT 3 or DOT 4 according to the brake fluid manufacturer's recommendations.

CAUTION: Some vehicle manufacturers, such as Chrysler, do not recommend the use of or the mixing of other types of polyglycol brake fluid and specify the use of DOT 3 brake fluid only. Always follow the vehicle manufacturer's recommendation.

BRAKE FLUID TESTING

- **Visual inspection.** Check the color of the brake fluid. It should be clear or almost clear. If it is dark brown or black, it should be replaced.
- **Test strips.** A quick and easy way to check the condition of the brake fluid is to use test strips. Always follow the instructions that come with the test strips for accurate results. ● **SEE FIGURE 17–9**.

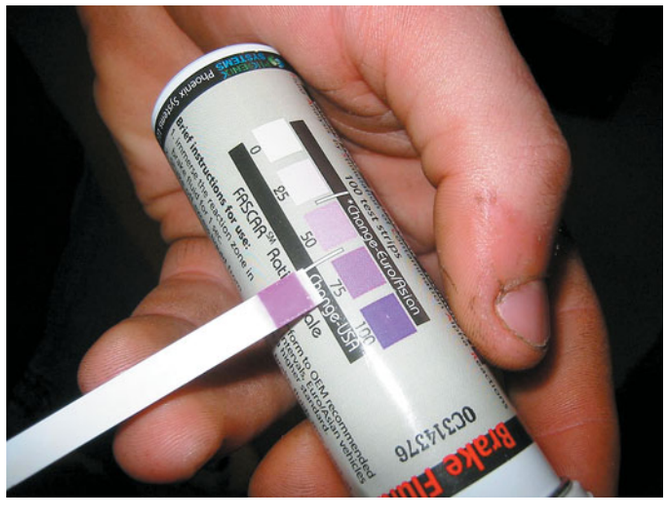


FIGURE 17–9 Brake fluid test strips are a convenient and easy-to-use method to determine if the brake fluid needs to be replaced.

? FREQUENTLY ASKED QUESTION

What Is Used in the Clutch Master Cylinder?

Vehicles equipped with a manual transmission often use a hydraulically operated clutch. This type of clutch operation uses a master cylinder and a slave cylinder near the clutch assembly. When the driver depresses the clutch pedal, the hydraulic pressure created in the master cylinder is transferred to the slave cylinder which moves and actuates the clutch. Most hydraulic clutches use DOT 3 brake fluid. Check to see that the level is between the maximum and the minimum levels as shown by lines on the reservoir. If low, check for a leak in the system as it is not normal for brake fluid level to decrease over time.

- **Boiling point.** The boiling point of brake fluid can be tested using a handheld tester. Follow the instructions that come with the tester.

CAUTION: If any mineral oil such as engine oil, automatic transmission fluid (ATF), or power steering fluid gets into the brake fluid, the rubber seals will swell and cause damage to the entire braking system. Every part that includes a rubber seal will require replacement.

ENGINE OIL INSPECTION

OIL LEVEL The oil level should be checked when the vehicle is parked on level ground and after the engine has been off for at least several minutes. The *oil level indicator*, commonly called a **dipstick**, is clearly marked and in a convenient location. ● **SEE FIGURE 17–10**.

To check the oil, remove the dipstick, wipe off the oil, and reinsert it all the way down. Once again remove the dipstick and check where the oil level touches the indicator. The "add" mark is usually at the 1 quart low point. ● **SEE FIGURE 17–11**.



FIGURE 17–10 A typical oil level indicator (dipstick).

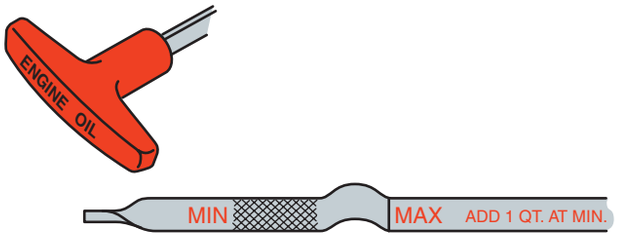


FIGURE 17–11 The oil level should be between the MAX and the MIN marks when the vehicle is on level ground and the oil has had time to drain into the oil pan.

? **FREQUENTLY ASKED QUESTION**

Can I Switch from Synthetic Oil to Regular Oil?

Yes. All oil is *miscible,* meaning that it can be readily mixed. Therefore, synthetic oil can be used one time and then regular mineral oil used the next time. Most important, however, is that the oil be changed at intervals that are never longer than specified by the vehicle manufacturer.

If oil needs to be added, use the specified oil and add to the engine through the oil fill opening (not through the dipstick hole as is done with automatic transmission fluid).

ENGINE OIL CHANGE INTERVALS Most automotive experts recommend that the engine oil be replaced and a new oil filter installed every 5,000 to 7,500 miles (8,000 to 12,000 km) or every six months, whichever occurs first. Most vehicles since the early 2000s have used an oil life monitor system to notify the driver when the engine oil should be changed. The oil life monitor will light a dash lamp when the oil needs to be changed. Most vehicle manufacturers recommend that the oil be changed according to a "normal" or "severe use" schedule. ● **SEE CHART 17–1**.

Most vehicles are driven under severe conditions if all of the factors above are considered. Always follow the vehicle manufacturer's recommended oil change intervals.

See Chapter 22 for details on oils and oil change procedure.

Normal Use	Severe Use
Most trips over 10 miles (16 km).	Most trips less than 4 to 10 miles (6 to 16 km).
Operating a vehicle when the outside temperature is above freezing (32°F/0°C).	Operating the vehicle when the outside temperature is below freezing (32°F/0°C).
Most trips do not include slow or stop-and-go driving.	Most trips include slow or stop-and-go driving.
Not towing a trailer or carrying a heavy load.	Towing a trailer or hauling a heavy load.
Driving without dusty conditions.	Driving in dusty conditions.
No police, taxi, or commercial use of the vehicle.	Use by police, taxi, or commercial operation.
The oil change interval recommended by most vehicle manufacturers under normal conditions is 7,500 miles (12,000 km) or six months, whichever occurs first.	The oil change interval recommended by most vehicle manufacturers operating under severe conditions is every 3,000 miles (4,800 km) or every three months, whichever occurs first.

CHART 17–1

The difference been "normal" and "severe" use as specified by many vehicle manufacturers.

? **FREQUENTLY ASKED QUESTION**

How Does an Oil Life Monitor Work?

While some vehicle manufacturers, such as Mercedes, use a sensor to measure oil temperature and acidity, most vehicle oil change monitors function three ways:

1. **Vehicle mileage.** This is the most commonly used vehicle service monitoring system. When a certain number of miles has occurred since it was reset, the control (usually the powertrain control module (PCM)) will turn on a dash light that states maintenance is required.
2. **Oil life computer program.** A computer program called an **algorithm**, or a series of mathematical calculations, is used to determine the life of the engine oil. For example, when the oil change warning light is reset, the oil life is reset to 100%. Then the PCM tracks the number of engine starts, the outside temperature, when the engine was started (based on intake air temperature [IAT] sensor input), and the number of miles traveled. Because long drives are easier on engine oil than short stop-and-go driving, the PCM deducts numbers faster during this condition.
3. **Oil condition sensor.** This sensor measures the dielectric properties of the oil, which changes when exposed to water, soot, ash, and glycol in the oil. A computer program takes the information from the sensor about the changes of the dielectric property of the oil to determine when to light the "change oil" lamp.



FIGURE 17–12 Visually check the level and color of coolant in the coolant recovery or surge tank.

WARNING

Remove the pressure cap only on a cold engine as the coolant will boil when pressure is released. This occurs because the coolant temperature is above the boiling point but it does not boil due to the pressure. When the pressure is released, all of the hot coolant immediately boils and expands outward from the opening where the cap was installed. The resulting geyser of boiling hot coolant can cause serve burns or even death.

FREQUENTLY ASKED QUESTION

What Is the Magnuson-Moss Act?

The Magnuson-Moss Act, passed into law in 1975, allows the use of non–original equipment replacement parts during the service or repair of a vehicle without losing the factory warranty. This means that any oil or air filter, spark plug, or other service part can be used unless the vehicle manufacturer furnishes these parts for free during the warranty period.

The vehicle manufacturer cannot deny paying a warranty claim for a fault unless the replacement part is proved to be the cause of the condition needed to be covered by the warranty.

Therefore, it is up to the business owner, service manager, or technician to determine if the replacement part is of good quality. While this is very difficult or impossible, unless defects are obviously visible, the best solution is to use the original equipment manufacturer (OEM) parts or service parts from a well-known company.

COOLING SYSTEM INSPECTION

STEPS INVOLVED Normal maintenance involves an occasional check of the following items.

1. Coolant level in the coolant recovery tank or in the surge tank ● **SEE FIGURE 17–12**.
2. The front of the radiator should be carefully inspected and cleaned of bugs, dirt, or mud that can often restrict airflow.
3. Maintenance should also include a visual inspection for signs of coolant system leaks and for the condition of the coolant hoses and accessory drive belts.

COOLANT TESTING

- **Visual inspection.** Coolant should be clean and close to the color when it was new. If dark or muddy, it should be replaced. Milky colored coolant is an indication of oil in the system that might be caused by a defective engine gasket. If the coolant is dark or muddy looking, it should be replaced.
- **Test strips.** Coolant test strips are available to test the condition of the coolant. Check to see that the test strips are being used on the specified type of coolant as some will work only on the old green inorganic additive technology (IAT) coolant.
- **Boiling/freezing points (refractometer and hydrometer).** A hydrometer can be used to check the freezing and boiling temperatures of the coolant. A refractometer can be used to check the freezing temperature of the coolant.
- **Proper reading.** A proper 50-50 mix of antifreeze and water should result in a freezing temperature of −34°F (−37°C).
  - If the freezing temperature is higher than −34°F (such as −20°F), there is too much water in the coolant.
  - If the freezing temperature is lower than −34°F (such as −46°F), there is too much antifreeze in the coolant. ● **SEE FIGURE 17–13**.

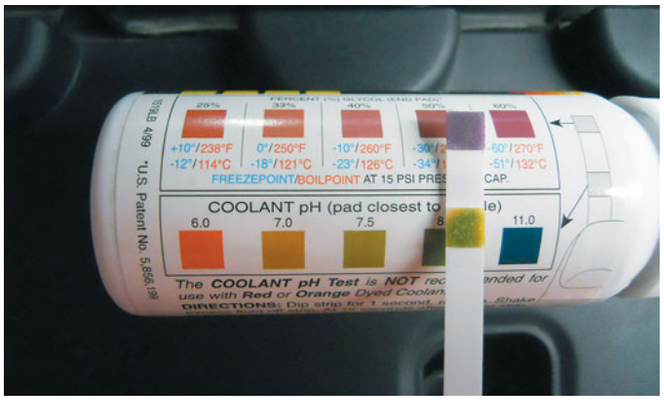
NOTE: Many hybrid electric vehicles use two separate cooling systems—one for the internal combustion engine (ICE) and the other to cool the electronics. Check service information for the exact procedures to follow.

See Chapter 20 for more details on coolant and coolant testing.

ANTIFREEZE/COOLANT DISPOSAL Used coolant drained from vehicles can usually be disposed of according to federal, state, and local laws. Check with recycling companies authorized by local or state government for the exact method recommended for disposal in your area. ● **SEE FIGURE 17–14.**



(a)



(b)

FIGURE 17–13 (a) A refractometer is used to measure the freezing point of coolant. A drop of coolant is added to a viewing screen, the lid is closed, and then held up to the light to view the display on the tool. (b) The use of tests strips is a convenient and cost-effective method to check coolant condition and freezing temperature.



FIGURE 17–14 Used coolant should be stored in a leak-proof container until it can be recycled or disposed of according to local, state, or federal laws. Note that the storage barrel is placed inside another container to catch any coolant that may spill out of the inside container.

RADIATOR AND HEATER HOSES

Upper and lower radiator hoses must be pliable, yet not soft. The lower radiator hose will be reinforced or contain an inner spring to prevent the hose from being sucked closed, since the lower hose is attached to the suction side of the water pump. The bypass hose (if equipped) and heater hoses come in the following inside diameter sizes.

- 1/2 inch
- 5/8 inch
- 3/4 inch

The heater hoses connect the engine cooling system to the heater core. A heater core looks like a small radiator and is located inside the vehicle. All automotive hose is constructed of rubber with reinforcing fabric weaving for strength. Sections of the coolant lines can be made from nylon-reinforced plastic or metal. All hoses should be inspected for leaks (especially near hose clamps), cracks, swollen areas indicating possible broken reinforcing material, and excessively brittle, soft, and swollen sections. Using a hand-operated pressure pump attached to the radiator opening is an excellent way to check for leaks. ● **SEE FIGURE 17–15**.



FIGURE 17–15 Using a hand-operated pressure tester. Do not exceed the pressure rating of the radiator cap when pressurizing the system. This vehicle had a leaking upper radiator that only leaked when the system was pressurized.

EMISSION-RELATED HOSES

Rubber hoses are also used in the following locations and for the following purposes.

- **Positive crankcase ventilation (PCV) system hose.** This type of hose has engine vacuum and requires specially designed hose if replacing the hose used for the PCV system.
- **Exhaust gas recirculation (EGR) system hose.** This type of hose has engine vacuum and requires specially designed hose if replacing the hose used for the EGR system.
- **Secondary air injection (SAI) system hoses.** This type of hose has engine vacuum or low pressure air and requires specially designed hose if replacing the hose used for the SAI system.

HOSE CLAMPS

There are several types of hose clamps used depending on the make, model, and year of vehicle. The three basic types are as follows:

1. Worm drive (also called a screw band type)
2. Banded-type clamp
3. Wire clamp (spring type) ● **SEE FIGURE 17–16**.

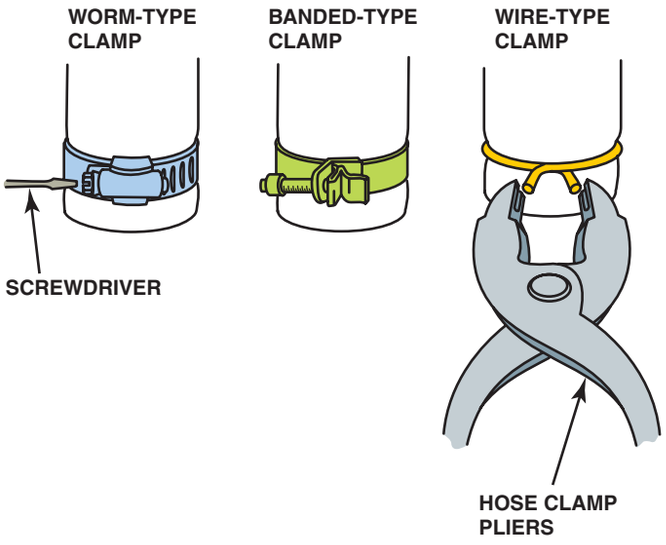


FIGURE 17–16 Hose clamps come in a variety of shapes and designs.

TECH TIP

The Cut-and-Peel Trick

It is often difficult to remove a radiator or heater hose from the fittings on the radiator or heater core. To avoid possible damage to expensive radiator or heater cores, do not pull or twist the hose to remove it. Simply use a utility knife and slit the hose lengthwise and then use your finger to peel the hose off of the radiator or heater core. Although this procedure will not work if the hose is to be reused, it is a real time saver when it comes to replacing old hoses. Sometimes using an angled pick that is dulled at the end will do a good job breaking the hose free.

AUTOMATIC TRANSMISSION FLUID CHECK

STEPS INVOLVED The **automatic transmission fluid (ATF)** is another important fluid that should be checked regularly. Most automatic transmission fluid levels should be checked under the following conditions.

- The vehicle should be parked on a level surface.
- The transmission fluid should be at normal operating temperature. This may require the vehicle to be driven several miles before the level is checked.
- The engine should be running with the transmission in neutral or park as specified by the vehicle manufacturer.

NOTE: Honda and Acura manufacturers usually specify that the transmission fluid be checked with the engine off. The recommended procedure is usually stamped on the transmission dipstick or written in the owner's manual and/or service manual.

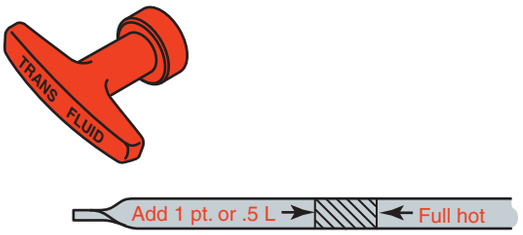


FIGURE 17–17 A typical automatic transmission dipstick.

To check the automatic transmission fluid, perform the following steps.

STEP 1 Start the engine and move the gear selector to all gear positions and return to park or neutral as specified by the vehicle manufacturer.

STEP 2 Remove the transmission/transaxle dipstick (fluid level indicator) and wipe it off using a clean cloth.

STEP 3 Reinsert the dipstick until fully seated. Remove the dipstick again and note the level. ● **SEE FIGURE 17–17.**

NOTE: Some transmissions or transaxles do not use a dipstick. Check service information for the exact procedure to follow to check the fluid level. Some vehicles require the use of a scan tool to check the level of the fluid.

- **Do not overfill any automatic transmission/transaxle.** Even if just 1/2 quart too much were added by mistake (for example, adding 1 quart when the fluid was at the "add" line instead of the correct amount of 1/2 quart) could cause the fluid to foam. Foaming of the ATF is caused by the moving parts inside the transmission/transaxle, which stir up the fluid and introduce air into it. This foamy fluid cannot adequately lubricate or operate the hydraulic clutches that make the unit function correctly.

NOTE: The "add" mark on most automatic transmission/transaxle dipsticks means that 1/2 quart (1/2 liter) of automatic transmission fluid needs to be added.

- **Smell the ATF on the dipstick.** If it seems burned or rancid, further service of the automatic transmission/transaxle will be necessary.
- **Look at the color of the fluid.** It should be red or light brown. A dark brown or black color indicates severe oxidation usually caused by too high an operating temperature. Further service and diagnosis of the automatic transmission/transaxle will be required.

NOTE: Chrysler warns that color and smell should not be used to determine the condition of ATF+4 used in most Chrysler-built vehicles since the 2000 model year. The dyes and additives can change during normal use and it is not an indication of fluid contamination. This is true for most highly friction-modified ATF. Always follow the vehicle manufacturer's recommendation.

TYPES OF AUTOMATIC TRANSMISSION FLUID Automatic transmission fluid is high-quality oil that has additives that resist oxidation, inhibit rust formation, and allow the fluid to flow easily at all temperatures. The automatic transmission fluid is dyed red for identification. Various vehicle manufacturers recommend a particular type of ATF based mainly on its friction characteristics. Friction is needed between the bands, plates, and clutches of an automatic transmission/transaxle.

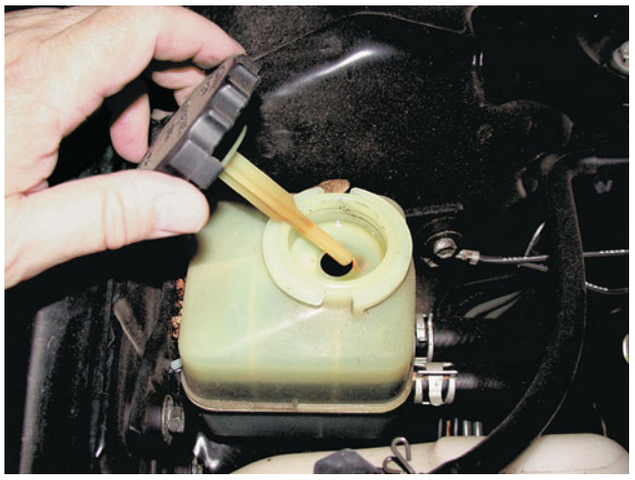


FIGURE 17–18 Most vehicles use a combination filler cap and level indicator (dipstick) that shows the level of power steering fluid in the reservoir.

TECH TIP

The Paper Towel Test

New ATF will penetrate a paper towel better than used oxidized ATF. To compare old fluid with new, place three drops of new fluid on a paper towel and three drops of used ATF on the paper towel about 3 inches from the first sample. Wait for 30 minutes. The new ATF will have expanded (penetrated through the paper towel) much farther than the old, oxidized fluid. This test can be used to convince a customer that the ATF should be changed according to the vehicle manufacturer's recommended interval even though, to the naked eye, the fluid looks okay.

See Chapter 128 for additional information about automatic transmission fluid and service procedures. Always use the exact ATF recommended by the vehicle manufacturer.

POWER STEERING FLUID

CHECKING POWER STEERING FLUID

Check power steering fluid level with the engine off. The cap for the power steering reservoir is marked with an icon of a steering wheel or the words "power steering." Remove the cap by twisting it counterclockwise and use the level indicator as part of the cap to determine the level.

Often the level marks are for cold and hot fluid.

- *If too low,* check for leaks especially at the high-pressure lines and fittings. Add the specified fluid to the correct level.
- *If too high,* use a fluid siphon pump or a "turkey baster" and remove the excess fluid until the level is correct.

TYPES OF POWER STEERING FLUID

The correct power steering fluid is *critical* to the operation and service life of the power steering system! The *exact* power steering fluid to use varies by vehicle manufacturer and sometimes between models made by the same vehicle manufacturer because of differences among various steering component manufacturers. Always check service information for the specified fluid to use. ● **SEE FIGURE 17–18.**

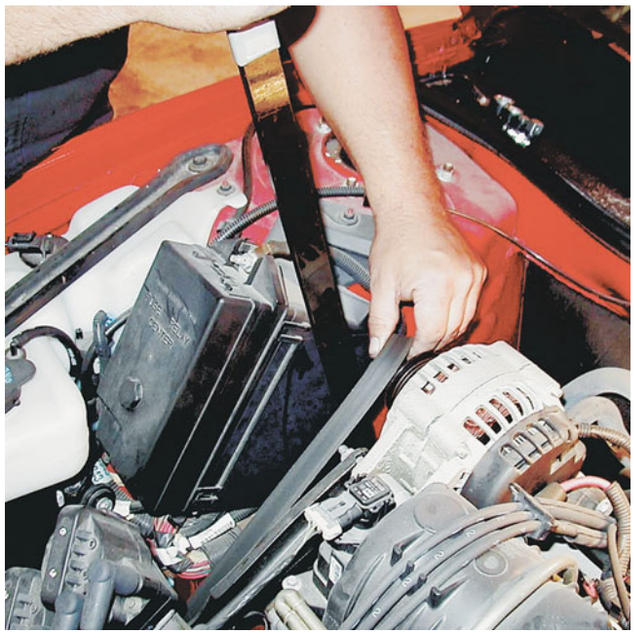


FIGURE 17–19 A special tool is useful when installing a new accessory drive belt. The long-handled wrench fits in a hole of the belt tensioner.

The types of power steering fluid can include:

- Automatic transmission fluid (check for the exact type)
- Power steering fluid
- Unique fluid that is specially designed for the vehicle

CAUTION: Do not use fluid that is labeled for all vehicles as this type may not be compatible with the seals used in the power steering system or provide the specified friction additives needed to provide the proper steering feel to the driver.

ACCESSORY DRIVE BELT INSPECTION

TYPES OF BELTS

Older V-belts (so-named because of their shape) are 34 degrees at the V. The pulley they ride through is generally 36 degrees. This 2-degree difference results in a wedging action and makes power transmission possible, but it is also the reason why V-belts must be closely inspected.

It is generally recommended that all belts, including the **serpentine** (or **Poly V**) belts be replaced every four to seven years. When a belt that turns the water pump breaks, the engine could rapidly overheat causing serious engine damage, and if one belt breaks, it often causes the other belts to become tangled, causing them to break. ● **SEE FIGURES 17–19 AND 17–20.**

BELT TENSION MEASUREMENT

There are four ways that vehicle manufacturers specify that the belt tension is within factory specifications.

1. **Belt tension gauge.** A belt tension gauge is needed to achieve the specified belt tension. Install the belt and operate the engine with all of the accessories turned on to "run-in" the belt



FIGURE 17–20 A typical worn serpentine accessory drive belt. Newer belts made from ethylene propylene diene monomer (EPDM) do not crack like older belts that were made from neoprene rubber.



FIGURE 17–21 A belt tension gauge displays the belt tension in pounds of force.

for at least five minutes. Adjust the tension of the accessory drive belt to factory specifications or use the table below for an example of the proper tension based on the size of the belt. ● **SEE FIGURE 17–21**.

Serpentine Belts

Number of Ribs Used	Tension Range (lb)
3	45–60
4	60–80
5	75–100
6	90–125
7	105–145

V-Belts

V-Belt Top Width (in.)	Tension Range (lb)
1/4	45–65
5/16	60–85
25/64	85–115
31/64	105–145

Replace any serpentine belt that has more than three cracks in any one rib that appears in a 3 inch span.

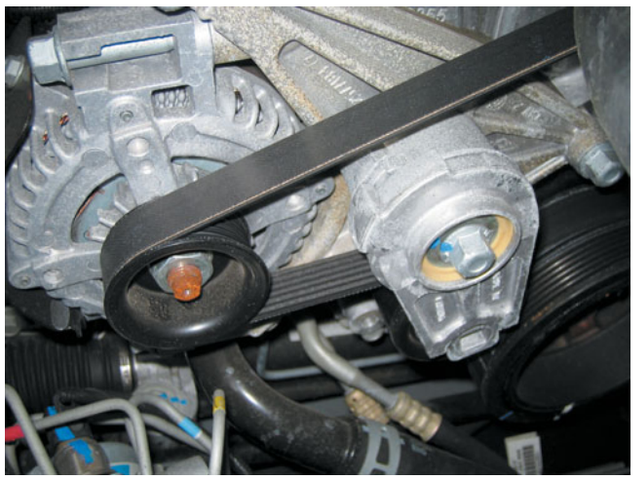


FIGURE 17–22 A spring-loaded accessory drive belt tensioner.

TECH TIP

The Water Spray Trick

Lower-than-normal alternator output could be the result of a loose or slipping drive belt. All belts (V and serpentine multigroove) use an interference angle between the angle of the Vs of the belt and the angle of the Vs on the pulley. Over time this interference angle is worn off the edges of the V of the belt. As a result, the belt may start to slip and make a squealing sound even if tensioned properly.

A fast method to determine if the noise is from the belt is to spray water from a squirt bottle at the belt with the engine running. If the noise stops, the belt is the cause of the noise. The water quickly evaporates; therefore, water simply finds the problem, it does not provide a short-term fix.

2. **Marks on a tensioner.** Many tensioners have marks that indicate the normal operating tension range for the accessory drive belt. Check service information for the preferred location of the tensioner mark. ● **SEE FIGURE 17–22**.
3. **Torque wrench reading.** Some vehicle manufacturers specify that a beam-type torque wrench be used to determine the torque needed to rotate the tensioner. If the torque reading is below specifications, the tensioner must be replaced.
4. **Deflection.** Depress the belt between the two pulleys that are the farthest apart and the flex or deflection should be 0.5 inch.

BELT ROUTING GUIDE Always check the belt routing diagram located on the underhood sticker or in service information for the proper routing when replacing an accessory drive belt. The belt routing can vary depending on engine size and accessories.

TIRE AND WHEEL SERVICE

INFLATION PRESSURE Tire pressure should be checked when the tires are cold. As a vehicle is driven, the flexing of the tire and friction between the tire and the road causes an increase in temperature.

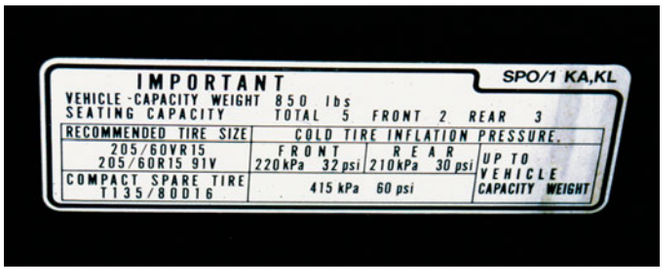


FIGURE 17–23 The specified tire inflation pressure is printed on a placard on the driver's door or doorpost. This information may also be located in the glove compartment, the owner's manual, and in service information.

- As the tire heats up, the air inside the tire also increases in temperature.
- The increased temperature of the air increases the air pressure inside the tire.
- The air pressure typically increases in pressure 4 to 6 psi after the vehicle has been driven several miles.
- If air is then removed from the hot tire, the tire would be underinflated. The tire pressure specified is for a tire that has not been driven and is therefore cold, so the air pressure should be checked before the vehicle has been driven more than 2 miles (3 km).

NOTE: Tire pressure changes according to air temperature about 1 psi per 10°F; therefore, during a change of season the tire pressure has to be adjusted. For example, when the summer temperature of 80°F changes to 40°F in the fall, the tire pressure will drop about 4 psi (80 − 40 = 40).

HOW TO CHECK TIRE PRESSURE

Use a good-quality tire pressure gauge and push it against the tire valve stem after removing the cap. Be sure no air escapes when the pressure gauge is used as this will cause an inaccurate reading. Compare the pressure reading with the specified tire pressure. The specified pressure is located on a placard attached to the driver's door or doorpost or in the glove compartment. ● **SEE FIGURE 17–23**.

CAUTION: Do not inflate tires to the maximum rating on the tire sidewall. Even though this pressure represents the maximum tire pressure, inflating the tires to this pressure usually results in a very harsh ride and often unacceptable handling.

SPECIFIED TIRE PRESSURE

The specified tire inflation pressure should always be used when checking or adjusting tire pressure. Tire pressure should be checked and adjusted if necessary after a tire rotation has been completed because some vehicles require different inflation pressure for front and rear tires. Therefore, when the tires are rotated, the front and rear tire inflation pressure may need to be adjusted. The spare tire should also be checked at each oil change interval. Check service information for the exact inflation pressure.

The recommendation sometimes includes a statement about tire pressures to use if operating under all highway-driving conditions or operating the vehicle in a fully loaded condition. Specifications for these conditions commonly include increasing the pressure, usually about 4 to 6 psi (27 to 41 kPa). ● **SEE FIGURE 17–24**.

TIRE INSPECTION

All tires should be carefully inspected for faults in the tire itself or for signs that something may be wrong with the steering or suspension systems of the vehicle. The tires should be checked for the following conditions.

- Thread depth (2/32 of an inch is the standard minimum allowable tread depth in most states)
- Unequal wear
- Cuts in the tread or sidewall
- Bulges or uneven sidewalls

Check the spare tire for proper inflation pressure as well as condition of the tire and wheel. See Chapter 114 for additional information on tire service procedure.



FIGURE 17–24 An electronic tire pressure gauge is usually more accurate than a mechanical "pencil type" gauge and more likely to provide consistent pressure readings. Do not allow air to escape when testing or the reading will not be accurate.

TECH TIP

Two Quick Checks

If the vehicle is hoisted on a frame-contact lift, perform two quick checks:

1. Spin each tire to check that the brakes are not dragging. You should be able to turn all four wheels by hand if the parking brake is off and the transmission is in neutral.
2. When spinning the tire, look over the top of the tire to check if it is round. An improperly mounted tire or a tire that is out-of-round due to a fault in the tire can be detected by watching for the outside of the tire to move up and down as it is being rotated.

TIRE ROTATION

To assure long life and even tire wear, it is important to rotate each tire to another location. Some rear-wheel-drive vehicles, for example, may show premature tire wear on the front tires. The wear usually starts on the outer tread row and usually appears as a front-to-back (high and low) wear pattern on individual tread blocks. These *blocks of tread* rubber are deformed during cornering, stopping, and turning, which can cause tire noise and/or tire roughness. While some shoulder wear on front tires is normal, it can be reduced by proper inflation, alignment, and tire rotation. ● **SEE FIGURE 17–25** for suggested methods of rotation.

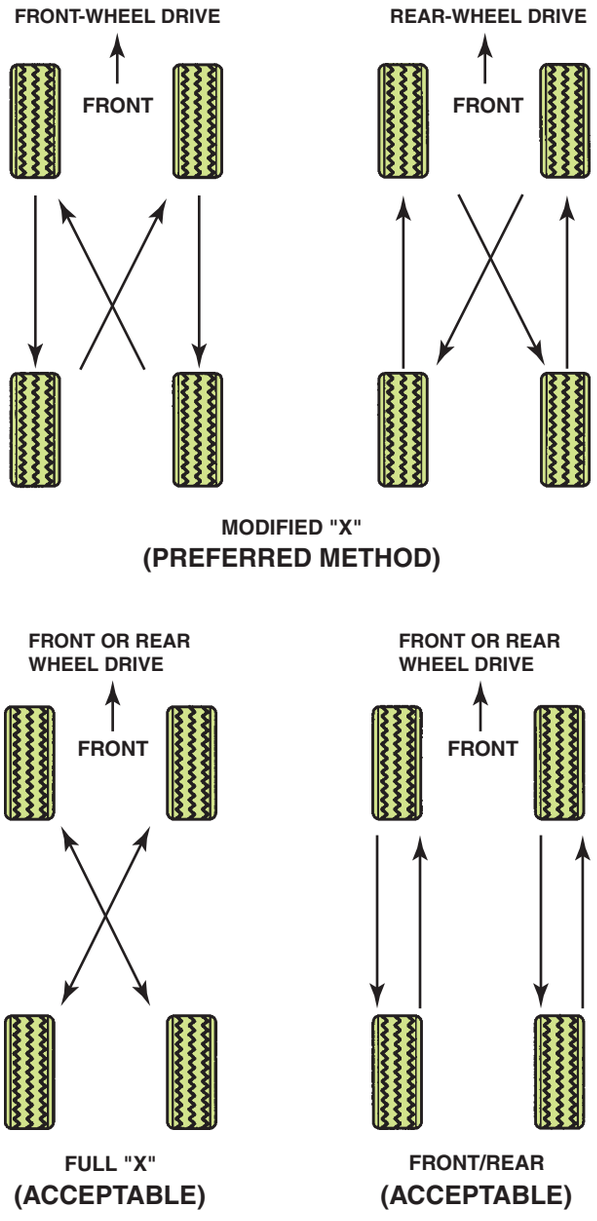


FIGURE 17–25 The method most often recommended is the modified X method. Using this method, each tire eventually is used at each of the four wheel locations. An easy way to remember the sequence, whether front-wheel drive or rear-wheel drive, is "Drive wheels straight, cross the nondrive wheels."

NOTE: Radial tires can cause a radial pull due to their construction. If the wheel alignment is correct, attempt to correct a pull by rotating the tires front to rear or, if necessary, side to side.

HINT: To help remember when to rotate the tires, just remember that it should be done at every other oil change. Most manufacturers recommend changing the engine oil every 5,000 miles (8,000 km) or every six months and recommend tire rotation every 10,000 (16,000 km) miles or every year.

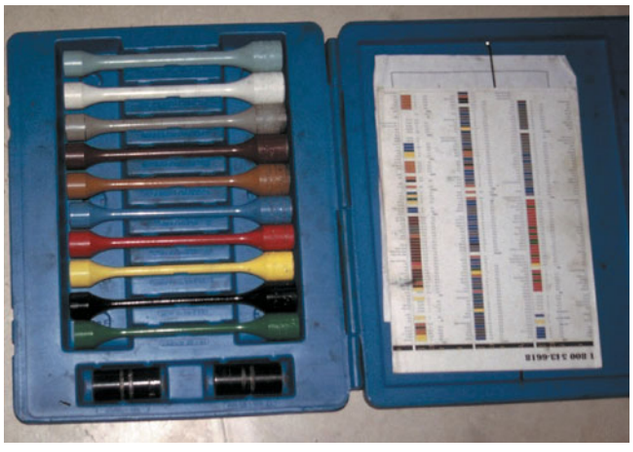
WHEEL MOUNTING TORQUE

There are two commonly used methods to ensure proper tire lug nut torque.

- **Torque wrench.** Using a torque wrench is the preferred method to tighten the wheel lug nuts.
- **Torque sticks.** These long sticks are calibrated to transmit a limited amount of torque to the lug nut when used according to factory instructions. Make certain that the wheel studs are clean and dry and torqued to manufacturer's specifications. Most vehicles specify a tightening torque of between 80 and 100 lb-ft (108 and 136 N-m).



(a)



(b)

FIGURE 17–26 (a) A torque absorbing adaptor commonly called a "torque stick" is being used to tighten lug nuts. The adapter should not be held during the tightening process because this can affect the torque applied and could cause personal injury if the torque stick broke. (b) A color-coded assortment of torque sticks.

TECH TIP

Check for Wheel Lock Key

Many vehicles have wheel locks that require a special key to remove. The wise technician should always ask the customer or service writer about wheel locks before pulling the vehicle into the shop or before the vehicle is hoisted.

CAUTION: Most manufacturers warn that the wheel studs should not be oiled or lubricated with grease because this can cause the wheel lug nuts to loosen while driving.

Always tighten lug nuts gradually, in the proper sequence (tighten one nut, skip one, and tighten the next nut), to prevent warping the brake drums or rotors, or bending a wheel. ● **SEE FIGURE 17–26.**

NOTE: Anytime you install a brand-new set of aluminum wheels, retorque the wheels after the first 25 miles. The soft aluminum often compresses slightly, loosening the torque on the wheels.



FIGURE 17–27 A hand-operated grease gun is being used to lubricate the steering component through a grease fitting.



FIGURE 17–28 Most vehicle manufacturers recommend the use of grease meeting the NLGI #2 and "GC" for wheel bearings and "LB" for chassis lubrication. Many greases have both designations and therefore can be used for wheel bearings or chassis lubrication.

REAL WORLD FIX

Waiting for the Second Click Story

A student service technician was observed applying a lot of force to a clicker-type torque wrench attached to a wheel lug nut. When the instructor asked what he was doing, the student replied that he was turning the lug nut tighter until he heard a second click from the torque wrench.

This was confusing to the instructor until the student explained that he had heard a second click of the torque wrench during the demonstration. The instructor at once realized that the student had heard a click when the proper torque was achieved, plus another click when the force on the torque wrench was released.

No harm occurred to the vehicle because all of the lug nuts were reinstalled and properly torqued. The instructor learned that a more complete explanation for the use of click-type torque wrenches was needed.

TECH TIP

Watch Out for Vents that Look Like Grease Fittings

Watch for what looks like a grease (Zerk) fitting but is somewhat smaller, as this may be a vent such as found on a late-model Dodge Caravan on the ball joints. If the grease gun does not fit on it, do not be tempted to remove and replace with a grease fitting.

CHASSIS LUBRICATION

GREASE FITTINGS Chassis lubrication refers to the greasing of parts that rub against each other or installing grease into a pivot (or ball joints) through a grease fitting. Grease fittings are also called **Zerk fittings** (named for Oscar U. Zerk) or **Alemite fittings** (named for the manufacturer of early grease fittings). These fittings contain a one-way check valve that prevents the grease from escaping. Grease fittings are used on steering components, such as tie-rod ends, and in the suspension ball joints, which require lubrication to prevent wear and noise caused by the action of a ball rotating within a joint during vehicle operation. ● **SEE FIGURE 17–27**.

The procedure for greasing a grease fitting includes the following steps.

STEP 1 Wipe off the fitting with a shop cloth.

STEP 2 Make sure the grease gun coupler is fully seated on the fitting.

STEP 3 Apply grease only until the dust boot swells.

STEP 4 If the fitting will not accept grease, replace it with a new one and retry.

STEP 5 Remove the grease gun and wipe any spilled grease from the fitting.

CAUTION: If too much grease is forced into a sealed grease boot, the boot itself may rupture, requiring the entire joint to be replaced.

TYPES OF GREASE Vehicle manufacturers specify the type and consistency of grease for each application. The technician should know what these specifications mean. Grease is oil with a thickening agent added to allow it to be installed in places where a liquid lubricant would not stay. Greases are named for their thickening agent, such as aluminum, barium, calcium, lithium, or sodium.

CAUTION: Grease types are often not compatible with each other.

The **American Society for Testing Materials (ASTM)** specifies the consistency of grease using a **penetration test.** The **National Lubricating Grease Institute (NLGI)** uses the penetration test as a guide to assign the grease a number. Low numbers are very fluid and higher numbers are more firm or hard. Most vehicle manufacturers specify NLGI #2 for wheel bearing and chassis lubrication. ● **SEE FIGURE 17–28**.

NLGI also specifies grease by its use, as follows:

- The "GC" designation is acceptable for wheel bearings.
- The "LB" designation is acceptable for chassis lubrication.

Many greases are labeled with both GC and LB and are therefore acceptable for both wheel bearings and chassis use, such as in lubricating ball joints and tie-rod ends.

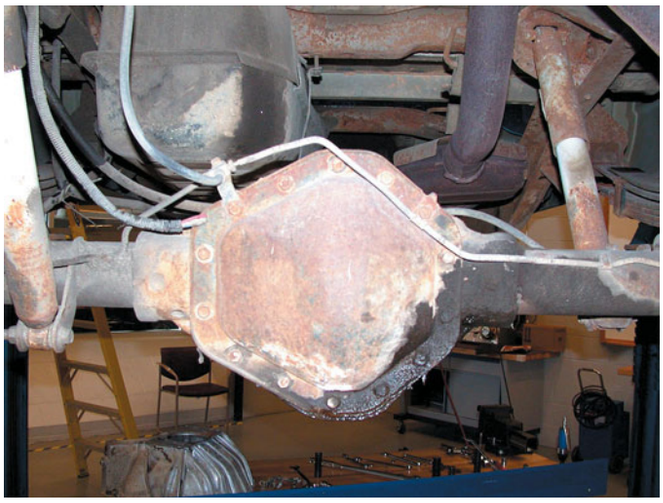


FIGURE 17–29 This differential assembly has been leaking fluid. The root cause should be determined and the unit filled to the proper level using the specified lubricant, to help prevent early failure and an expensive repair later.

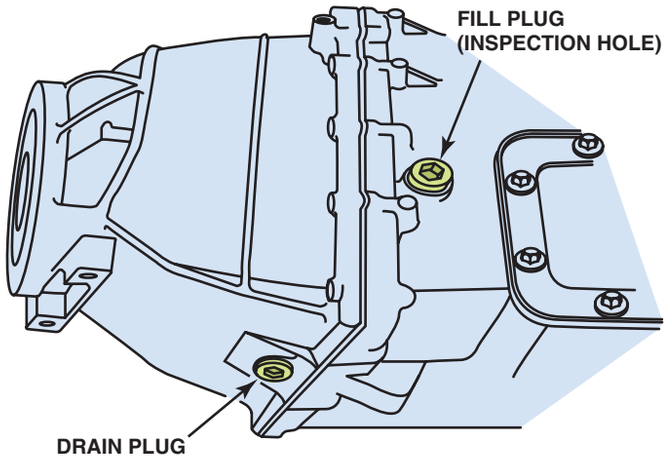


FIGURE 17–30 Always ensure that the fill plug can be accessed and removed *before* draining the fill from a manual transmission.

DIFFERENTIAL FLUID CHECK

PROCEDURE FOR CHECKING Rear-wheel-drive vehicles use a differential in the rear of the vehicle to change the direction of power flow from the engine to the rear wheels. The differential also provides a gear reduction to increase engine torque applied to the drive wheels. Four-wheel-drive vehicles also use a differential at the front of the vehicle in addition to the differential in the rear. To check the differential fluid level and condition, perform the following steps.

STEP 1 Hoist the vehicle safely.

STEP 2 Visually check for any signs of leakage. ● **SEE FIGURE 17–29.**

STEP 3 Remove the inspection plug from the side or rear cover of the differential assembly.

STEP 4 Insert your small finger into the hole in the housing and then remove your finger.

- If the differential fluid is on your finger, then the fluid level is okay. Rub the fluid between your fingers. If the fluid is not gritty feeling, reinstall the inspection plug. If the fluid is gritty feeling, further service will be necessary to determine the cause and correct it.
- If the differential fluid is not on your finger, then the fluid level is too low.

NOTE: The reason for the low fluid level should be determined. If repairs are not completed immediately, additional differential fluid should be added by pumping it into the differential through the inspection hole.

DIFFERENTIAL LUBRICANTS All differentials use hypoid gear sets; and a special lubricant is necessary because the gears both roll and slide between their meshed teeth. Gear lubes are specified by the **American Petroleum Institute (API).** Most differentials require:

1. SAE 80W-90 GL-5 *or*
2. SAE 75W-90 GL-5 *or*
3. SAE 80W GL-5

Limited slip differentials (often abbreviated LSD) often use an additive that modifies the friction characteristics of the rear axle lubricant to prevent chattering while cornering.

TECH TIP

Check the Fill Plug Before Draining a Transmission

Experienced technicians have learned that it is wise to check that the fill plug can be removed *before* draining the manual transmission or transfer case through the drain plug. If the fill plug cannot be removed, then the fluid should not be drained until the problem is resolved. Once the fluid has been drained, there is no option but to do whatever it takes to get the fill plug open. This process is often difficult and may result in having to replace the entire assembly. ● **SEE FIGURE 17–30.**

MANUAL TRANSMISSION/ TRANSAXLE LUBRICANT CHECK

TYPES OF MANUAL TRANSMISSION FLUID Manual transmissions/transaxles may use any one of the following lubricants.

- Gear lube (usually SAE 80W-90)
- Automatic transmission fluid (ATF)
- Engine oil (usually SAE 5W-30)
- Manual transmission fluid (sometimes called **synchromesh transmission fluid**, or **STF**). This type of lubricant is similar to ATF, with special additives to ease shifting especially when cold.

PROCEDURE FOR CHECKING To check manual transmissions/transaxles lubricant, perform the following:

- Hoist the vehicle safely.
- Locate the transmission/transaxle inspection (fill) plug. Consult the factory service manual for the proper plug to remove, to check the fluid level.
- If the fluid drips out of the hole, then the level is correct. If the fluid runs out of the hole, the level is too full. Allow it to flow out until it stops. The correct level of fluid is at the bottom of the inspection hole.
- If low, first determine the correct fluid to use and then fill until the fluid level is at the bottom of the inspection hole or until the fluid runs out of the inspection hole.

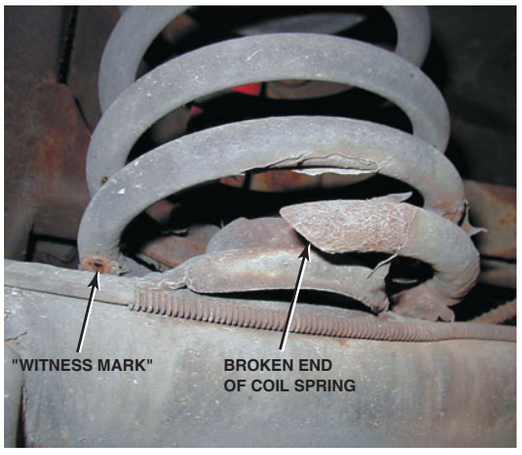


FIGURE 17–31 A broken coil spring was found during an under-vehicle inspection. The owner was not aware of a problem and it did not make any noise, but the vehicle stability was affected.



FIGURE 17–32 This corroded muffler was found during a visual inspection, but was not detected by the driver because it was relatively quiet.

UNDER-VEHICLE INSPECTION

VISUAL CHECKS Other items underneath the vehicle that may need checking or lubricating include:

- Shock absorbers and springs. ● **SEE FIGURE 17–31**.
- Transmission/transaxle shift linkage (check the service manual for the correct lubricant to use)
- Exhaust system including all pipes and hangers. ● **SEE FIGURE 17–32**.
- Brake lines for evidence of damage or leakage
- Shock absorbers for leakage or damaged mounts
- Steering linkage for obvious looseness or damaged or missing parts
- Parking brake cable guides

CAUTION: Do not lubricate plastic-coated parking brake cables. The lubricant can destroy the plastic coating.

REVIEW QUESTIONS

1. Why should brake fluid not be filled above the full or MAX level as indicated on the master cylinder reservoir?
2. Why should brake fluid be kept in an airtight container?
3. How do you check differential fluid?
4. What are four lubricants that a manual transmission/transaxle *may* require depending on exact year, make, and model of the vehicle.

CHAPTER QUIZ

1. When should the engine oil be replaced?
   a. According to the vehicle manufacturer's recommended interval based on time and mileage, whichever occurs first
   b. Every three months regardless of miles
   c. Every 3,000 miles regardless of time
   d. All of the above
2. Most vehicle manufacturers specify brake fluid that meets what specification?
   a. DOT 2 **c.** DOT 4
   b. DOT 3 **d.** DOT 5
3. The cabin filter can be accessed from _____.
   a. Under the hood on some vehicles
   b. Under the dash on some vehicles
   c. From under the vehicle on some vehicles
   d. Either a or b
4. Before draining a manual transmission to replace the fluid, what should the technician do first?
   a. Check service information for the specified fluid
   b. Check to see if the fill plug can be removed
   c. Purchase SAE 80W-90 gear lube
   d. Both a and b
5. Coolant can be checked using _____.
   a. Boiling/freezing points using a refractometer and hydrometer
   b. Visual inspection
   c. Test strips
   d. All of the above
6. Accessory drive belt tension is determined by _____.
   a. Marks on the tensioner
   b. Torque required to rotate the tensioner using a beam-type torque wrench
   c. Belt tension using a belt tension gauge
   d. Any of the above depending on the specified procedure as found in service information.
7. Using the modified X tire rotation method on a front-wheel-drive vehicle would place the right front tire on the _____.
   a. Left front **c.** Right rear
   b. Left rear **d.** Right front
8. Most vehicle manufacturers specify a lug nut (wheel nut) tightening torque specification of about _____.
   a. 80 to 100 lb-ft **c.** 125 to 150 lb-ft
   b. 100 to 125 lb-ft **d.** 150 to 175 lb-ft

9. A grease labeled NLGI #2 GC is suitable for use on what vehicle components?
   a. Wheel bearings
   b. Chassis parts
   c. Both wheel bearings and chassis parts
   d. Door hinges only

10. A service technician removed the inspection/fill plug from the differential of a rear-wheel- drive vehicle and gear lube started to flow out. Technician A says to quickly replace the plug to prevent any more loss of gear lube. Technician B says to catch the fluid and allow the fluid to continue to drain. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

SECTION VI Engine Repair

18 Gasoline Engine Operation, Parts, and Specifications
19 Diesel Engine Operation and Diagnosis
20 Coolant
21 Cooling System Operation and Diagnosis
22 Engine Oil
23 Lubrication System Operation and Diagnosis
24 Intake and Exhaust Systems
25 Turbocharging and Supercharging
26 Engine Condition Diagnosis
27 In-Vehicle Engine Service
28 Engine Removal and Disassembly
29 Engine Cleaning and Crack Detection
30 Cylinder Head and Valve Guide Service
31 Valve and Seat Service
32 Camshafts and Valve Trains
33 Pistons, Rings, and Connecting Rods
34 Engine Blocks
35 Crankshafts, Balance Shafts, and Bearings
36 Gaskets and Sealants
37 Engine Assembly and Dynamometer Testing
38 Engine Installation and Break-in

chapter 18

GASOLINE ENGINE OPERATION, PARTS, AND SPECIFICATIONS

OBJECTIVES: **After studying Chapter 18, the reader should be able to:** • Prepare for Engine Repair (A1) ASE certification test content area "A" (General Engine Diagnosis). • Explain how a four-stroke cycle gasoline engine operates. • List the various characteristics by which vehicle engines are classified. • Discuss how a compression ratio is calculated. • Explain how engine size is determined. • Describe how displacement is affected by the bore and stroke of the engine.

KEY TERMS: Block 147 • Bore 152 • Bottom dead center (BDC) 149 • Boxer 149 • Cam-in-block design 150 • Camshaft 150 • Combustion 147 • Combustion chamber 147 • Compression ratio (CR) 155 • Connecting rod 149 • Crankshaft 149 • Cycle 149 • Cylinder 149 • Displacement 154 • Double overhead camshaft (DOHC) 151 • Exhaust valve 149 • External combustion engine 147 • Four-stroke cycle 149 • Intake valve 149 • Internal combustion engine 147 • Mechanical force 147 • Mechanical power 147 • Naturally aspirated 151 • Nonprincipal end 152 • Oil galleries 148 • Overhead valve (OHV) 150 • Pancake 149 • Piston stroke 149 • Principal end 152 • Pushrod engine 150 • Rotary engine 152 • Single overhead camshaft (SOHC) 150 • Stroke 154 • Supercharger 151 • Top dead center (TDC) 149 • Turbocharger 151 • Wankel engine 152

PURPOSE AND FUNCTION

The purpose and function of an engine is to convert the heat energy of burning fuel into mechanical energy. In a typical vehicle, mechanical energy is then used to perform the following:

- Propel the vehicle
- Power the air-conditioning system and power steering
- Produce electrical power for use throughout the vehicle

ENERGY AND POWER

Engines use energy to produce power. The chemical energy in fuel is converted to heat energy by the burning of the fuel at a controlled rate. This process is called **combustion.** If engine combustion occurs within the power chamber, the engine is called an **internal combustion engine.**

NOTE: An external combustion engine burns fuel outside of the engine itself, such as a steam engine.

Engines used in automobiles are internal combustion heat engines. They convert the chemical energy of the gasoline into heat within a power chamber that is called a **combustion chamber.** Heat energy released in the combustion chamber raises the temperature of the combustion gases within the chamber. The increase in gas temperature causes the pressure of the gases to increase. The pressure developed within the combustion chamber is applied to the head of a piston to produce a usable **mechanical force**, which is then converted into useful **mechanical power.**

ENGINE CONSTRUCTION OVERVIEW

BLOCK All automotive and truck engines are constructed using a solid frame, called a **block.** A block is constructed of cast iron or aluminum and provides the foundation for most of the engine components and systems. The block is cast and then machined to very close tolerances to allow other parts to be installed.

ROTATING ASSEMBLY Pistons are installed in the block and move up and down during engine operation. Pistons are connected to connecting rods, which connect the pistons to the crankshaft. The crankshaft converts the up-and-down motion of the piston to rotary motion, which is then transmitted to the drive wheels and propels the vehicle. ● **SEE FIGURE 18–1**.

CYLINDER HEADS All engines use a cylinder head to seal the top of the cylinders, which are in the engine block. The cylinder head also contains both intake valves that allow air and fuel into the cylinder and exhaust valves, which allow the hot gases left over to escape from the engine. Cylinder heads are constructed of cast iron or aluminum and are then machined for the valves and other valve-related components. ● **SEE FIGURE 18–2**.



FIGURE 18–1 The rotating assembly for a V-8 engine that has eight pistons and connecting rods and one crankshaft.

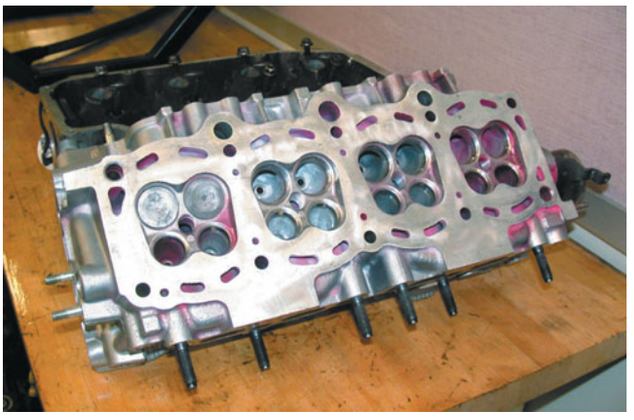


FIGURE 18–2 A cylinder head with four valves per cylinder, two intake valves (larger) and two exhaust valves (smaller).

? FREQUENTLY ASKED QUESTION

What Is a Flat-Head Engine?

A flat-head engine is an older type engine design that has the valves in the block. The valves are located next to the cylinders and the air-fuel mixture, and exhaust flows through the block to the intake and exhaust manifolds. Because the valves are in the block, the heads are flat and, therefore, are called flat-head engines. The most commonly known was the Ford flat-head V-8 produced from 1932 until 1953. Typical flat-head engines included:

- Inline 4-cylinder engines (many manufacturers)
- Inline 6-cylinder engines (many manufacturers)
- Inline 8-cylinder engines (many manufacturers)
- V-8s (Cadillac and Ford)
- V-12s (Cadillac and Lincoln)

ENGINE PARTS AND SYSTEMS

INTAKE AND EXHAUST MANIFOLDS Air and fuel enter the engine through an intake manifold and exit the engine through the exhaust manifold. Intake manifolds operate cooler than exhaust manifolds and are therefore constructed of nylon-reinforced plastic or aluminum. Exhaust manifolds must be able to withstand hot exhaust gases, so most are constructed from cast iron or steel tubing.

COOLING SYSTEM All engines must have a cooling system to control engine temperatures. While some older engines were air cooled, all current production passenger vehicle engines are cooled by circulating antifreeze coolant through passages in the block and cylinder head. The coolant picks up the heat from the engine and after the thermostat opens, the water pump circulates the coolant through the radiator where the excess heat is released to the outside air, cooling the coolant. The coolant is continuously circulated through the cooling system and the temperature is controlled by the thermostat. ● **SEE FIGURE 18–3**.

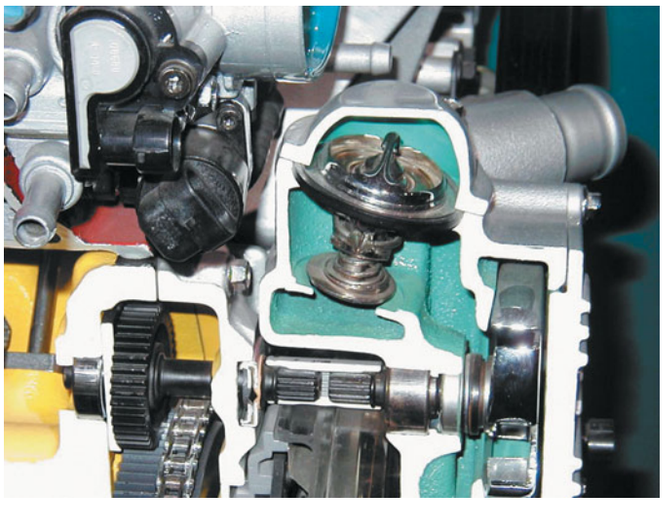


FIGURE 18–3 The coolant temperature is controlled by the thermostat, which opens and allows coolant to flow to the radiator when the temperature reaches the rating temperature of the thermostat.

LUBRICATION SYSTEM All engines contain moving and sliding parts that must be kept lubricated to reduce wear and friction. The oil pan, bolted to the bottom of the engine block, holds 4 to 7 quarts (4 to 7 liters) of oil. An oil pump, which is driven by the engine, forces the oil through the oil filter and then into passages in the crankshaft and block. These passages are called **oil galleries.** The oil is also forced up to the valves and then falls down through openings in the cylinder head and block, then back into the oil pan. ● **SEE FIGURE 18–4**.

FUEL SYSTEM AND IGNITION SYSTEM All engines require both a fuel system to supply fuel to the cylinders and an ignition system to ignite the air-fuel mixture in the cylinders. The fuel system includes the following components.

- Fuel tank, where fuel is stored and where most fuel pumps are located
- Fuel filter and lines, which transfer the fuel for the fuel tank to the engine
- Fuel injectors, which spray fuel into the intake manifold or directly into the cylinder, depending on the type of system used

The ignition system is designed to take 12 volts from the battery and convert it to 5,000 to 40,000 volts needed to jump the gap of a spark plug. Spark plugs are threaded into the cylinder head of each cylinder, and when the spark occurs, it ignites the air-fuel mixture in the cylinder creating pressure and forcing the piston down in the cylinder. The following components are part of the ignition system.

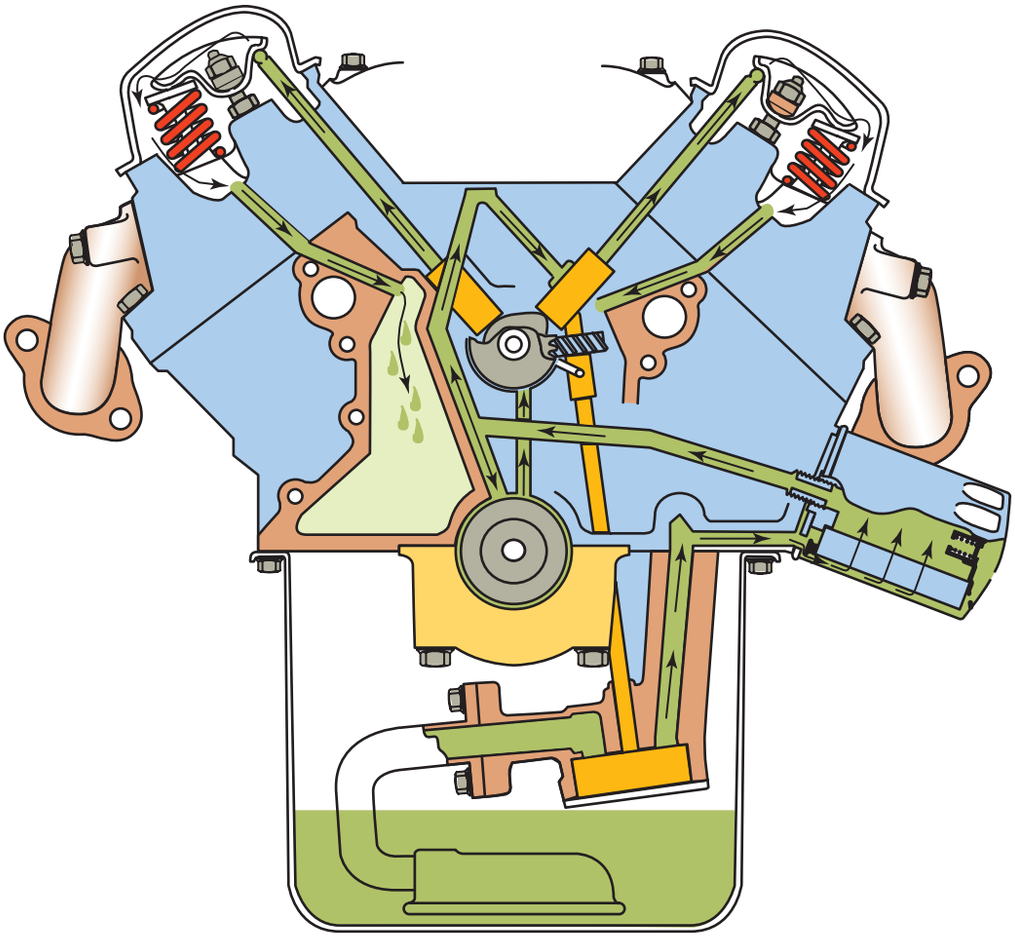


FIGURE 18–4 A typical lubrication system, showing the oil pan, oil pump, oil filter, and oil passages.

- **Spark plugs.** Provide an air gap inside the cylinder where a spark occurs to start combustion
- **Sensor(s).** Includes crankshaft position (CKP) and camshaft position (CMP) sensors, used by the powertrain control module (PCM) to trigger the ignition coil(s) and the fuel injectors
- **Ignition coils.** Increase battery voltage to 5,000 to 40,000 volts
- **Ignition control module (ICM).** Controls when the spark plug fires
- **Associated wiring.** Electrically connects the battery, ICM, coil, and spark plugs

FOUR-STROKE CYCLE OPERATION

PRINCIPLES The first **four-stroke cycle** engine was developed by a German engineer, Nickolaus Otto, in 1876. Most automotive engines use the four-stroke cycle of events. The process begins by the starter motor rotating the engine until combustion takes place. The four-stroke cycle is repeated for each cylinder of the engine. ● **SEE FIGURE 18–5**.

A piston that moves up and down, or reciprocates, in a **cylinder** can be seen in Figure 18–5. The piston is attached to a **crankshaft** with a **connecting rod.** This arrangement allows the piston to reciprocate (move up and down) in the cylinder as the crankshaft rotates. ● **SEE FIGURE 18–6**.

OPERATION Engine cycles are identified by the number of piston strokes required to complete the cycle. A **piston stroke** is a one-way piston movement either from top to bottom or bottom to top of the cylinder. During one stroke, the crankshaft rotates 180 degrees (1/2 revolution). A **cycle** is a complete series of events that continually repeats. Most automobile engines use a four-stroke cycle.

- **Intake stroke.** The **intake valve** is open and the piston inside the cylinder travels downward, drawing a mixture of air and fuel into the cylinder. The crankshaft rotates 180 degrees from **top dead center (TDC)** to **bottom dead center (BDC)** and the camshaft rotates 90 degrees.
- **Compression stroke.** As the engine continues to rotate, the intake valve closes and the piston moves upward in the cylinder, compressing the air-fuel mixture. The crankshaft rotates 180 degrees from bottom dead center (BDC) to top dead center (TDC) and the camshaft rotates 90 degrees.
- **Power stroke.** When the piston gets near the top of the cylinder, the spark at the spark plug ignites the air-fuel mixture, which forces the piston downward. The crankshaft rotates 180 degrees from top dead center (TDC) to bottom dead center (BDC) and the camshaft rotates 90 degrees.
- **Exhaust stroke.** The engine continues to rotate, and the piston again moves upward in the cylinder. The exhaust valve opens, and the piston forces the residual burned gases out of the **exhaust valve** and into the exhaust manifold and exhaust system. The crankshaft rotates 180 degrees from bottom dead center (BDC) to top dead center (TDC) and the camshaft rotates 90 degrees.

This sequence repeats as the engine rotates. To stop the engine, the electricity to the ignition system is shut off by the ignition switch, which stops the spark to the spark plugs.

The combustion pressure developed in the combustion chamber at the correct time will push the piston downward to rotate the crankshaft.

THE 720-DEGREE CYCLE Each cycle (four strokes) of events requires that the engine crankshaft make two complete revolutions, or 720 degrees (360 degrees × 2 = 720 degrees). Each stroke of the cycle requires that the crankshaft rotate 180 degrees. The greater the number of cylinders, the closer together the power strokes of the individual cylinders will occur. The number of degrees that the crankshaft rotates between power strokes can be expressed as an angle. To find the angle between cylinders of an engine, divide the number of cylinders into 720 degrees.

Angle with 3 cylinders: 720/3 = 240 degrees
Angle with 4 cylinders: 720/4 = 180 degrees
Angle with 5 cylinders: 720/5 = 144 degrees
Angle with 6 cylinders: 720/6 = 120 degrees
Angle with 8 cylinders: 720/8 = 90 degrees
Angle with 10 cylinders: 720/10 = 72 degrees

This means that in a 4-cylinder engine, a power stroke occurs at every 180 degrees of the crankshaft rotation (every 1/2 rotation). A V-8 is a much smoother operating engine because a power stroke occurs twice as often (every 90 degrees of crankshaft rotation).

ENGINE CLASSIFICATION AND CONSTRUCTION

Engines are classified by several characteristics, including:

- **Number of strokes.** Most automotive engines use the four-stroke cycle.
- **Cylinder arrangement.** An engine with more cylinders is smoother operating because the power pulses produced by the power strokes are more closely spaced. An inline engine places all cylinders in a straight line. The 4-, 5-, and 6-cylinder engines are commonly manufactured inline engines. A V-type engine, such as a V-6 or V-8, has the number of cylinders split and built into a V shape. ● **SEE FIGURE 18–7**. Horizontally opposed 4- and 6-cylinder engines have two banks of cylinders that are horizontal, resulting in a low engine. This style of engine is used in Porsche and Subaru engines, and is often called the **boxer** or **pancake** engine design. ● **SEE FIGURE 18–8**.
- **Longitudinal and transverse mounting.** Engines may be mounted either parallel with the length of the vehicle (longitudinally) or crosswise (transversely). ● **SEE FIGURES 18–9 AND 18–10**. The same engine may be mounted in various vehicles in either direction.

  NOTE: Although it might be possible to mount an engine in different vehicles both longitudinally and transversely, the engine component parts may *not* be interchangeable. Differences can include different engine blocks and crankshafts, as well as different water pumps.

- **Valve and camshaft number and location.** The number of valves per cylinder and the number and location of camshafts

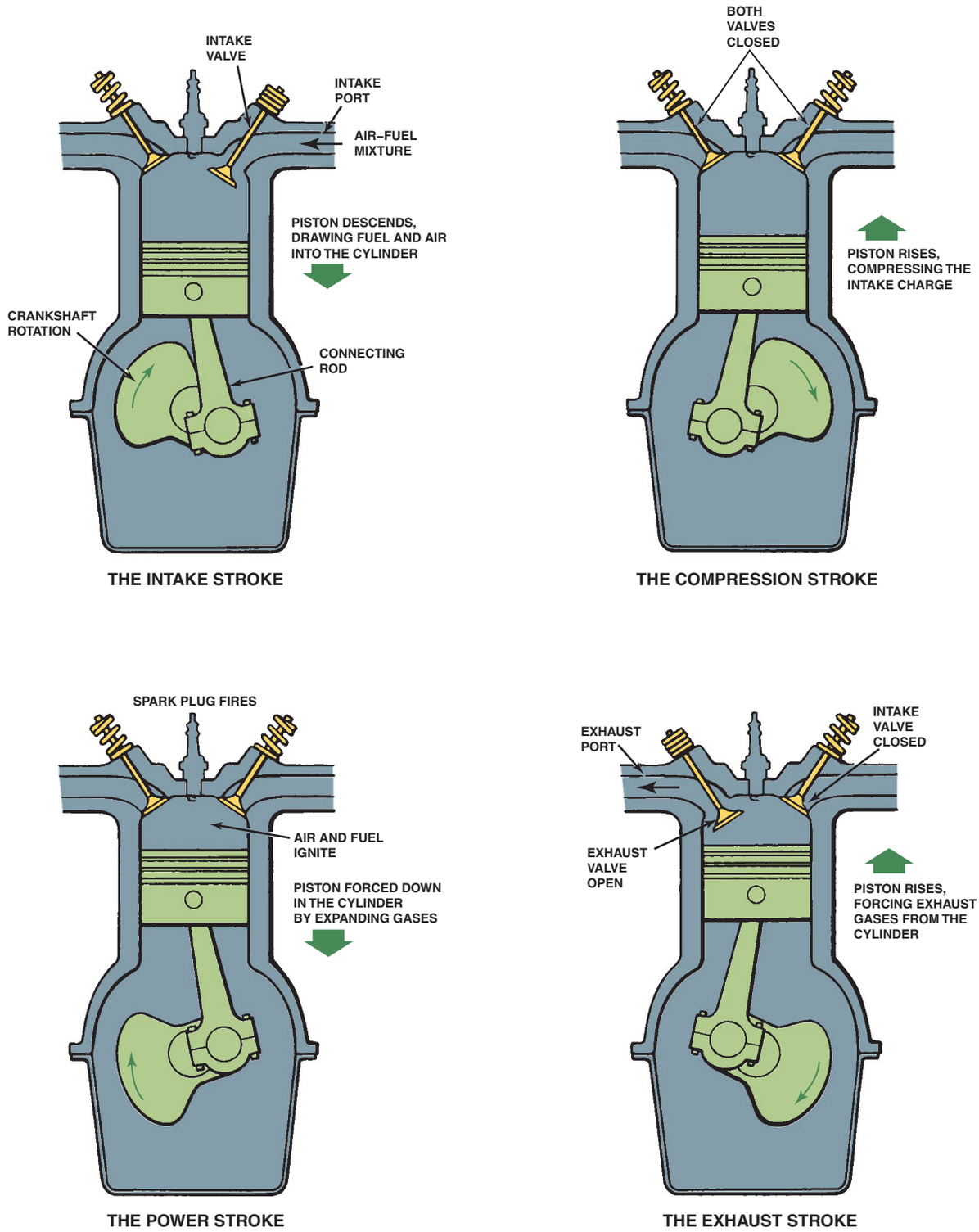


FIGURE 18–5 The downward movement of the piston draws the air-fuel mixture into the cylinder through the intake valve on the intake stroke. On the compression stroke, the mixture is compressed by the upward movement of the piston with both valves closed. Ignition occurs at the beginning of the power stroke, and combustion drives the piston downward to produce power. On the exhaust stroke, the upward-moving piston forces the burned gases out the open exhaust valve.

are major factors in engine operation. A typical older-model engine uses one intake valve and one exhaust valve per cylinder. Many newer engines use two intake and two exhaust valves per cylinder. The valves are opened by a **camshaft.** Some engines use one camshaft for the intake valves and a separate camshaft for the exhaust valves. When the camshaft is located in the block, the valves are operated by lifters, pushrods, and rocker arms.

This type of engine is called:

- A **pushrod engine**
- **Cam-in-block design**
- **Overhead valve (OHV)**, because an overhead valve engine has the valves located in the cylinder head (● **SEE FIGURE 18–11**.)

When one overhead camshaft is used, the design is called a **single overhead camshaft (SOHC)** design. When two overhead

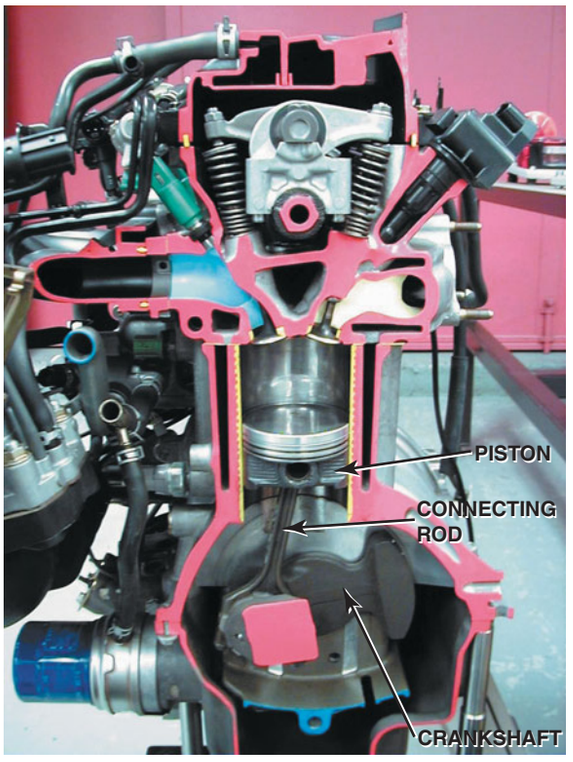


FIGURE 18–6 Cutaway of an engine showing the cylinder, piston, connecting rod, and crankshaft.

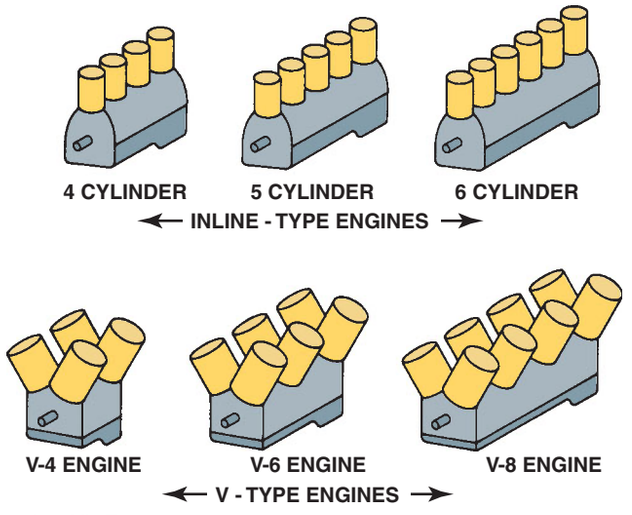


FIGURE 18–7 Automotive engine cylinder arrangements.

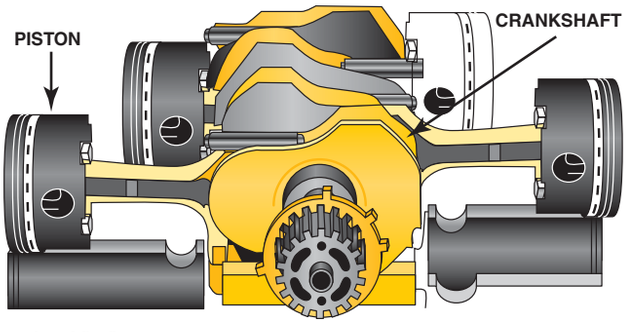


FIGURE 18–8 A horizontally opposed engine design helps to lower the vehicle's center of gravity.

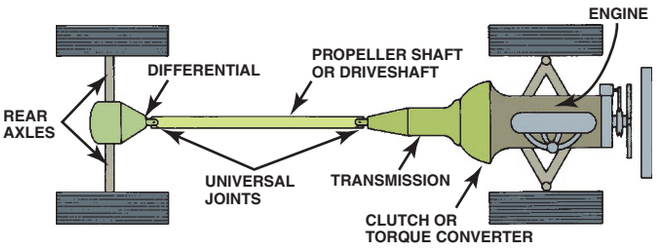


FIGURE 18–9 A longitudinally mounted engine drives the rear wheels through a transmission, driveshaft, and differential assembly.

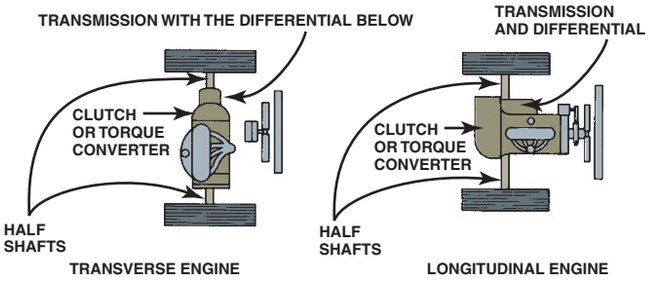


FIGURE 18–10 Two types of front-engine, front-wheel drive mountings.

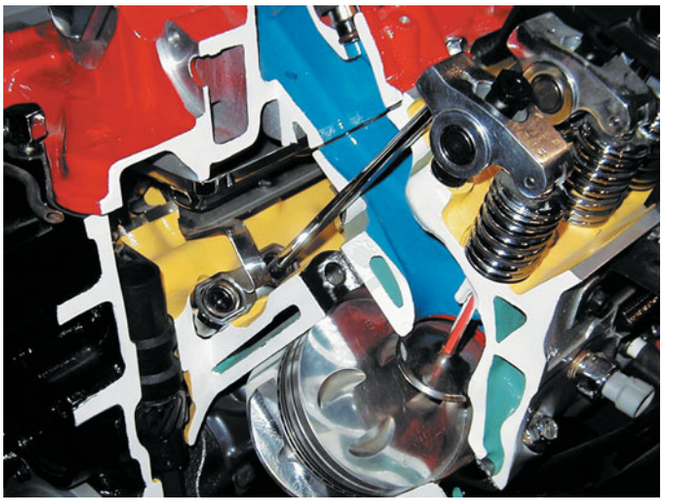


FIGURE 18–11 Cutaway of an overhead valve (OHV) V-8 engine showing the lifters, pushrods, roller rocker arms, and valves.

camshafts are used, the design is called a **double overhead camshaft (DOHC)** design. ● **SEE FIGURES 18–12 AND 18–13**.

NOTE: A V-type engine uses two banks or rows of cylinders. An SOHC design, therefore, uses two camshafts but only one camshaft per bank (row) of cylinders. A DOHC V-6, therefore, has four camshafts, two for each bank.

- **Type of fuel.** Most engines operate on gasoline, whereas some engines are designed to operate on ethanol (E85), methanol (M85), natural gas, propane, or diesel fuel.
- **Cooling method.** Most engines are liquid cooled, but some older models were air cooled. Air-cooled engines, such as the original VW Beatle, could not meet exhaust emission standards.
- **Type of induction pressure.** If atmospheric air pressure is used to force the air-fuel mixture into the cylinders, the engine is called **naturally aspirated.** Some engines use a **turbocharger** or **supercharger** to force the air-fuel mixture into the cylinder for even greater power.

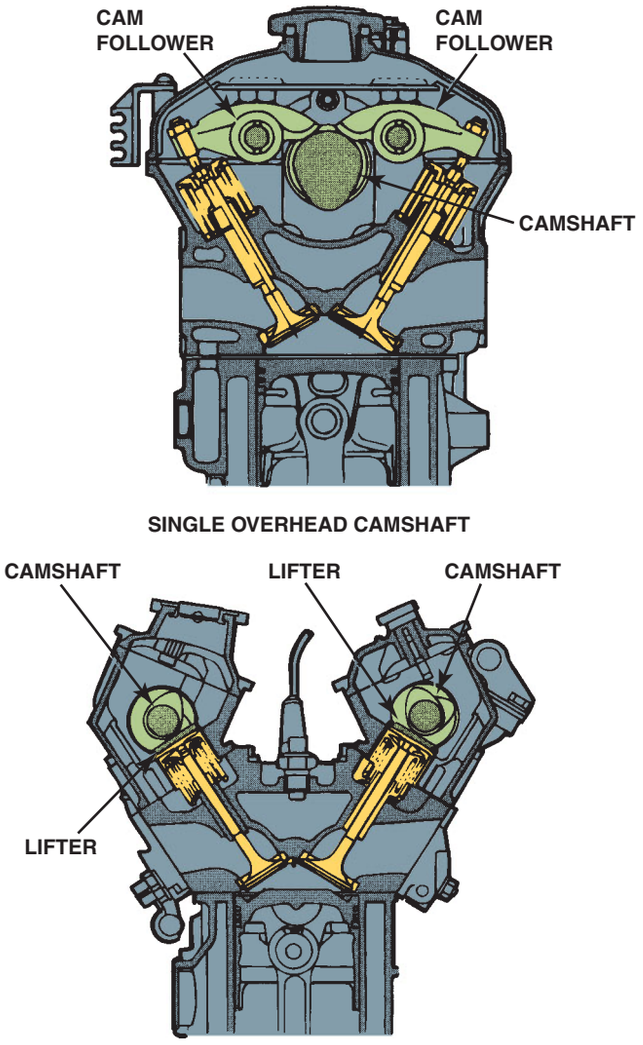


FIGURE 18–12 SOHC engines usually require additional components, such as a rocker arm, to operate all of the valves. DOHC engines often operate the valves directly.

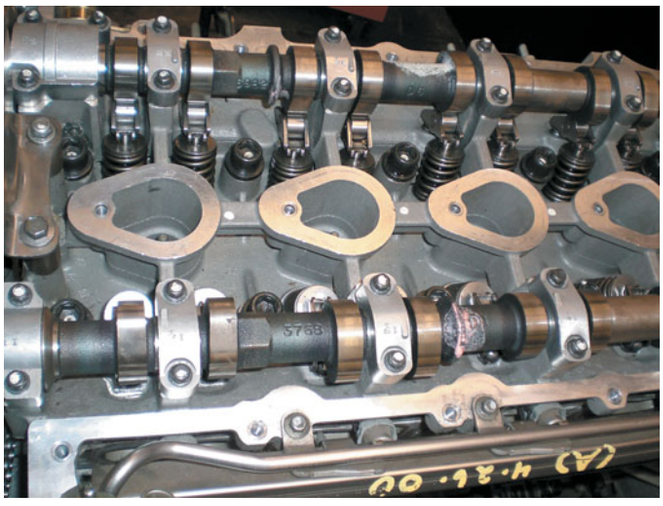


FIGURE 18–13 A DOHC engine uses a camshaft for the intake valves and a separate camshaft for the exhaust valves in each cylinder head.

FREQUENTLY ASKED QUESTION

What Is a Rotary Engine?

A successful alternative engine design is the **rotary engine**, also called the **Wankel engine** after its inventor, Felix Heinrich Wankel (1902–1988), a German inventor. The Mazda RX-7 and RX-8 represent the only long-term use of the rotary engine. The rotating combustion chamber engine runs very smoothly, and it produces high power for its size and weight.

The basic rotating combustion chamber engine has a triangular-shaped rotor turning in a housing. The housing is in the shape of a geometric figure called a two-lobed epitrochoid. A seal on each corner, or apex, of the rotor is in constant contact with the housing, so the rotor must turn with an eccentric motion. This means that the center of the rotor moves around the center of the engine. The eccentric motion can be seen in ● **FIGURE 18–14**.

FREQUENTLY ASKED QUESTION

Where Does an Engine Stop?

When the ignition system is turned off, the firing of the spark plugs stops and the engine will rotate until it stops due to the inertia of the rotating parts. The greatest resistance that occurs in the engine happens during the compression stroke. It has been determined that an engine usually stops when one of the cylinders is about 70 degrees before top dead center (BTDC) on the compression stroke with a variation of plus or minus 10 degrees.

This explains why technicians discover that the starter ring gear is worn at two locations on a 4-cylinder engine. The engine stops at one of the two possible places depending on which cylinder is on the compression stroke.

ENGINE ROTATION DIRECTION The SAE standard for automotive engine rotation is counterclockwise (CCW) as viewed from the flywheel end (clockwise as viewed from the front of the engine). The flywheel end of the engine is the end to which the power is applied to drive the vehicle. This is called the **principal end** of the engine. The **nonprincipal end** of the engine is opposite the principal end and is generally referred to as the *front* of the engine, where the accessory belts are used. ● **SEE FIGURE 18–15**.

Therefore, in most rear-wheel-drive vehicles, the engine is mounted longitudinally with the principal end at the rear of the engine. Most transversely mounted engines also adhere to the same standard for direction of rotation. Many Honda engines, and some marine applications, may differ from this standard.

ENGINE MEASUREMENT

BORE The diameter of a cylinder is called the **bore.** The larger the bore, the greater the area on which the gases have to work. Pressure is measured in units, such as pounds per square inch (PSI). The greater the area (in square inches), the higher the force exerted by the pistons to rotate the crankshaft. ● **SEE FIGURE 18–16**.

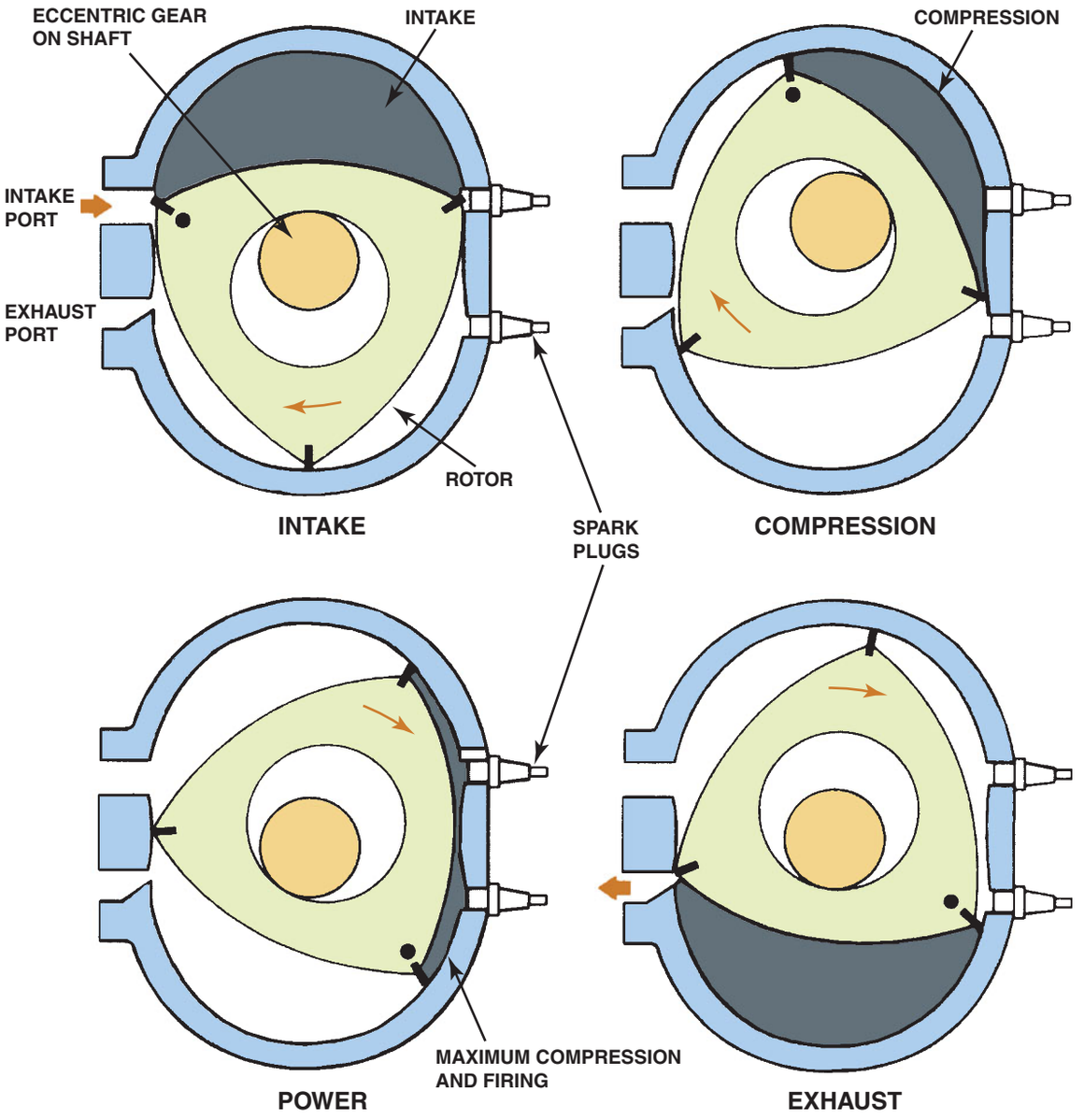


FIGURE 18–14 A rotary engine operates on the four-stroke cycle but uses a rotor instead of a piston and crankshaft to achieve intake, compression, power, and exhaust stroke.

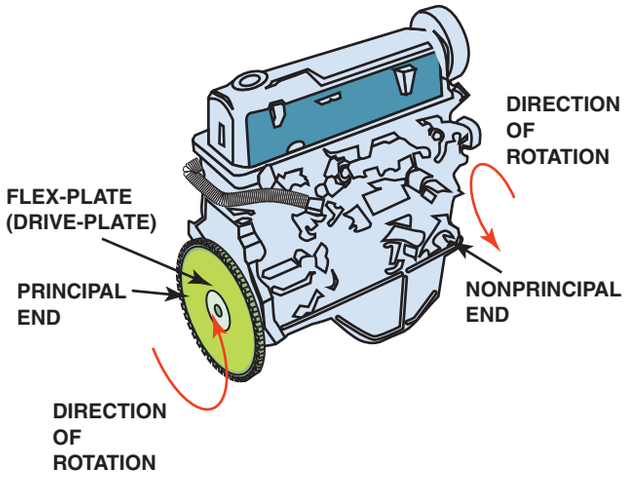


FIGURE 18–15 Inline 4-cylinder engine showing principal and nonprincipal ends. Normal direction of rotation is clockwise (CW) as viewed from the front or accessory belt (nonprincipal) end.

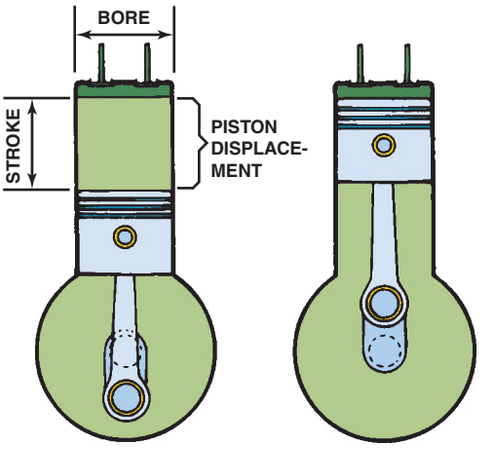


FIGURE 18–16 The bore and stroke of pistons are used to calculate an engine's displacement.

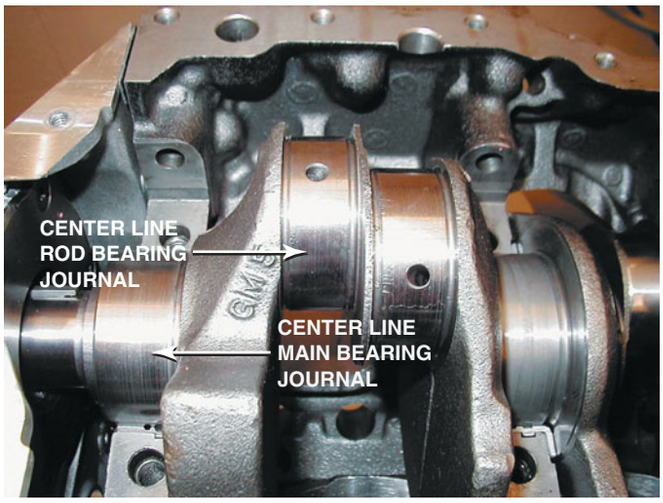


FIGURE 18–17 The distance between the centerline of the main bearing journal and the centerline of the connecting rod journal determines the stroke of the engine. This photo is a little unusual because it shows a V-6 with a splayed crankshaft used to even out the impulses on a 90-degree, V-6 engine design.

STROKE

The **stroke** of an engine is the distance the piston travels from top dead center (TDC) to bottom dead center (BDC). This distance is determined by the throw of the crankshaft. The throw is the distance from the centerline of the crankshaft to the centerline of the crankshaft rod journal. The throw is one-half of the stroke. ● **SEE FIGURE 18–17**.

The longer this distance is, the greater the amount of air-fuel mixture that can be drawn into the cylinder. The more air-fuel mixture inside the cylinder, the more force will result when the mixture is ignited.

NOTE: Changing the connecting rod length does *not* change the stroke of an engine. Changing the connecting rod only changes the position of the piston in the cylinder. Only the crankshaft determines the stroke of an engine.

DISPLACEMENT

Engine size is described as displacement. **Displacement** is the cubic inch (cu. in.) or cubic centimeter (cc) volume displaced or how much air is moved by all of the pistons. A liter (L) is equal to 1,000 cubic centimeters; therefore, most engines today are identified by their displacement in liters.

1 L = 1,000 cc

1 L = 61 cu. in.

1 cu. in. = 16.4 cc

CONVERSION

- To convert cubic inches to liters, divide cubic inches by 61.02.

$$\text{Liters} = \frac{\text{Cubic inches}}{61.02}$$

- To convert liters into cubic inches, multiply by 61.02.

$$\text{Cubic inches} = \text{Liters} \times 61.02$$

CALCULATING CUBIC INCH DISPLACEMENT

The formula to calculate the displacement of an engine is basically the formula for determining the volume of a cylinder multiplied by the number of cylinders.

TECH TIP

How Fast Can an Engine Rotate?

Most passenger vehicle engines are designed to rotate at low speed for the following reasons.

- Maximum efficiency is achieved at low engine speed. A diesel engine used in a large ship, for example, will rotate at about 100 RPM for maximum efficiency.
- Piston ring friction is the highest point of friction in the engine. The slower the engine speed, the less loss to friction from the piston rings.

However, horsepower is what is needed to get a vehicle down the road quickly. Horsepower is torque times engine speed divided by 5,252. Therefore, a high engine speed usually indicates a high horsepower. For example, a Formula 1 race car is limited to 2.4 liter V-8 but uses a 1.6 in. (40 mm) stroke. This extremely short stroke means that the engine can easily achieve the upper limit allowed by the rules of 18,000 RPM while producing over 700 horsepower.

The larger the engine, the more power the engine is capable of producing. Several sayings are often quoted about engine size:

"There is no substitute for cubic inches."
"There is no replacement for displacement."

Although a large engine generally uses more fuel, making an engine larger is often the easiest way to increase power.

The formula is:

Cubic inch displacement = π (pi) × R^2 × Stroke × Number of cylinders

R = Radius of the cylinder or one-half of the bore.
The πR^2 part is the formula for the area of a circle.

Applying the formula to a 6-cylinder engine:

- Bore = 4.000 in.
- Stroke = 3.000 in.
- π = 3.14
- R = 2 inches
- R^2 = 4 (2^2 or 2 × 2)

Cubic inches = 3.14 × 4 (R^2) × 3 (stroke) × 6 (number of cylinders).

Cubic inches = 226 cubic inches

Because 1 cubic inch equals 16.4 cubic centimeters, this engine displacement equals 3,706 cubic centimeters or, rounded to 3,700 cubic centimeters, 3.7 liters. ● **SEE CHART 18–1** for an example of engine sizes for a variety of bore and stroke measurements.

ENGINE SIZE CONVERSION

Many vehicle manufacturers will round the displacement so the calculated cubic inch displacement may not agree with the published displacement value. ● **SEE CHART 18–2**.

V-8 ENGINE					
STROKE	3.50	3.75	3.875	4.00	4.125
BORE	Cu. In.	Cu. In.	Cu. In.	Cu. In.	Cu. In.
3.00	199	212	219	226	233
3.125	214	229	237	244	252
3.250	232	249	257	265	274
3.375	251	269	277	286	295
3.500	269	288	298	308	317
3.625	288	309	319	330	339
3.750	309	332	343	354	365
3.875	331	354	366	378	390
4.00	352	377	389	402	414
4.125	373	399	413	426	439
6-CYLINDER ENGINE					
STROKE	3.50	3.75	3.875	4.00	4.125
BORE	Cu. In.	Cu. In.	Cu. In.	Cu. In.	Cu. In.
3.00	148	159	164	169	175
3.125	161	172	178	184	190
3.250	174	186	193	199	205
3.375	188	201	208	215	222
3.500	202	216	223	228	238
3.625	216	232	239	247	255
3.750	232	249	257	265	273
3.875	248	266	275	283	292
4.00	264	283	292	301	311
4.125	280	299	309	319	329
4-CYLINDER ENGINE					
STROKE	3.50	3.75	3.875	4.00	4.125
BORE	Cu. In.	Cu. In.	Cu. In.	Cu. In.	Cu. In.
3.00	99	106	110	113	117
3.125	107	115	119	123	126
3.250	116	124	129	133	137
3.375	125	134	139	143	148
3.500	135	144	149	152	159
3.625	144	158	160	165	170
3.750	155	166	171	177	182
3.875	165	177	183	189	195
4.00	176	188	195	201	207
4.125	186	200	206	213	220

CHART 18–1

To find the cubic inch displacement, find the bore that is closest to the actual value, then go across to the closest stroke value.

COMPRESSION RATIO

DEFINITION **Compression ratio (CR)** is the ratio of the difference in the cylinder volume when the piston is at the bottom of the stroke to the volume in the cylinder above the piston when the piston is at the top of the stroke. The compression ratio of an engine is an important consideration when rebuilding or repairing an engine. ● **SEE FIGURE 18–18.**

If Compression Is Lower	If Compression Is Higher
Lower power	Higher power possible
Poorer fuel economy	Better fuel economy possible
Easier engine cranking	Harder to crank engine, especially when hot
More advanced ignition timing possible without spark knock (detonation)	Less ignition timing required to prevent spark knock (detonation)

LITERS TO CUBIC INCHES					
LITERS	CUBIC INCHES	LITERS	CUBIC INCHES	LITERS	CUBIC INCHES
1.0	61	3.2	196	5.4	330
1.3	79	3.3	200 / 201	5.7	350
1.4	85	3.4	204	5.8	351
1.5	91	3.5	215	6.0	366 / 368
1.6	97 / 98	3.7	225	6.1	370
1.7	105	3.8	229 / 231 / 232	6.2	381
1.8	107 / 110 / 112	3.9	239 / 240	6.4	389 / 390 / 391
1.9	116	4.0	241 / 244	6.5	396
2.0	121 / 122	4.1	250 / 252	6.6	400
2.1	128	4.2	255 / 258	6.9	420
2.2	132 / 133 / 134 / 135	4.3	260 / 262 / 265	7.0	425 / 427 / 428 / 429
2.3	138 / 140	4.4	267	7.2	440
2.4	149	4.5	273	7.3	445
2.5	150 / 153	4.6	280 / 281	7.4	454
2.6	156 / 159	4.8	292	7.5	460
2.8	171 / 173	4.9	300 / 301	7.8	475 / 477
2.9	177	5.0	302 / 304 / 305 / 307	8.0	488
3.0	181 / 182 / 183	5.2	318	8.8	534
3.1	191	5.3	327		

CHART 18–2

Liters to cubic inches is often not exact and can result in representing several different engine sizes based on their advertised size in liters.

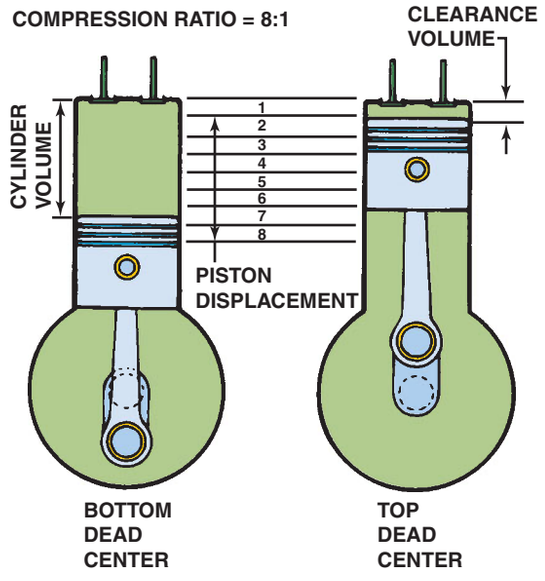


FIGURE 18–18 Compression ratio is the ratio of the total cylinder volume (when the piston is at the bottom of its stroke) to the clearance volume (when the piston is at the top of its stroke).

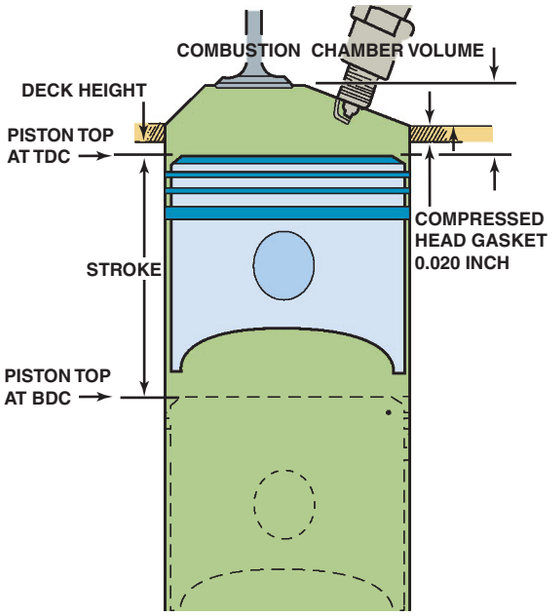


FIGURE 18–19 Combustion chamber volume is the volume above the piston when the piston is at top dead center.

CALCULATING COMPRESSION RATIO

The compression ratio (CR) calculation uses the formula:

$$CR = \frac{\text{Volume in cylinder with piston at bottom of cylinder}}{\text{Volume in cylinder with piston at top center}}$$

● **SEE FIGURE 18–19.**

For example: What is the compression ratio of an engine with 50.3 cu. in. displacement in one cylinder and a combustion chamber volume of 6.7 cu. in.?

$$CR = \frac{50.3 + 6.7 \text{cu. in.}}{6.7 \text{ cu. in.}} = \frac{57.0}{6.7} = 8.5$$

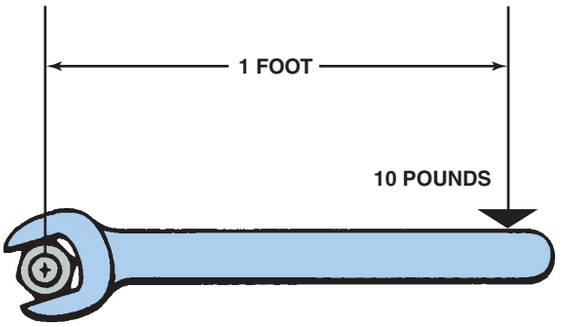


FIGURE 18–20 Torque is a twisting force equal to the distance from the pivot point times the force applied expressed in units called pound-feet (lb-ft) or newton-meters (N-m).

FREQUENTLY ASKED QUESTION

Is Torque ft-lb or lb-ft?

The definition of torque is a force (lb) applied to an object times the distance from that object (ft). Therefore, based on the definition of the term, torque should be:

lb-ft (a force times a distance)

Newton-meter (N-m) (a force times a distance)

However, torque is commonly labeled, even on some torque wrenches as ft-lb.

TECH TIP

Quick-and-Easy Engine Efficiency Check

A good, efficient engine is able to produce a lot of power from little displacement. A common rule of thumb is that an engine is efficient if it can produce 1 horsepower per cubic inch of displacement. Many engines today are capable of this feat, such as the following:

Ford: 4.6 liter V-8 (281 cu. in.): 305 hp
Chevrolet: 3.0 liter V-6 (207 cu. in.): 210 hp
Chrysler: 3.5 liter V-6 (214 cu. in.): 214 hp
Acura: 3.2 liter V-6 (195 cu. in.): 260 hp

An engine is very powerful for its size if it can produce 100 hp per liter. This efficiency goal is harder to accomplish. Most factory stock engines that can achieve this feat are supercharged or turbocharged.

CHANGING COMPRESSION RATIO

Any time an engine is modified, the compression ratio should be checked to make sure it is either the same as it was originally or has been changed to match the diesel compression ratio. Factors that can affect compression ratio include:

- **Head gasket thickness.** A thicker than stock gasket will decrease the compression ratio and a thinner than stock gasket will increase the compression ratio.
- **Increasing the cylinder size.** If the bore or stroke is increased, a greater amount of air will be compressed into the combustion chamber, which will increase the compression ratio.

TORQUE AND HORSEPOWER

DEFINITION OF TORQUE

Torque is the term used to describe a rotating force that may or may not result in motion. Torque is measured as the amount of force multiplied by the length of the lever through which it acts. If you use a 1 ft long wrench to apply 10 pounds (lb) of force to the end of the wrench to turn a bolt, then you are exerting 10 pound-feet (lb-ft) of torque. ● **SEE FIGURE 18–20**.

Torque is the twisting force measured at the end of the crankshaft and measured on a dynamometer. Engine torque is always expressed at a specific engine speed (RPM) or range of engine speeds where the torque is at the maximum. For example, an engine may be listed as producing 275 lb-ft @ 2,400 RPM.

The metric unit for torque is newton-meters, because the newton is the metric unit for force and the distance is expressed in meters.

1 pound-foot = 1.3558 newton-meters

1 newton-meter = 0.7376 pound-foot

DEFINITION OF POWER

The term *power* means the rate of doing work. Power equals work divided by time. Work is achieved when a certain amount of mass (weight) is moved a certain distance by a force. If the object is moved in 10 seconds or 10 minutes does not make a difference in the amount of work accomplished, but it does affect the amount of power needed. Power is expressed in units of foot-pounds per minute and power also includes the engine speed (RPM) where the maximum power is achieved. For example, an engine may be listed as producing 280 hp @ 4400 RPM.

HORSEPOWER AND ALTITUDE

Because the density of the air is lower at high altitude, the power that a normal engine can develop is greatly reduced at high altitude. According to SAE conversion factors, a nonsupercharged or nonturbocharged engine loses about 3% of its power for every 1,000 ft (300 m) of altitude.

Therefore, an engine that develops 200 brake horsepower at sea level will only produce about 116 brake horsepower at the top of Pike's Peak in Colorado at 14,110 ft (4,300 m) (3% × 14 – 42%). Supercharged and turbocharged engines are not as greatly affected by altitude as normally aspirated engines, which are those engines that breathe air at normal atmospheric pressure.

REVIEW QUESTIONS

1. What are the strokes of a four stroke cycle?
2. If an engine at sea level produces 100 hp, how many horsepower would it develop at 6,000 ft of altitude?

CHAPTER QUIZ

1. All overhead valve engines _____.
   a. Use an overhead camshaft
   b. Have the valves located in the cylinder head
   c. Operate by the two-stroke cycle
   d. Use the camshaft to close the valves
2. An SOHC V-8 engine has how many camshafts?
   a. One **c.** Three
   b. Two **d.** Four
3. The coolant flow through the radiator is controlled by the _____.
   a. Size of the passages in the block
   b. Thermostat
   c. Cooling fan(s)
   d. Water pump
4. Torque is expressed in units of _____.
   a. Pound-feet
   b. Foot-pounds
   c. Foot-pounds per minute
   d. Pound-feet per second
5. Horsepower is expressed in units of _____.
   a. Pound-feet **c.** Foot-pounds per minute
   b. Foot-pounds **d.** Pound-feet per second
6. A normally aspirated automobile engine loses about _____ power per 1,000 ft of altitude.
   a. 1% **c.** 5%
   b. 3% **d.** 6%
7. One cylinder of an automotive four-stroke cycle engine completes a cycle every _____.
   a. 90 degrees **c.** 360 degrees
   b. 180 degrees **d.** 720 degrees
8. How many rotations of the crankshaft are required to complete each stroke of a four-stroke cycle engine?
   a. One-fourth **c.** One
   b. One-half **d.** Two
9. A rotating force is called _____.
   a. Horsepower **c.** Combustion pressure
   b. Torque **d.** Eccentric movement
10. Technician A says that a crankshaft determines the stroke of an engine. Technician B says that the length of the connecting rod determines the stroke of an engine. Which technician is correct?
    a. Technician A only **c.** Both Technicians A and B
    b. Technician B only **d.** Neither Technician A nor B

chapter 19

DIESEL ENGINE OPERATION AND DIAGNOSIS

OBJECTIVES: **After studying Chapter 19, the reader should be able to:** • Prepare for ASE Engine Performance (A8) certification test content area "C" (Fuel, Air Induction, and Exhaust Systems Diagnosis and Repair). • Explain how a diesel engine works. • Describe the difference between direct injection (DI) and indirect injection (IDI) diesel engines. • List the parts of the typical diesel engine fuel system. • Explain how glow plugs work. • List the advantages and disadvantages of a diesel engine.

KEY TERMS: Diesel exhaust fluid (DEF) 170 • Diesel exhaust particulate filter (DPF) 169 • Diesel oxidation catalyst (DOC) 168 • Differential pressure sensor (DPS) 169 • Direct injection (DI) 160 • Glow plug 164 • Heat of compression 158 • High-pressure common rail (HPCR) 162 • Hydraulic electronic unit injection (HEUI) 162 • Indirect injection (IDI) 160 • Injection pump 158 • Lift pump 161 • Opacity 174 • Pop tester 173 • Particulate matter (PM) 168 • Regeneration 169 • Selective catalytic reduction (SCR) 170 • Soot 168 • Urea 170 • Water-fuel separator 161

DIESEL ENGINES

FUNDAMENTALS In 1892, a German engineer named Rudolf Diesel perfected the compression ignition engine that bears his name. The diesel engine uses heat created by compression to ignite the fuel, so it requires no spark ignition system.

The diesel engine requires compression ratios of 16:1 and higher. Incoming air is compressed until its temperature reaches about 1,000°F (540°C). This is called **heat of compression.** As the piston reaches the top of its compression stroke, fuel is injected into the cylinder, where it is ignited by the hot air. ● **SEE FIGURE 19–1.**

As the fuel burns, it expands and produces power. Because of the very high compression and torque output of a diesel engine, it is made heavier and stronger than the same size gasoline-powered engine.

A diesel engine uses a fuel system with a precision **injection pump** and individual fuel injectors. The pump delivers fuel to the injectors at a high pressure and at timed intervals. Each injector sprays

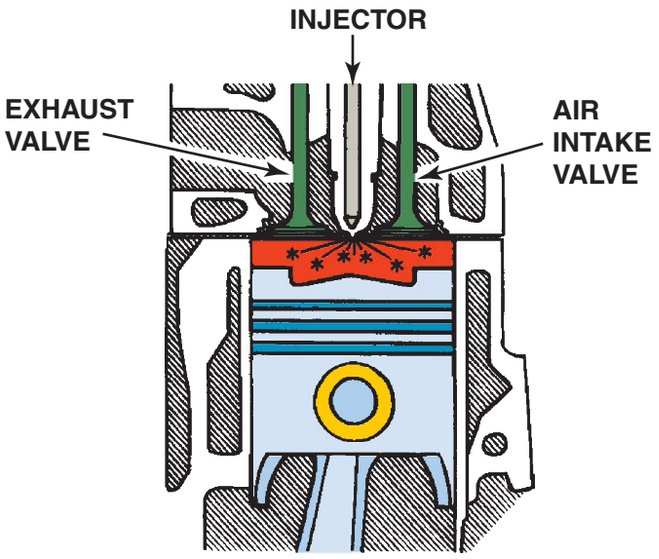


FIGURE 19–1 Diesel combustion occurs when fuel is injected into the hot, highly compressed air in the cylinder.

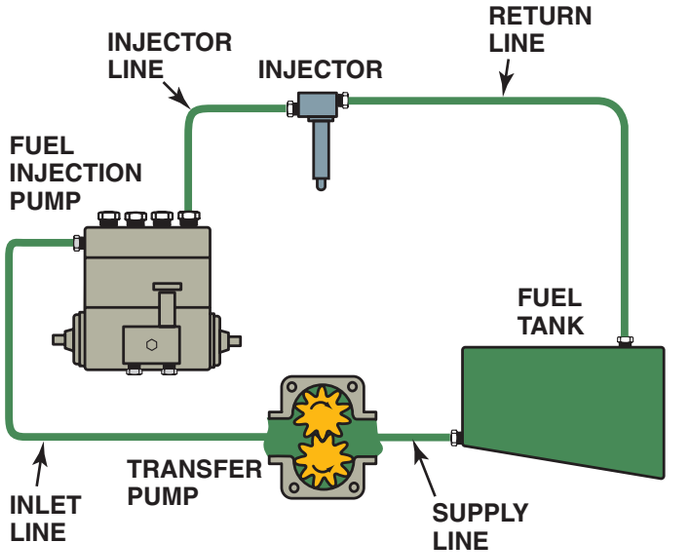


FIGURE 19–2 A typical injector pump type of automotive diesel fuel–injection system.

fuel into the combustion chamber at the precise moment required for efficient combustion. ● **SEE FIGURE 19–2.**

ADVANTAGES AND DISADVANTAGES

A diesel engine has several advantages compared to a similar size gasoline-powered engine, including:

1. More torque output
2. Greater fuel economy
3. Long service life

A diesel engine has several disadvantages compared to a similar size gasoline-powered engine, including:

1. Engine noise, especially when cold and/or at idle speed
2. Exhaust smell
3. Cold weather startability
4. Vacuum pump that is needed to supply the vacuum needs of the heat, ventilation, and air-conditioning system
5. Heavier than a gasoline engine

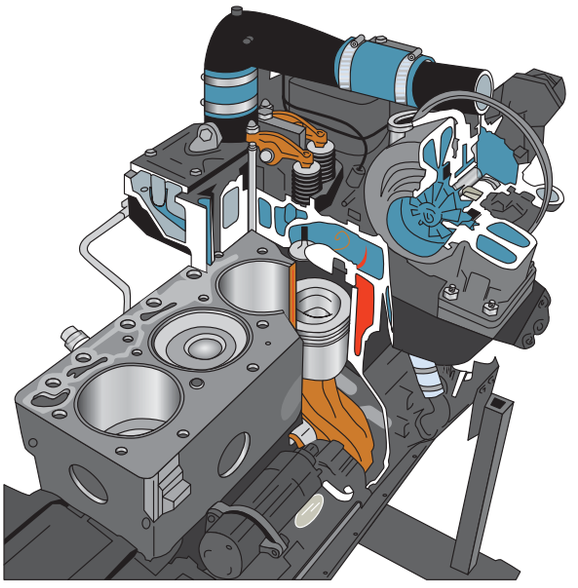


FIGURE 19–3 A Cummins diesel engine as found in a Dodge pickup truck. A high-pressure pump (up to 30,000 PSI) is used to supply diesel fuel to this common rail, which has tubes running to each injector. Note the thick cylinder walls and heavy-duty construction.

SYSTEM OR COMPONENT	DIESEL ENGINE	GASOLINE ENGINE
Block	Cast iron and heavy (● **SEE FIGURE 19–3.**)	Cast iron or aluminum and as light as possible
Cylinder head	Cast iron or aluminum	Cast iron or aluminum
Compression ratio	17:1 to 25:1	8:1 to 12:1
Peak engine speed	2000 to 2500 RPM	5000 to 8000 RPM
Pistons	Aluminum with combustion pockets and heavy-duty connecting rods (● **SEE FIGURE 19–4.**)	Aluminum, usually flat top or with valve relief but no combustion pockets

CHART 19–1

Comparison between a typical gasoline and a diesel engine.

6. Fuel availability
7. Extra cost compared to a gasoline engine

CONSTRUCTION

Diesel engines must be constructed heavier than gasoline engines because of the tremendous pressures that are created in the cylinders during operation. ● **SEE CHART 19–1.** The torque output of a diesel engine is often double or more than the same size gasoline-powered engines.

AIR-FUEL RATIOS

In a diesel engine, air is not controlled by a throttle as in a gasoline engine. Instead, the amount of fuel injected is varied to control power and speed. The air-fuel mixture of a diesel can vary from as lean as 85:1 at idle to as rich as 20:1 at full load. This higher air-fuel ratio and the increased compression pressures make the diesel more fuel efficient than a gasoline engine, in part because diesel engines do not suffer from throttling losses. Throttling losses involve the power needed in a gasoline engine to draw air past a closed or partially closed throttle.

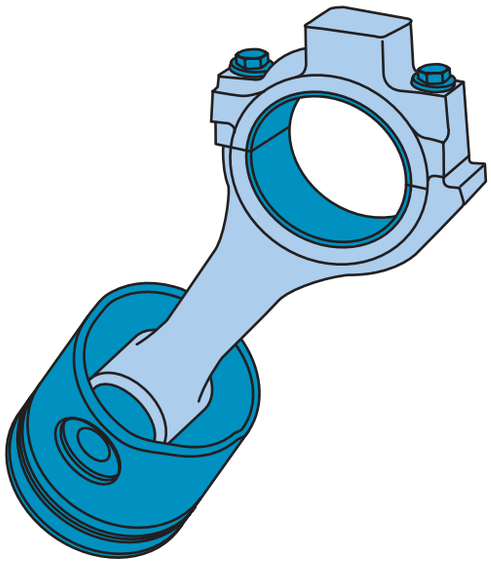


FIGURE 19–4 A rod/piston assembly from a 5.9 liter Cummins diesel engine used in a Dodge pickup truck.

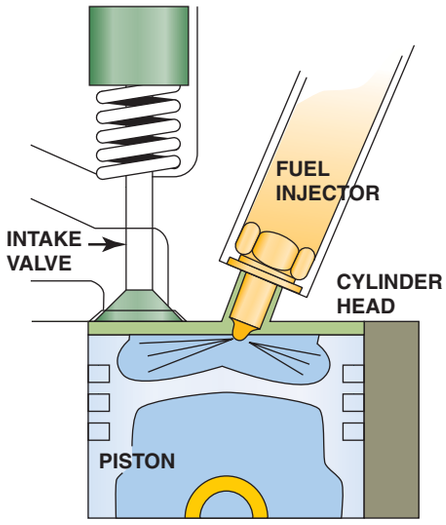


FIGURE 19–6 A direct injection diesel engine injects the fuel directly into the combustion chamber. Many designs do not use a glow plug.

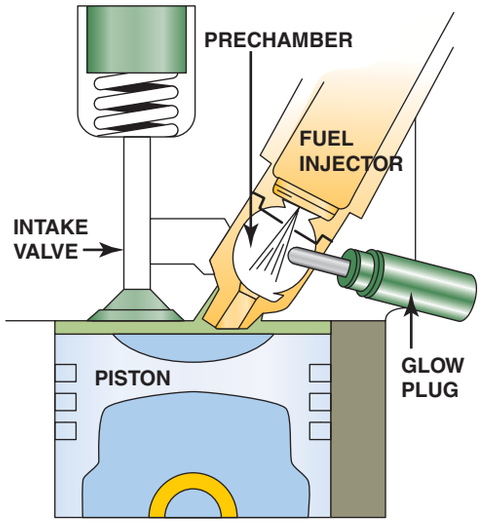


FIGURE 19–5 An indirect injection diesel engine uses a prechamber and a glow plug.

In a gasoline engine, the speed and power are controlled by the throttle valve, which controls the amount of air entering the engine. Adding more fuel to the cylinders of a gasoline engine without adding more air (oxygen) will not increase the speed or power of the engine. In a diesel engine, speed and power are not controlled by the amount of air entering the cylinders because the engine air intake is always wide open. Therefore, the engine always has enough oxygen to burn the fuel in the cylinder and will increase speed (and power) when additional fuel is supplied.

NOTE: Many newer diesel engines are equipped with a throttle valve. This valve is used by the emission control system and is not designed to control the speed of the engine.

INDIRECT AND DIRECT INJECTION

In an **indirect injection** (abbreviated **IDI**) diesel engine, fuel is injected into a small prechamber, which is connected to the cylinder by a narrow opening. The initial combustion takes place in this prechamber. This has the effect of slowing the rate of combustion, which tends to reduce noise. ● **SEE FIGURE 19–5**.

All indirect diesel injection engines require the use of a glow plug which is an electrical heater that helps start the combustion process.

In a **direct injection** (abbreviated **DI**) diesel engine, fuel is injected directly into the cylinder. The piston incorporates a depression where initial combustion takes place. Direct injection diesel engines are generally more efficient than indirect injection engines, but have a tendency to produce greater amounts of noise. ● **SEE FIGURE 19–6**.

While some direct injection diesel engines use glow plugs to help cold starting and to reduce emissions, many direct injection diesel engines do not use glow plugs.

DIESEL FUEL IGNITION

Ignition occurs in a diesel engine by injecting fuel into the air charge, which has been heated by compression to a temperature greater than the ignition point of the fuel or about 1,000°F (538°C). The chemical reaction of burning the fuel creates heat, which causes the gases to expand, forcing the piston to rotate the crankshaft. A four-stroke diesel engine requires two rotations of the crankshaft to complete one cycle.

- On the intake stroke, the piston passes TDC, the intake valve(s) opens, and filtered air enters the cylinder, while the exhaust valve(s) remains open for a few degrees to allow all of the exhaust gases to escape from the previous combustion event.
- On the compression stroke, after the piston passes BDC, the intake valve(s) closes and the piston travels up to TDC (completion of the first crankshaft rotation).
- On the power stroke, the piston nears TDC on the compression stroke and diesel fuel is injected into the cylinder by the injectors. The ignition of the fuel does not start immediately but the heat of compression starts the combustion phases in the cylinder. During this power stroke, the piston passes TDC and the expanding gases force the piston down, rotating the crankshaft.
- On the exhaust stroke, as the piston passes BDC, the exhaust valve(s) opens and the exhaust gases start to flow out of the cylinder. This continues as the piston travels up to TDC, pumping the spent gases out of the cylinder. At TDC, the second crankshaft rotation is complete.

THREE PHASES OF COMBUSTION

There are three distinct phases or parts to the combustion in a diesel engine.

1. **Ignition delay.** Near the end of the compression stroke, fuel injection begins, but ignition does not begin immediately. This period is called *ignition delay.*
2. **Rapid combustion.** This phase of combustion occurs when the fuel first starts to burn, creating a sudden rise in cylinder pressure. It is this sudden and rapid rise in combustion chamber pressure that causes the characteristic diesel engine knock.
3. **Controlled combustion.** After the rapid combustion occurs, the rest of the fuel in the combustion chamber begins to burn and injection continues. This process occurs in an area near the injector that contains fuel surrounded by air. This fuel burns as it mixes with the air.

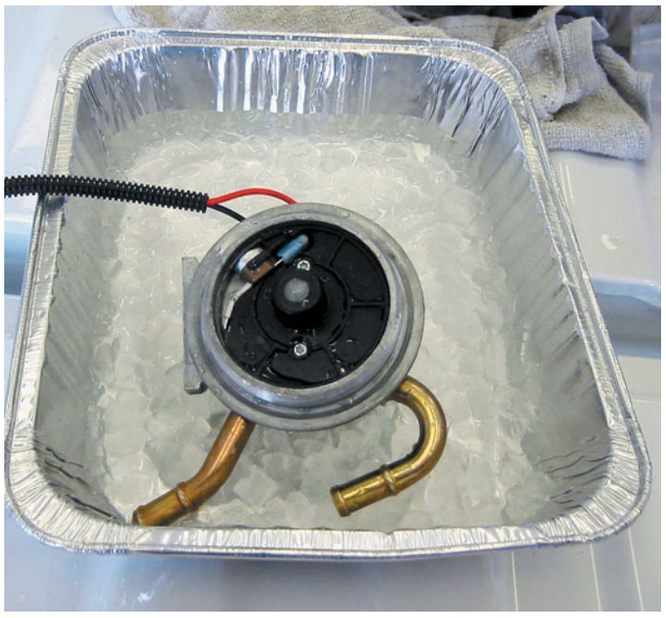


FIGURE 19–7 A fuel temperature sensor is being tested using an ice bath.

FUEL TANK AND LIFT PUMP

PARTS INVOLVED A fuel tank used on a vehicle equipped with a diesel engine differs from the one used with a gasoline engine in the following ways.

- The filler neck is larger for diesel fuel. The nozzle size is 15/16 in. (24 mm) instead of 13/16 in. (21 mm) for gasoline filler necks. Truck stop diesel nozzles for large over-the-road trucks are usually larger, 1.25 in. or 1.5 in. (32 mm or 38 mm) to allow for faster fueling of large-capacity fuel tanks.
- There are no evaporative emission control devices or a charcoal (carbon) canister. Diesel fuel is not as volatile as gasoline and, therefore, diesel vehicles do not have evaporative emission control devices.

The diesel fuel is usually drawn from the fuel tank by a separate pump, called a **lift pump** and delivers the fuel to the injection pump. Between the fuel tank and the lift pump is a **water-fuel separator.** Water is heavier than diesel fuel and sinks to the bottom of the separator. Part of normal routine maintenance on a vehicle equipped with a diesel engine is to drain the water from the water-fuel separator. A float is often used inside the separator, which is connected to a warning light on the dash that lights if the water reaches a level where it needs to be drained. The water separator is often part of the fuel filter assembly. Both the fuel filter and the water separator are common maintenance items.

NOTE: Water can cause corrosive damage and wear to diesel engine parts because it is not a good lubricant. Water cannot be atomized by a diesel fuel injector nozzle and will often "blow out" the nozzle tip.

Many diesel engines also use a *fuel temperature sensor.* The computer uses this information to adjust fuel delivery based on the density of the fuel. ● **SEE FIGURE 19–7**.

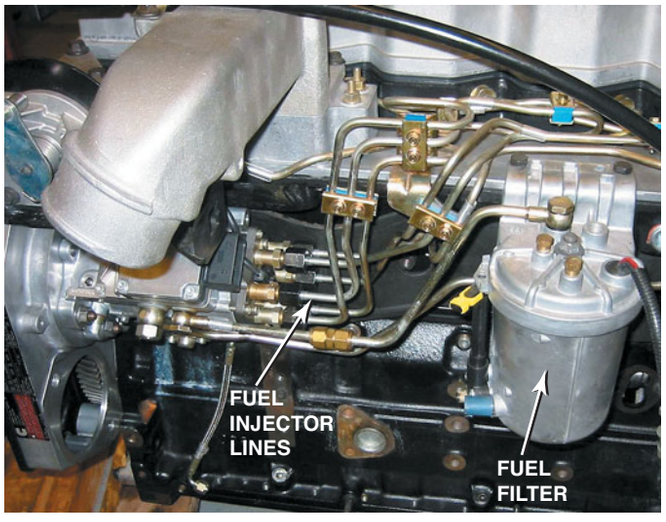


FIGURE 19–8 A typical distributor-type diesel injection pump showing the pump, lines, and fuel filter.

INJECTION PUMP

NEED FOR HIGH-PRESSURE FUEL PUMP A diesel engine injection pump is used to increase the pressure of the diesel fuel from very low values from the lift pump to the extremely high pressures needed for injection.

- The lift pump is a *low-pressure, high-volume pump.*
- The high-pressure injection pump is a *high-pressure, low-volume pump.*

Injection pumps are usually driven by a gear off the camshaft at the front of the engine. As the injection pump shaft rotates, the diesel fuel is fed from a fill port to a high-pressure chamber. If a distributor-type injection pump is used, the fuel is forced out of the injection port to the correct injector nozzle through the high-pressure line. ● **SEE FIGURE 19–8**.

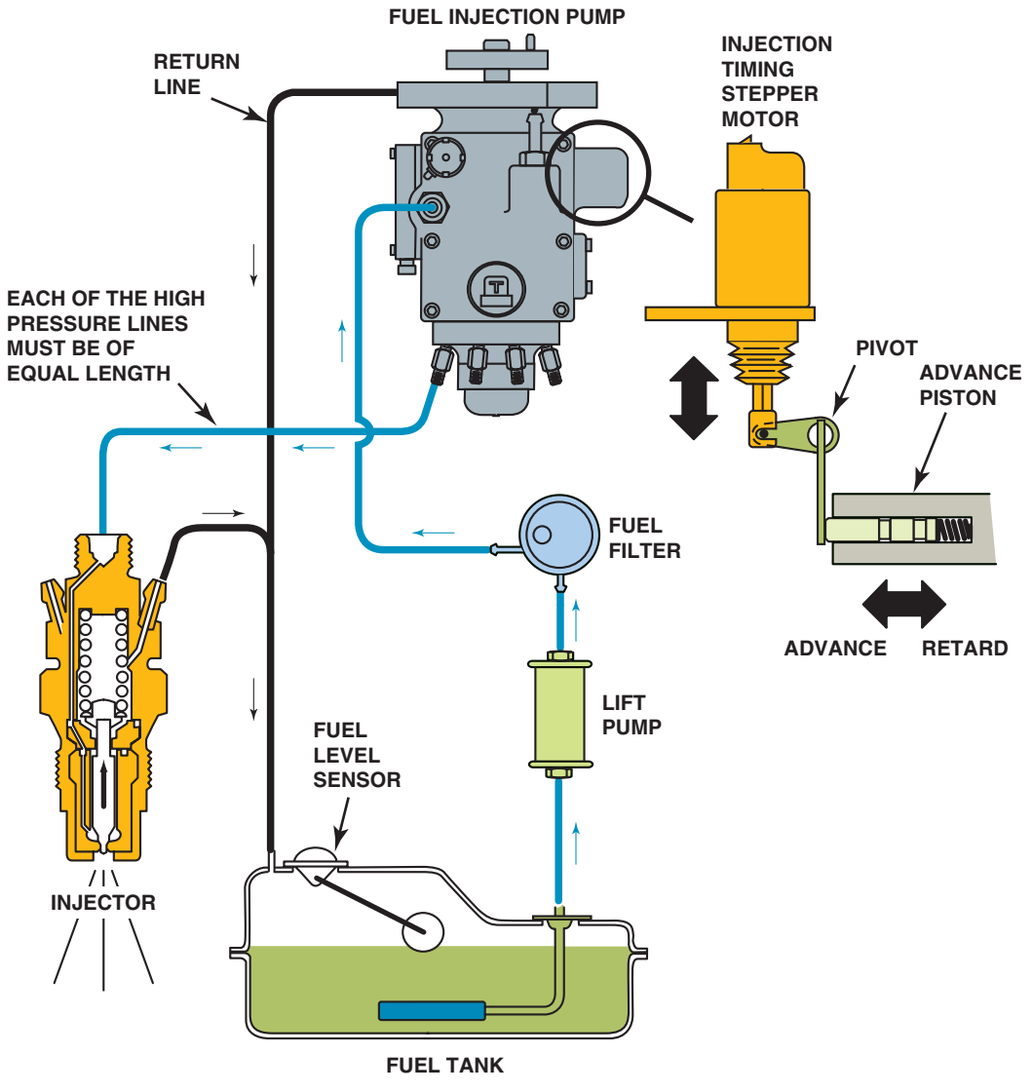


FIGURE 19–9 A schematic of Standadyne diesel fuel–injection pump assembly showing all of the related components.

NOTE: Because of the very tight tolerances in a diesel engine, the smallest amount of dirt can cause excessive damage to the engine and to the fuel-injection system.

DISTRIBUTOR INJECTION PUMP

A distributor diesel injection pump is a high-pressure pump assembly with lines leading to each individual injector. The high-pressure lines between the distributor and the injectors must be the exact same length to ensure proper injection timing. The high-pressure fuel causes the injectors to open. Due to the internal friction of the lines, there is a slight delay before fuel pressure opens the injector nozzle. The injection pump itself creates the injection advance needed for engine speeds above idle often by using a stepper motor attached to the advance piston, and the fuel is then discharged into the lines. ● **SEE FIGURE 19–9.**

NOTE: The lines expand some during an injection event. This is how timing checks are performed. The pulsing of the injector line is picked up by a probe used to detect the injection event similar to a timing light used to detect a spark on a gasoline engine.

HIGH-PRESSURE COMMON RAIL

Newer diesel engines use a fuel delivery system referred to as a **high-pressure common rail (HPCR)** design. Diesel fuel under high pressure, over 20,000 PSI (138,000 kPa), is applied to the injectors, which are opened by a solenoid controlled by the computer. Because the injectors are computer controlled, the combustion process can be precisely controlled to provide maximum engine efficiency with the lowest possible noise and exhaust emissions. ● **SEE FIGURE 19–10.**

HEUI SYSTEM

PRINCIPLES OF OPERATION

Ford 7.3 and 6.0 liter (and Navistar) diesels use a system called a **hydraulic electronic unit injection** system, or **HEUI** system. The components used include:

- High-pressure engine oil pump and reservoir
- Pressure regulator for the engine oil
- Passages in the cylinder head for flow of fuel to the injectors

OPERATION

The engine oil is pressurized to provide an opening pressure strong enough to overcome the fuel pressure when the solenoid is commanded to open by the PCM. The system functions as follows:

- Fuel is drawn from the tank by the tandem fuel pump, which circulates fuel at low pressure through the fuel filter/water

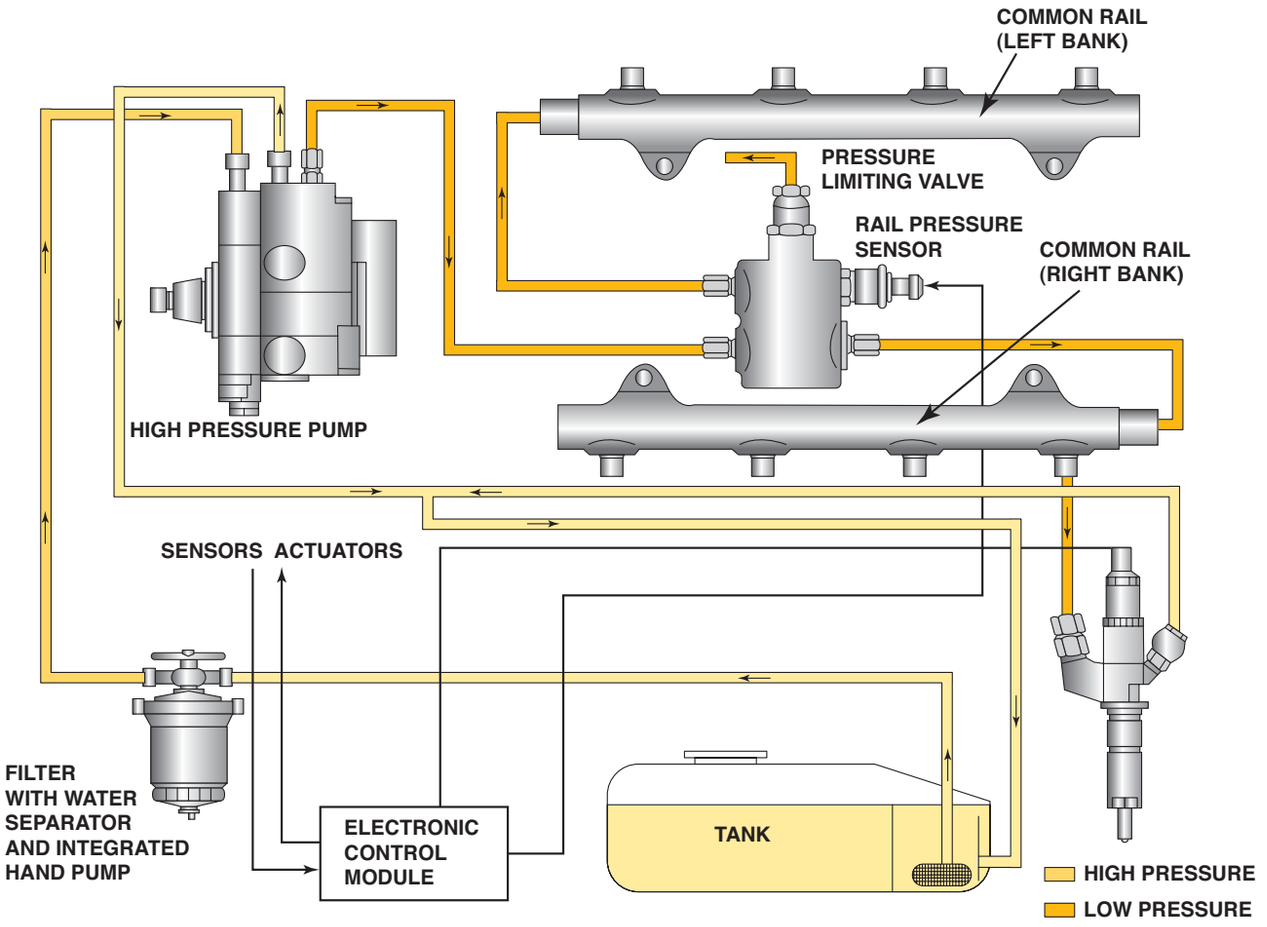


FIGURE 19–10 Overview of a computer-controlled high-pressure common rail V-8 diesel engine.

TECH TIP

Change Oil Regularly in a Ford Diesel Engine

Ford 7.3 and 6.0 liter diesel engines pump unfiltered oil from the sump to the high-pressure oil pump and then to the injectors. This means that not changing oil regularly can contribute to accumulation of dirt in the engine and will subject the fuel injectors to wear and potential damage as particles suspended in the oil get forced into the injectors.

separator/fuel heater bowl and then fuel is directed back to the fuel pump where fuel is pumped at high pressure into the cylinder head fuel galleries.

- The injectors, which are hydraulically actuated by engine oil pressure from the high-pressure oil pump, are then fired by the powertrain control module (PCM). The control system for the fuel injectors is the PCM, and the injectors are fired based on sensor inputs received by the PCM. ● **SEE FIGURE 19–11**.

HEUI injectors rely on O-rings to keep fuel and oil from mixing or escaping, causing performance problems or engine damage. HEUI injectors use five O-rings. The three external O-rings should be replaced with updated O-rings if they fail. The two internal O-rings are not replaceable and if these fail, the injector(s) must be replaced. The most common symptoms of injector O-ring trouble include:

- Oil getting in the fuel
- The fuel filter element turning black

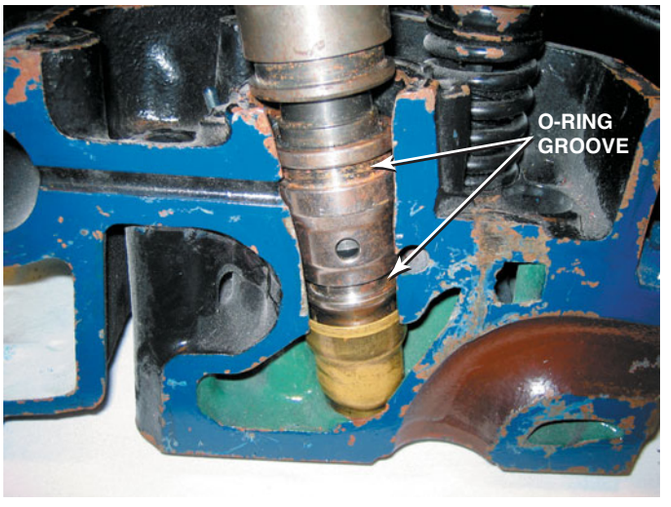


FIGURE 19–11 A HEUI injector from a Ford PowerStroke diesel engine. The O-ring grooves indicate the location of the O-rings that seal the fuel section of the injector from coolant and from the engine oil.

- Long cranking times before starting
- Sluggish performance
- Reduction in power
- Increased oil consumption (This often accompanies O-ring problems or any fault that lets fuel in the oil.)

TECH TIP

Never Allow a Diesel Engine to Run Out of Fuel

If a gasoline-powered vehicle runs out of gasoline, it is an inconvenience and a possible additional expense to get some gasoline. However, if a vehicle equipped with a diesel engine runs out of fuel, it can be a major concern.

Besides adding diesel fuel to the tank, the other problem is getting all of the air out of the pump, lines, and injectors so the engine will operate correctly.

The procedure usually involves cranking the engine long enough to get liquid diesel fuel back into the system, but at the same time keeping cranking time short enough to avoid overheating the starter. Consult service information for the exact service procedure if the diesel engine is run out of fuel.

NOTE: Some diesel engines, such as the General Motors Duramax V-8, are equipped with a priming pump located under the hood on top of the fuel filter. Pushing down and releasing the priming pump with a vent valve open will purge any trapped air from the system. Always follow the vehicle manufacturer's instructions.



FIGURE 19–12 Typical computer-controlled diesel engine fuel injectors.

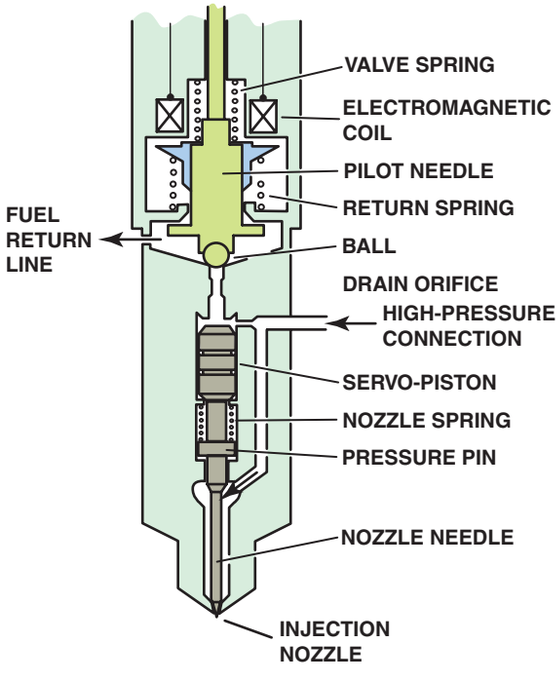


FIGURE 19–13 A Duramax injector showing all the internal parts.

DIESEL INJECTOR NOZZLES

PARTS INVOLVED Diesel injector nozzles are spring-loaded closed valves that spray fuel directly into the combustion chamber or precombustion chamber when the injector is opened. Injector nozzles are threaded or clamped into the cylinder head, one for each cylinder, and are replaceable as an assembly.

The tip of the injector nozzle has many holes to deliver an atomized spray of diesel fuel into the cylinder. Parts of a diesel injector nozzle include:

- **Heat shield.** This is the outer shell of the injector nozzle and may have external threads where it seals in the cylinder head.
- **Injector body.** This is the inner part of the nozzle and contains the injector needle valve and spring, and threads into the outer heat shield.
- **Diesel injector needle valve.** This precision machined valve and the tip of the needle seal against the injector body when it is closed. When the valve is open, diesel fuel is sprayed into the combustion chamber. This passage is controlled by a computer-controlled solenoid on diesel engines equipped with computer-controlled injection.
- **Injector pressure chamber.** The pressure chamber is a machined cavity in the injector body around the tip of the injector needle. Injection pump pressure forces fuel into this chamber, forcing the needle valve open.

DIESEL INJECTOR NOZZLE OPERATION The electric solenoid attached to the injector nozzle is computer controlled and opens to allow fuel to flow into the injector pressure chamber. ● **SEE FIGURE 19–12.**

The fuel flows down through a fuel passage in the injector body and into the pressure chamber. The high fuel pressure in the pressure chamber forces the needle valve upward, compressing the needle valve return spring and forcing the needle valve open. When the needle valve opens, diesel fuel is discharged into the combustion chamber in a hollow cone spray pattern.

Any fuel that leaks past the needle valve returns to the fuel tank through a return passage and line. ● **SEE FIGURE 19–13.**

GLOW PLUGS

PURPOSE AND FUNCTION Glow plugs are always used in diesel engines equipped with a precombustion chamber and may be used in direct injection diesel engines to aid starting. A **glow plug** is a heating element that uses 12 volts from the battery and aids in the starting of a cold engine by providing heat to help the fuel to ignite. ● **SEE FIGURE 19–14.**



FIGURE 19–14 A glow plug assortment showing the various types and sizes of glow plugs used. Always use the specified glow plugs.

As the temperature of the glow plug increases, the resistance of the heating element inside increases, thereby reducing the current in amperes needed by the glow plugs.

OPERATION Most glow plugs used in newer vehicles are controlled by the powertrain control module, which monitors coolant temperature and intake air temperature. The glow plugs are turned on or pulsed on or off depending on the temperature of the engine. The PCM will also keep the glow plug turned on after the engine starts, to reduce white exhaust smoke (unburned fuel) and to improve idle quality after starting. ● **SEE FIGURE 19–15**.

The "wait to start" lamp (if equipped) will light when the engine and the outside temperatures are low to allow time for the glow plugs to get hot.

HEATED INLET AIR Some diesel engines, such as the Dodge Cummins and the General Motors 6.6 liter Duramax V-8, use an electrical heater wire to warm the intake air to help in cold weather starting and running. ● **SEE FIGURE 19–16**.

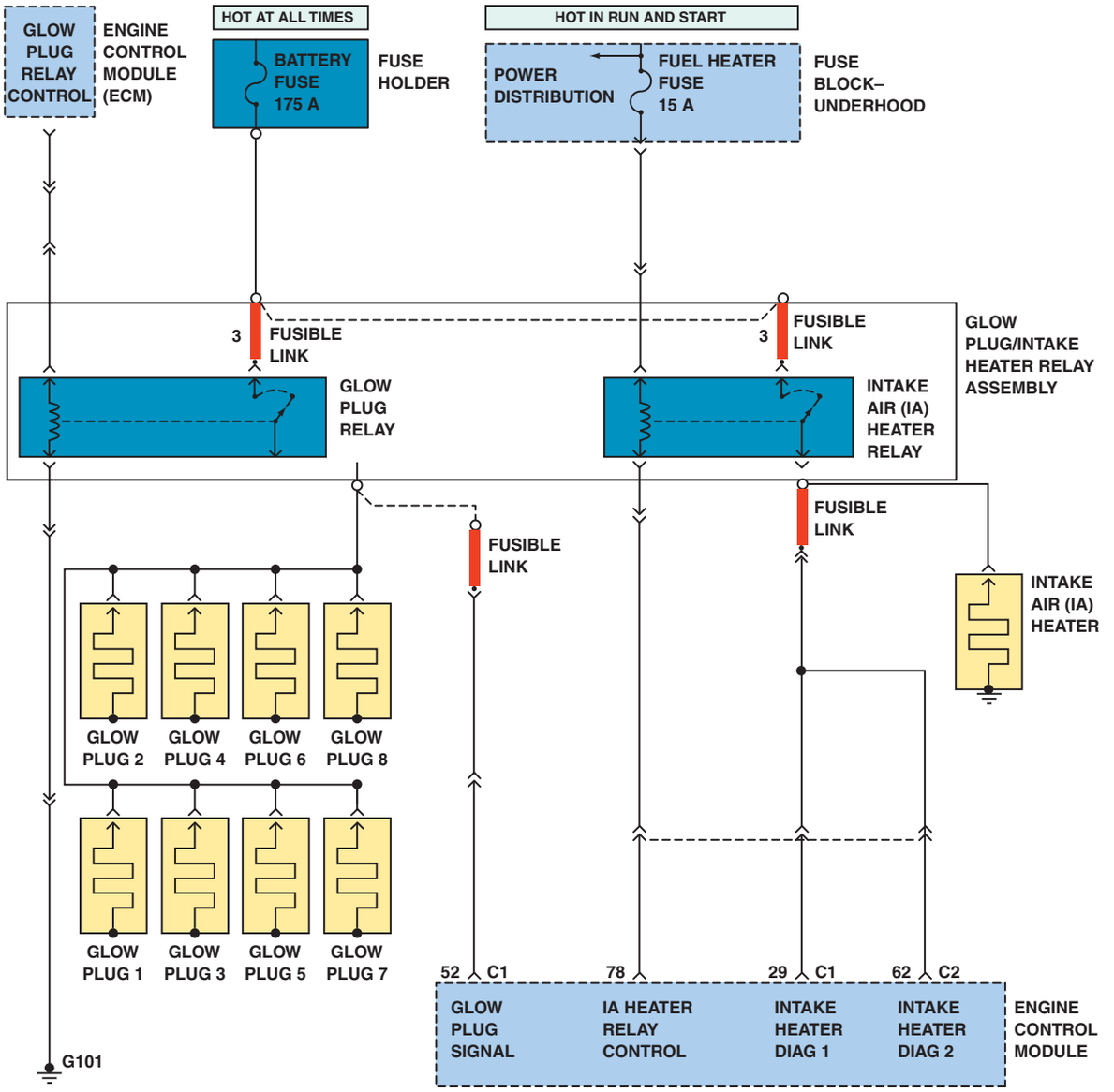


FIGURE 19–15 A schematic of a typical glow plug circuit. Notice that the glow plug relay and intake air heater relay are both computer controlled.



FIGURE 19–16 A wire-wound electric heater is used to warm the intake air on some diesel engines.

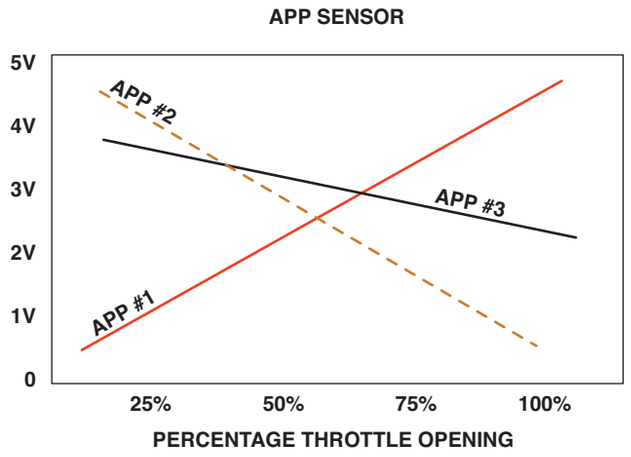


FIGURE 19–17 A typical accelerator pedal position (APP) sensor uses three different sensors in one package with each creating a different voltage as the accelerator is moved.

? FREQUENTLY ASKED QUESTION

How Can You Tell If Gasoline Has Been Added to the Diesel Fuel by Mistake?

If gasoline has been accidentally added to diesel fuel and is burned in a diesel engine, the result can be very damaging to the engine. The gasoline can ignite faster than diesel fuel, which would tend to increase the temperature of combustion. This high temperature can harm injectors and glow plugs, as well as pistons, head gaskets, and other major diesel engine components. If contaminated fuel is suspected, first smell the fuel at the filler neck. If the fuel smells like gasoline, then the tank should be drained and refilled with diesel fuel. If the smell test does not indicate a gasoline or any rancid smell, then test a sample for proper specific gravity.

NOTE: Diesel fuel designed for on-road use should be green. Red diesel fuel (high sulfur) should only be found in off-road or farm equipment.

ENGINE-DRIVEN VACUUM PUMP

Because a diesel engine is unthrottled, it creates very little vacuum in the intake manifold. Several engine and vehicle components operate using vacuum, such as the exhaust gas recirculation (EGR) valve and the heating and ventilation blend and air doors. Most diesels used in cars and light trucks are equipped with an engine-driven vacuum pump to supply the vacuum for these components.

DIESEL FUEL HEATERS

Diesel fuel heaters help prevent power loss and stalling in cold weather. The heater is placed in the fuel line between the tank and the primary filter. Some coolant heaters are thermostatically controlled, which allows fuel to bypass the heater once it has reached operating temperature.

ACCELERATOR PEDAL POSITION SENSOR

Some light-truck diesel engines are equipped with an electronic throttle to control the amount of fuel injected into the engine. Because a diesel engine does not use a throttle in the air intake, the only way to control engine speed is by controlling the amount of fuel being injected into the cylinders. Instead of a mechanical link from the accelerator pedal to the diesel injection pump, a throttle-by-wire system uses an accelerator pedal position (APP) sensor. To ensure safety, it consists of three separate sensors that change in voltage as the accelerator pedal is depressed. ● **SEE FIGURE 19–17**.

The computer checks for errors by comparing the voltage output of each of the three sensors inside the APP and compares them to what they should be if there are no faults. If an error is detected, the engine and vehicle speed are often reduced.

DIESEL ENGINE TURBOCHARGERS

TURBOCHARGED DIESELS A turbocharger greatly increases engine power by pumping additional compressed air into the combustion chambers. This allows a greater quantity of fuel to be burned in the cylinders resulting in greater power output. In a turbocharger, the turbine wheel spins as exhaust gas flows out of the engine and drives the turbine blades. The turbine spins the compressor wheel at the opposite end of the turbine shaft, pumping air into the intake system. ● **SEE FIGURE 19–18**.

AIR CHARGE COOLER The first component in a typical turbocharger system is an air filter through which ambient air passes before entering the compressor. The air is compressed, which raises its density (mass/unit volume). All currently produced light-duty diesels use an air charge cooler whose purpose is to cool the compressed air to further raise the air density. Cooler air entering the engine means more power can be produced by the engine. ● **SEE FIGURE 19–19**.

VARIABLE TURBOCHARGER A variable turbocharger is used on many diesel engines for boost control. Boost pressure is controlled independent of engine speed and a wastegate is not needed. The adjustable vanes mount to a unison ring that allows the vanes to move. As the position of the unison ring rotates, the vanes change angle. The vanes are opened to minimize flow at the turbine and exhaust back pressure at low engine speeds. To increase turbine speed, the vanes are closed. The velocity of the exhaust gases increases, as does the speed of the turbine. The unison ring is connected to a cam that is positioned by a rack-and-pinion gear. The turbocharger's vane position actuator solenoid connects to a hydraulic piston, which moves the rack to rotate the pinion gear and cam. ● **SEE FIGURE 19–20**.

The turbocharger vane position control solenoid valve is used to advance the unison ring's relationship to the turbine and thereby articulate the vanes. This solenoid actuates a spool valve that applies oil pressure to either side of a piston. Oil flow has three modes: apply, hold, and release.

- *Apply* moves the vanes toward a closed position.
- *Hold* maintains the vanes in a fixed position.
- *Release* moves the vanes toward the open position.

The turbocharger vane position actuation is controlled by the ECM, which can change turbine boost efficiency independent of engine speed. The ECM provides a control signal to the valve solenoid along with a low-side reference. A pulse-width-modulated signal from the ECM moves the valve to the desired position.

EXHAUST GAS RECIRCULATION

The EGR system recycles some exhaust gas back into the intake stream to cool combustion, which reduces oxides of nitrogen (NOx) emissions. The EGR system includes:

- Plumbing that carries some exhaust gas from the turbocharger exhaust inlet to the intake ports
- EGR control valve
- Stainless steel cooling element used to cool the exhaust gases (● **SEE FIGURE 19–21**.)



FIGURE 19–18 A Cummins diesel turbocharger is used to increase the power and torque of the engine.

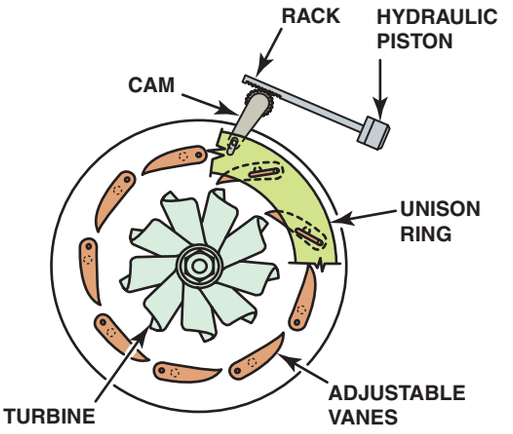


FIGURE 19–20 A variable vane turbocharger allows the boost to be controlled without the need of a wastegate.

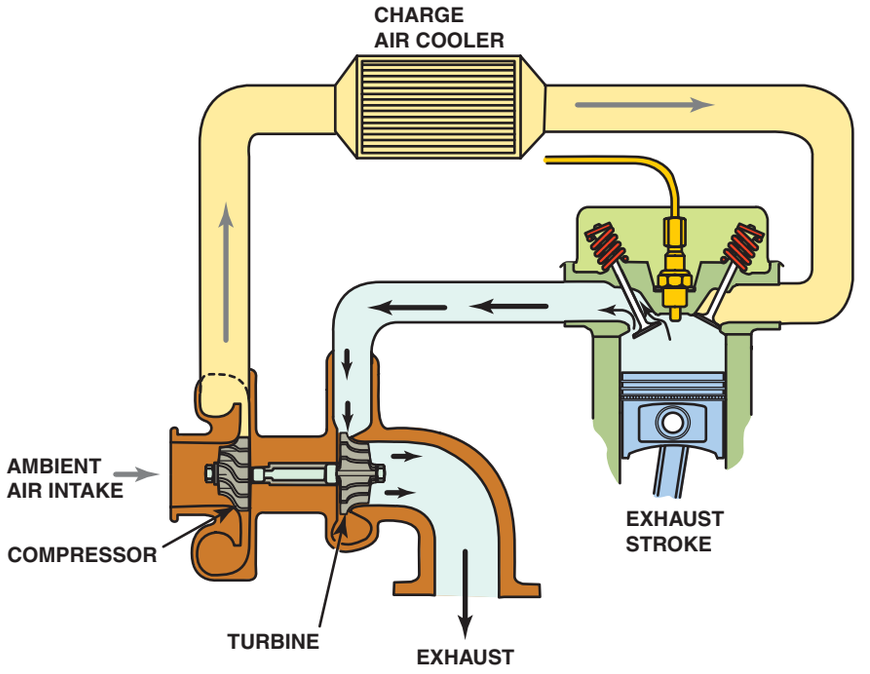


FIGURE 19–19 An air charge cooler is used to cool the compressed air.



FIGURE 19–21 A cutaway showing the exhaust cooler. The cooler the exhaust is, the more effective it is in controlling NOx emissions.

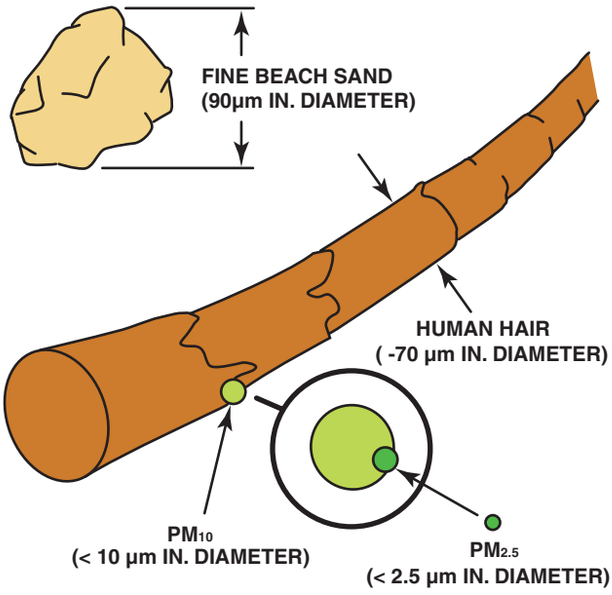


FIGURE 19–22 Relative size of particulate matter to a human hair.

The EGR valve is PCM controlled and often uses a DC stepper motor and worm gear to move the valve stem open. The gear is not attached to the valve and can only force it open. Return spring force closes the valve. The EGR valve and sensor assembly is a five-wire design. The PCM uses the position sensor to verify that valve action is as commanded.

DIESEL PARTICULATE MATTER

PARTICULATE MATTER STANDARDS

Particulate matter (PM), also called **soot**, refers to tiny particles of solid or semisolid material suspended in the atmosphere. This includes particles between 0.1 micron and 50 microns in diameter. The heavier particles, larger than 50 microns, typically tend to settle out quickly due to gravity. Particulates are generally categorized as follows:

- **Total suspended particulate (TSP).** Refers to all particles between 0.1 and 50 microns. Up until 1987, the Environmental Protection Agency (EPA) standard for particulates was based on levels of TSP.
- **PM10.** Refers to particulate matter of 10 microns or less (approximately 1/6 the diameter of a human hair). EPA has a standard for particles based on levels of PM10.
- **PM2.5.** Refers to particulate matter of 2.5 microns or less (approximately 1/20 the diameter of a human hair), also called "fine" particles. In July 1997, the EPA approved a standard for PM2.5. ● **SEE FIGURE 19–22.**

SOOT CATEGORIES

In general, soot particles produced by diesel combustion fall into the following categories.

- **Fine.** Less than 2.5 microns
- **Ultrafine.** Less than 0.1 micron, and make up 80% to 95% of soot

? FREQUENTLY ASKED QUESTION

What Is the Big Deal for the Need to Control Very Small Soot Particles?

For many years soot or particulate matter (PM) was thought to be less of a health concern than exhaust emissions from gasoline engines. It was felt that the soot could simply fall to the ground without causing any noticeable harm to people or the environment. However, it was discovered that the small soot particulates when breathed in are not expelled from the lungs like larger particles but instead get trapped in the deep areas of the lungs where they accumulate.

DIESEL OXIDATION CATALYST

PURPOSE AND FUNCTION

Diesel oxidation catalysts (DOC) are used in all light-duty diesel engines, since 2007. They consist of a flow-through honeycomb-style substrate structure that is wash coated with a layer of catalyst materials, similar to those used in a gasoline engine catalytic converter. These materials include the precious metals platinum and palladium, as well as other base metal catalysts.

Catalysts chemically react with exhaust gas to convert harmful nitrogen oxide into nitrogen dioxide, and to oxidize absorbed hydrocarbons. The chemical reaction acts as a combustor for the unburned fuel that is characteristic of diesel compression ignition. The main function of the DOC is to start a regeneration event by converting the fuel-rich exhaust gases to heat.

The DOC also reduces:

- Carbon monoxide (CO)
- Hydrocarbons (HC)
- Odor-causing compounds such as aldehydes and sulfur ● **SEE FIGURE 19–23.**

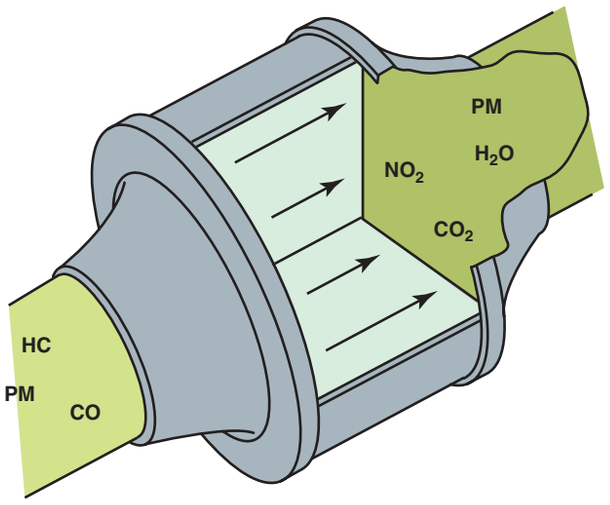


FIGURE 19–23 Chemical reaction within the DOC.

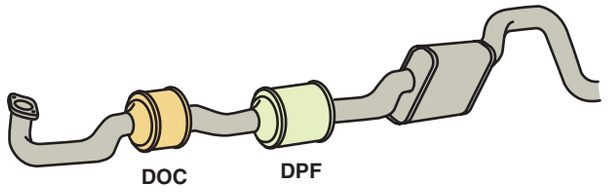


FIGURE 19–24 Aftertreatment of diesel exhaust is handled by the DOC and DPF.

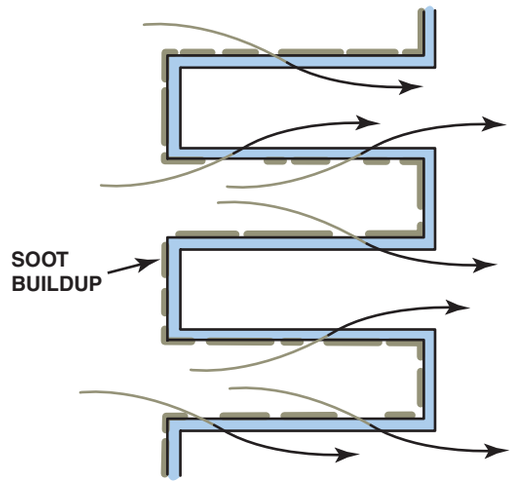


FIGURE 19–25 The soot is trapped in the passages of the DPF. The exhaust has to flow through the sides of the trap and exit.

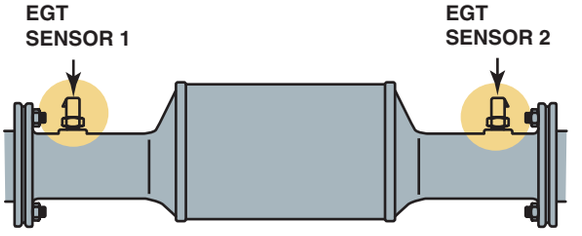


FIGURE 19–26 EGT 1 and EGT 2 are used by the PCM to help control after treatment.

DIESEL EXHAUST PARTICULATE FILTER

PURPOSE AND FUNCTION **Diesel exhaust particulate filters (DPFs)** are used in all light-duty diesel vehicles, since 2007, to meet the exhaust emissions standards. The heated exhaust gas from the DOC flows into the DPF, which captures diesel exhaust gas particulates (soot) to prevent them from being released into the atmosphere. This is done by forcing the exhaust through a porous cell which has a silicon carbide substrate with honeycomb-cell-type channels that trap the soot. The main difference between the DPF and a typical catalyst filter is that the entrance to every other cell channel in the DPF substrate is blocked at one end. So instead of flowing directly through the channels, the exhaust gas is forced through the porous walls of the blocked channels and exits through the adjacent open-ended channels. This type of filter is also referred to as a "wall-flow" filter. ● **SEE FIGURE 19–24**.

OPERATION Soot particulates in the gas remain trapped on the DPF channel walls where, over time, the trapped particulate matter will begin to clog the filter. The filter must therefore be purged periodically to remove accumulated soot particles. The process of purging soot from the DPF is described as **regeneration.** When the temperature of the exhaust gas is increased, the heat incinerates the soot particles trapped in the filter and is effectively renewed. ● **SEE FIGURE 19–25**.

EXHAUST GAS TEMPERATURE SENSORS The following two exhaust gas temperature sensors are used to help the PCM control the DPF.

- EGT sensor 1 is positioned between the DOC and the DPF where it can measure the temperature of the exhaust gas entering the DPF.
- EGT sensor 2 measures the temperature of the exhaust gas stream immediately after it exits the DPF.

The powertrain control module monitors the signals from the EGT sensors as part of its calibrations to control DPF regeneration. Proper exhaust gas temperatures at the inlet of the DPF are crucial for proper operation and for starting the regeneration process. Too high a temperature at the DPF will cause the DPF substrate to melt or crack. Regeneration will be terminated at temperatures above 1,470°F (800°C). With too low a temperature, self-regeneration will not fully complete the soot-burning process. ● **SEE FIGURE 19–26**.

DPF DIFFERENTIAL PRESSURE SENSOR The DPF **differential pressure sensor (DPS)** has two pressure sample lines.

- One line is attached before the DPF.
- The other is located after the DPF.

The exact location of the DPS varies by vehicle model type such as medium duty, pickup, or van. By measuring the exhaust supply (upstream) pressure from the DOC, and the post DPF (downstream) pressure, the PCM can determine differential pressure, also called "delta" pressure, across the DPF. Data from the DPF differential pressure sensor is used by the PCM to calibrate for controlling DPF exhaust system operation.

DIESEL PARTICULATE FILTER REGENERATION The primary reason for soot removal is to prevent the buildup of exhaust back pressure. Excessive back pressure increases fuel consumption, reduces power output, and can potentially cause engine

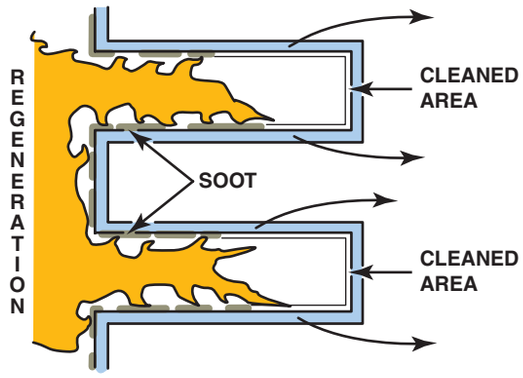


FIGURE 19–27 Regeneration burns the soot and renews the DPF.

damage. Several factors can trigger the diesel PCM to perform regeneration, including:

- Distance since last DPF regeneration
- Fuel used since last DPF regeneration
- Engine run time since last DPF regeneration
- Exhaust differential pressure across the DPF

DPF REGENERATION PROCESS A number of engine components are required to function together for the regeneration process to be performed, as follows:

1. PCM controls that impact DPF regeneration include late post injections, engine speed, and adjusting fuel pressure.
2. Adding late post injection pulses provides the engine with additional fuel to be oxidized in the DOC, which increases exhaust temperatures entering the DPF to 900°F (500°C) or higher. ● **SEE FIGURE 19–27**.
3. The intake air valve acts as a restrictor that reduces air entry to the engine, which increases engine operating temperature.
4. The intake air heater may also be activated to warm intake air during regeneration.

TYPES OF DPF REGENERATION DPF regeneration can be initiated in a number of ways, depending on the vehicle application and operating circumstances. The two main regeneration types are as follows:

- **Passive regeneration.** During normal vehicle operation when driving conditions produce sufficient load and exhaust temperatures, passive DPF regeneration may occur. This passive regeneration occurs without input from the PCM or the driver. A passive regeneration may typically occur while the vehicle is being driven at highway speed or towing a trailer.
- **Active regeneration.** Active regeneration is commanded by the PCM when it determines that the DPF requires it to remove excess soot buildup and conditions for filter regeneration have been met. Active regeneration is usually not noticeable to the driver. The vehicle needs to be driven at speeds above 30 mph for approximately 20 to 30 minutes to complete a full regeneration. During regeneration, the exhaust gases reach temperatures above 1,000°F (550°C). Active regeneration is usually not noticeable to the driver.

WARNING

Tailpipe outlet exhaust temperature will be greater than 572°F (300°C) during service regeneration. To help prevent personal injury or property damage from fire or burns, keep vehicle exhaust away from any object and people.

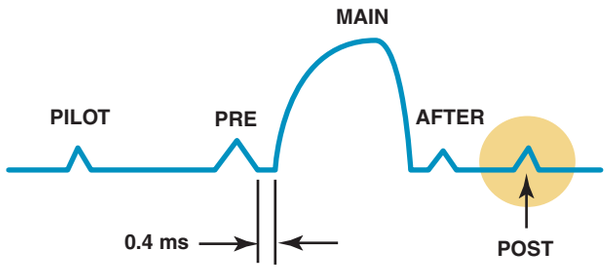


FIGURE 19–28 The post injection pulse occurs to create the heat needed for regeneration.

FREQUENTLY ASKED QUESTION

Will the Postinjection Pulses Reduce Fuel Economy?

Maybe. Due to the added fuel-injection pulses and late fuel-injection timing, an increase in fuel consumption may be noticed on the driver information center (DIC) during the regeneration time period. A drop in overall fuel economy should not be noticeable. ● **SEE FIGURE 19–28**.

FREQUENTLY ASKED QUESTION

What Is an Exhaust Air Cooler?

An exhaust air cooler is simply a section of tailpipe that has slits for air to enter. As hot exhaust rushes past the gap, outside air is drawn into the area which reduces the exhaust discharge temperature. The cooler significantly lowers exhaust temperature at the tailpipe from about 800°F (430°C) to approximately 500°F (270°C). ● **SEE FIGURE 19–29**.

ASH LOADING Regeneration will not burn off ash. Only the particulate matter (PM) is burned off during regeneration. Ash is a noncombustible by-product from normal oil consumption. Ash accumulation in the DPF will eventually cause a restriction in the particulate filter. To service an ash-loaded DPF, the DPF will need to be removed from the vehicle and cleaned or replaced. Low ash content engine oil (API CJ-4) is required for vehicles with the DPF system. The CJ-4 rated oil is limited to 1% ash content.

SELECTIVE CATALYTIC REDUCTION

PURPOSE AND FUNCTION **Selective catalytic reduction (SCR)** is a method used to reduce NOx emissions by injecting urea into the exhaust stream. Instead of using large amounts of exhaust gas recirculation (EGR), the SCR system uses a urea. **Urea** is used as a nitrogen fertilizer. It is colorless, odorless, and nontoxic. Urea is called **diesel exhaust fluid (DEF)** in North America and AdBlue in Europe. ● **SEE FIGURE 19–30**.

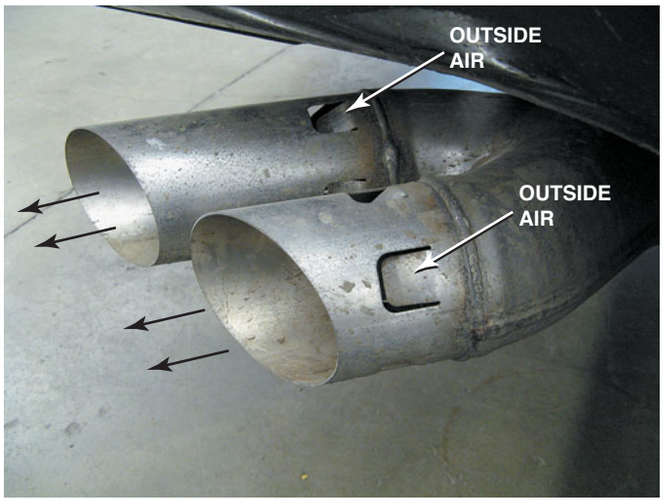


FIGURE 19–29 The exhaust is split into two outlets and has slits to help draw outside air in as the exhaust leaves the tailpipe. The end result is cooler exhaust gases exiting the tailpipe.



FIGURE 19–30 Diesel exhaust fluid costs $3 to $4 a gallon and is housed in a separate container that holds from 5 to 10 gallons, or enough to last until the next scheduled oil change in most diesel vehicles that use SCR.

The urea is injected into the catalyst where it sets off a chemical reaction which converts nitrogen oxides (NOx) into nitrogen (N_2) and water (H_2O). Vehicle manufacturers size the onboard urea storage tank so that it needs to be refilled at about each scheduled oil change or every 7,500 miles (12,000 km). A warning light alerts the driver when the urea level needs to be refilled. If the warning light is ignored and the diesel exhaust fluid is not refilled, current EPA regulations require that the operation of the engine be restricted and may not start unless the fluid is refilled. This regulation is designed to prevent the engine from being operated without the fluid, which, if not, would greatly increase exhaust emissions. ● **SEE FIGURE 19–31**.

ADVANTAGES OF SCR Using urea injection instead of large amounts of EGR results in the following advantages.

- Potential higher engine power output for the same size engine
- Reduced NOx emissions up to 90%
- Reduced HC and CO emissions up to 50%
- Reduced particulate matter (PM) by 50%

DISADVANTAGES OF SCR Using urea injection instead of large amounts of EGR results in the following disadvantages.

- Onboard storage tank required for the urea

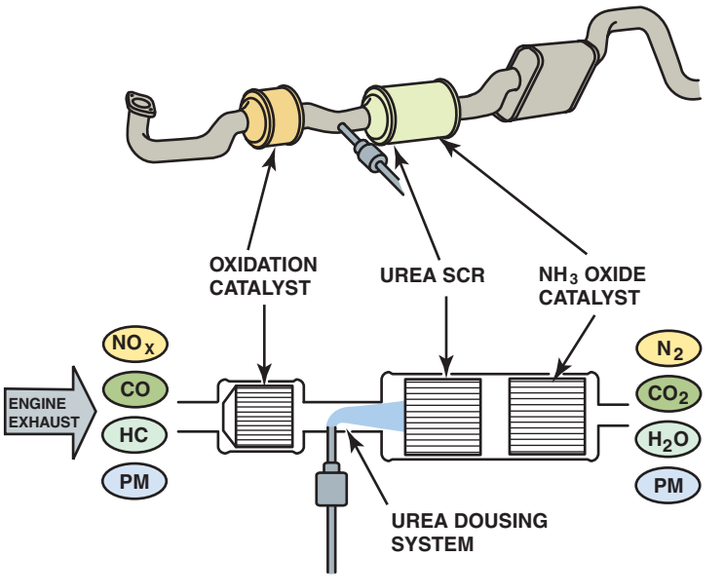


FIGURE 19–31 Urea (diesel exhaust fluid) injection is used to reduce NOx exhaust emissions. It is injected after the diesel oxidation catalyst (DOC) and before the diesel particulate filter (DPF) on this 6.7 liter Ford diesel engine.

- Difficult to find local sources of urea
- Increased costs to the vehicle owner due to having to refill the urea storage tank

DIESEL EXHAUST SMOKE DIAGNOSIS

Although some exhaust smoke is considered normal operation for many diesel engines, especially older units, the cause of excessive exhaust smoke should be diagnosed and repaired.

BLACK SMOKE Black exhaust smoke is caused by incomplete combustion because of a lack of air or a fault in the injection system that could cause an excessive amount of fuel in the cylinders. Items that should be checked include the following:

- Fuel specific gravity (API gravity)
- Injector balance test to locate faulty injectors using a scan tool
- Proper operation of the engine coolant temperature (ECT) sensor
- Proper operation of the fuel rail pressure (FRP) sensor
- Restrictions in the intake or turbocharger
- Engine oil usage

WHITE SMOKE White exhaust smoke occurs most often during cold engine starts because the smoke is usually condensed fuel droplets. White exhaust smoke is also an indication of cylinder misfire on a warm engine. The most common causes of white exhaust smoke include:

- Inoperative glow plugs
- Low engine compression
- Incorrect injector spray pattern
- Coolant leak into the combustion chamber

GRAY OR BLUE SMOKE Blue exhaust smoke is usually due to oil consumption caused by worn piston rings, scored cylinder walls, or defective valve stem seals. Gray or blue smoke can also be caused by a defective injector(s).

DIESEL PERFORMANCE DIAGNOSIS

Diesel engines can be diagnosed using a scan tool in most cases, because most of the pressure sensors values can be displayed. Common faults include:

- Hard starting
- No start
- Extended cranking before starting
- Low power

Using a scan tool, check the sensor values in **CHART 19–2** to help pin down the source of the problem. Also check the minimum pressures that are required to start the engine if a no-start condition is being diagnosed. **SEE FIGURE 19–32**.

DIESEL TROUBLESHOOTING CHART	
5.9 Dodge Cummins 2003–2008	
Low-pressure pump	8–12 PSI
Pump amperes	4 A
Pump volume	45 oz. in 30 sec.
High-pressure pump	5,000–23,000 PSI
Idle PSI	5,600–5,700 PSI
Electronic Fuel Control (EFC) maximum fuel pressure	Disconnect EFC to achieve maximum pressure
Injector volts	90 V
Injector amperes	20 A
Glow plug amperes	60–80 A × 2 (120–160 A)
Minimum PSI to start	5,000 PSI
GM Duramax 2001–2008	
Low-pressure pump vacuum	2–10 in. Hg
Pump amperes	NA
Pump volume	NA
High-pressure pump	5 K-2.3 K-2.6 K PSI
Idle PSI	5,000–6,000 PSI (30–40 MPa)
Fuel Rail Pressure Regulator (FRPR) maximum fuel pressure	Disconnect to achieve maximum pressure
Injector volts	48 V or 93 V
Injector amperes	20 A
Glow plug amperes	160 A
Minimum to start	1,500 PSI (10 MPa)
Sprinter 2.7 2002–2006	
Low-pressure pump	6–51 PSI
High-pressure pump	800–23,000 PSI
Idle PSI	4,900 PSI
Fuel Rail Pressure Control (FRPC) maximum fuel pressure	Apply power and ground to FRPC to achieve maximum pressure
Injector volts	80 V
Injector amperes	20 A
Glow plug amperes	17 A each (85–95 A total)
Minimum to start	3,200 PSI (1–1.2 V to start)
6.0 Powerstroke 2003–2008	
Low-pressure pump	50–60 PSI
High-pressure pump	500–4,000 PSI
Idle PSI	500 PSI +
Injection Pressure Regulator (IPR) maximum fuel pressure	Apply power and ground to IPR
Injector volts	48 V
Injector amperes	20 A
Glow plug amperes	20–25 A each (160–200 A total)
Minimum to start	500 PSI (0.85 V)

CHART 19–2

The values can be obtained by using a scan tool and basic test equipment. Always follow the vehicle manufacturer's recommended procedures.



FIGURE 19–32 A pressure gauge checking the fuel pressure from the lift pump on a Cummins 6.7 liter diesel.

COMPRESSION TESTING

A compression test is fundamental for determining the mechanical condition of a diesel engine. Worn piston rings can cause low power and excessive exhaust smoke. To test the compression on a diesel engine, the following will have to be done.

- Remove the glow plug (if equipped) or the injector.
- Use a diesel compression gauge, as the compression is too high to use a gasoline engine compression gauge.

A diesel engine should produce at least 300 PSI (2,068 kPa) of compression pressure and all cylinders should be within 50 PSI (345 kPa) of each other. ● **SEE FIGURE 19–33**.

GLOW PLUG RESISTANCE BALANCE TEST

Glow plugs increase in resistance as their temperature increases. All glow plugs should have about the same resistance when checked with an ohmmeter. A similar test of the resistance of the glow plugs can be used to detect a weak cylinder. This test is particularly helpful on a diesel engine that is not computer controlled. To test for even cylinder balance using glow plug resistance, perform the following on a warm engine.

1. Unplug, measure, and record the resistance of all glow plugs.
2. With the wires still removed from the glow plugs, start the engine.
3. Allow the engine to run for several minutes to allow the combustion inside the cylinder to warm the glow plugs.
4. Measure the plugs and record the resistance of all glow plugs.
5. The resistance of all glow plugs should be higher than at the beginning of the test. A glow plug that is in a cylinder that is not firing correctly will not increase in resistance as much as the others.
6. Another test is to measure exhaust manifold temperature at each exhaust port using an infrared thermometer or a pyrometer. Misfiring cylinders will run cold.

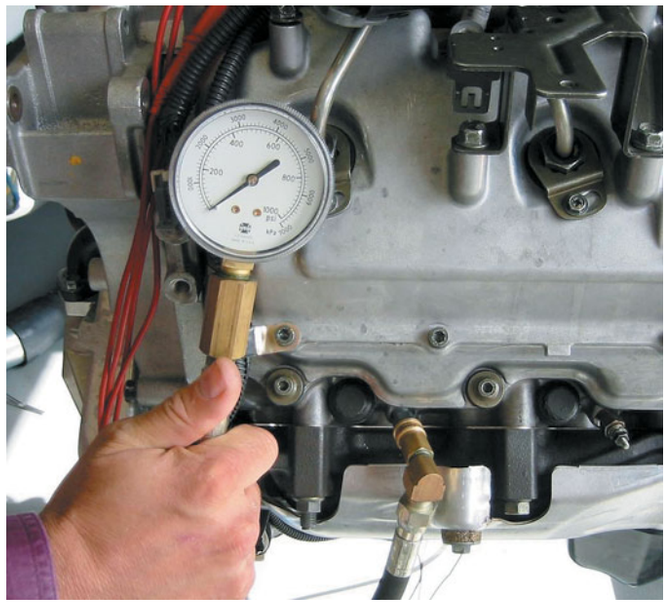


FIGURE 19–33 A compression gauge that is designed for the higher compression rate of a diesel engine should be used when checking the compression.



FIGURE 19–34 A typical pop tester used to check the spray pattern of a diesel engine injector.

INJECTOR POP TESTING

A **pop tester** is a device used for checking a diesel injector nozzle for proper spray pattern. The handle is depressed and pop-off pressure is displayed on the gauge. ● **SEE FIGURE 19–34**.

The spray pattern should be a hollow cone, but will vary depending on design. The nozzle should also be tested for leakage (dripping of the nozzle) while under pressure. If the spray pattern is not correct, then cleaning, repairing, or replacing the injector nozzle may be necessary.

	20% opacity
	40% opacity
	60% opacity
	80% opacity
	100% opacity

CHART 19–3

An opacity test is sometimes used during a state emission test on diesel engines.

TECH TIP

Always Use Cardboard to Check for High-Pressure Leaks

If diesel fuel is found on the engine, a high-pressure leak could be present. When checking for such a leak, wear protective clothing including safety glasses, a face shield, gloves, and a long-sleeved shirt. Then use a piece of cardboard to locate the high-pressure leak. When a Duramax diesel is running, the pressure in the common rail and injector tubes can reach over 20,000 PSI. At these pressures, the diesel fuel is atomized and cannot be seen but can penetrate the skin and cause personal injury. A leak will be shown as a dark area on the cardboard. When a leak is found, shut off the engine and find the exact location of the leak without the engine running.

CAUTION: Sometimes a leak can actually cut through the cardboard, so use extreme care.

DIESEL EMISSION TESTING

OPACITY TEST The most common diesel exhaust emission test used in state or local testing programs is called the opacity test. **Opacity** means the percentage of light that is blocked by the exhaust smoke.

- A 0% opacity means that the exhaust has no visible smoke and does not block light from a beam projected through the exhaust smoke.
- A 100% opacity means that the exhaust is so dark that it completely blocks light from a beam projected through the exhaust smoke.
- A 50% opacity means that the exhaust blocks half of the light from a beam projected through the exhaust smoke. **SEE CHART 19–3.**



FIGURE 19–35 The letters on the side of this injector on a Cummins 6.7 liter diesel indicate the calibration number for the injector.

TECH TIP

Do Not Switch Injectors

In the past, it was common practice to switch diesel fuel injectors from one cylinder to another when diagnosing a dead cylinder problem. However, most high-pressure common rail systems used in new diesels utilize precisely calibrated injectors that should not be mixed up during service. Each injector has its own calibration number. **SEE FIGURE 19–35.**

SNAP ACCELERATION TEST In a snap acceleration test, the vehicle is held stationary, with wheel chocks in place and brakes released as the engine is rapidly accelerated to high idle, with the transmission in neutral while smoke emissions are measured. This test is conducted a minimum of six times and the three most consistent measurements are averaged for a final score.

ROLLING ACCELERATION TEST Vehicles with a manual transmission are rapidly accelerated in low gear from an idle speed to a maximum governed RPM while the smoke emissions are measured.

STALL ACCELERATION TEST Vehicles with automatic transmissions are held in a stationary position with the parking brake and service brakes applied while the transmission is placed in "drive." The accelerator is depressed and held momentarily while smoke emissions are measured.

The standards for diesels vary according to the type of vehicle and other factors, but usually include a 40% opacity or less.

REVIEW QUESTIONS

1. What is the difference between direct injection and indirect injection?
2. What are the three phases of diesel ignition?
3. What are the two most commonly used types of diesel injection systems?
4. Why are glow plugs kept working after the engine starts?
5. What exhaust aftertreatment is needed to achieve exhaust emission standards for vehicles 2007 and newer?
6. What are the advantages and disadvantages of SCR?

CHAPTER QUIZ

1. How is diesel fuel ignited in a warm diesel engine?
   a. Glow plugs
   b. Heat of compression
   c. Spark plugs
   d. Distributorless ignition system
2. Which type of diesel injection produces less noise?
   a. Indirect injection (IDI) **c.** Common rail
   b. Direct injection **d.** Distributor injection
3. Which diesel injection system requires the use of a glow plug?
   a. Indirect injection (IDI)
   b. High-pressure common rail
   c. Direct injection
   d. Distributor injection
4. The three phases of diesel ignition include _____.
   a. Glow plug ignition, fast burn, slow burn
   b. Slow burn, fast burn, slow burn
   c. Ignition delay, rapid combustion, controlled combustion
   d. Glow plug ignition, ignition delay, controlled combustion
5. What fuel system component is used in a vehicle equipped with a diesel engine that is seldom used on the same vehicle when it is equipped with a gasoline engine?
   a. Fuel filter **c.** Fuel return line
   b. Fuel supply line **d.** Water-fuel separator
6. The diesel injection pump is usually driven by a _____.
   a. Gear off the camshaft **c.** Shaft drive off the crankshaft
   b. Belt off the crankshaft **d.** Chain drive off the camshaft
7. Which diesel system supplies high-pressure diesel fuel to all of the injectors all of the time?
   a. Distributor **c.** High-pressure common rail
   b. Inline **d.** Rotary
8. Glow plugs should have high resistance when _____ and lower resistance when _____.
   a. Cold/warm **c.** Wet/dry
   b. Warm/cold **d.** Dry/wet
9. Technician A says that glow plugs are used to help start a diesel engine and are shut off as soon as the engine starts. Technician B says that the glow plugs are turned off as soon as a flame is detected in the combustion chamber. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
10. What part should be removed to test cylinder compression on a diesel engine?
    a. Injector
    b. Intake valve rocker arm and stud
    c. Glow plug
    d. Glow plug or injector

chapter 20 COOLANT

OBJECTIVES: **After studying Chapter 20, the reader should be able to:** • Prepare for ASE Engine Repair (A1) certification test content area "D" (Lubrication and Cooling Systems Diagnosis and Repair). • Describe the various types of antifreeze coolants. • Discuss how to store, recycle, and discard used coolant. • Discuss how to test coolant.

KEY TERMS: DEX-COOL 176 • Electrolysis 180 • Embittered coolant 177 • Ethylene glycol based coolant 176 • Galvanic activity 180 • Hybrid organic acid technology (HOAT) 177 • Inorganic acid technology (IAT) 176 • Organic acid technology (OAT) 176 • Passivation 181 • Phosphate hybrid organic acid technology (PHOAT) 177 • Propylene glycol (PG) 177 • Refractometer 179

COOLANT FUNDAMENTALS

PURPOSE OF COOLANT

Coolant is used in the cooling system because it:

1. Transfers heat from the engine to the radiator
2. Protects the engine and the cooling system from rust and corrosion
3. Prevents freezing in cold climates

Coolant is a mixture of antifreeze and water. Water is able to absorb more heat per gallon than any other liquid coolant. Under standard conditions, the following occurs.

- Water boils at 212°F (100°C) at sea level.
- Water freezes at 32°F (0°C).
- When water freezes, it increases in volume by about 9%. The expansion of the freezing water can easily crack engine blocks, cylinder heads, and radiators.

A curve depicting freezing point as compared with the percentage of antifreeze mixture is shown in ● **FIGURE 20–1**.

FREEZING/BOILING TEMPERATURES

It should be noted that the freezing point increases as the antifreeze concentration is

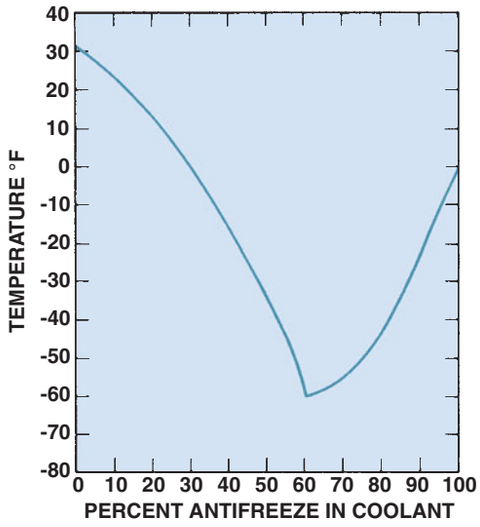


FIGURE 20–1 Graph showing the relationship of the freezing point of the coolant to the percentage of antifreeze used in the coolant.

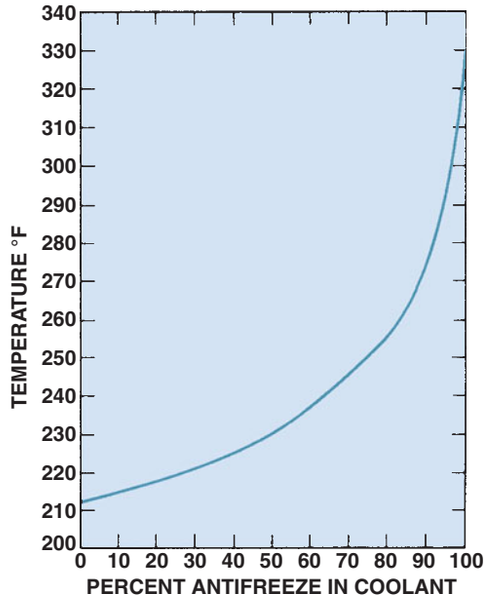


FIGURE 20–2 Graph showing how the boiling point of the coolant increases as the percentage of antifreeze in the coolant increases.

increased above 60%. The normal mixture is 50% antifreeze and 50% water. Ethylene glycol antifreeze contains:

- Anticorrosion additives
- Rust inhibitors
- Water pump lubricants

At the maximum level of protection, an ethylene glycol concentration of 60% will absorb about 85% as much heat as will water. Ethylene glycol based antifreeze also has a higher boiling point than water. A curve depicting freezing point as compared with the percentage of antifreeze mixture is shown in ● **FIGURE 20–2**.

If the coolant boils, it vaporizes and does not act as a cooling agent because it is not in liquid form or in contact with the cooling surfaces.

All coolants have rust and corrosion inhibitors to help protect the metals in the engine and cooling systems.

COOLANT COMPOSITION

All manufacturers recommend the use of **ethylene glycol based coolant**, which contains:

- Ethylene glycol (EG): 47%
- Water: 50%
- Additives: 3%



FIGURE 20–3 Havoline was the first company to make and market OAT coolant. General Motors uses the term DEX-COOL.

Regardless of the type of coolant and its color, the only difference among all original equipment coolants is in the additives. This means that about 97% of all coolants are the same. The only difference is in the additive package and color used to help identify the coolant.

TYPES OF COOLANT

INORGANIC ACID TECHNOLOGY

Inorganic additive technology (IAT) is conventional coolant that has been used for over 50 years. Most conventional green antifreeze contains inorganic salts such as:

- Sodium silicate (silicates)
- Phosphates
- Borates

Silicates have been found to be the cause of erosive wear to water pump impellers. The color of IAT coolant is green. Phosphates in these coolants can cause deposits to form if used with water that is hard (contains minerals). IAT coolants used in new vehicles were phased out in the mid-1990s.

ORGANIC ACID TECHNOLOGY

Organic acid technology (OAT) coolant contains ethylene glycol, but does not contain silicates or phosphates. The color of this type of coolant is usually orange.

DEX-COOL, developed by Havoline, is just one brand of OAT coolant, which has been used in General Motors vehicles since 1996. ● **SEE FIGURE 20–3**.

DEX-COOL uses ethylhexanoic acid (2-EH) as a corrosive inhibitor. 2-EH is prone to damage plastics, such as Nylon 6.6 used in intake manifold gaskets and radiators. Other brands of OAT coolant that are also orange but do not contain 2-EH include:

- Zerex G30 or G05 OAT
- Peak Global OAT

FREQUENTLY ASKED QUESTION

What Is a "G" Coolant?

The "G" coolants come from the trade name *Glysantin* of BASF in Europe and Valvoline (Zerex) in the United States. The following is a summary of the types listed by G number.

- G05: different from DEX-COOL in certain amounts of additives
- G30 and G34: nonsilicate and phosphate free
- G11: blue VW used before 1997
- G12: pink/red VW 1997+ (purple VW 2003+)
  - HOAT formulation
  - Phosphate free
- G48: low silicate and phosphate free
  - Blue
  - Nitrates, amines, phosphate (NAP) free

These coolants are usually available in premix (with water) and pure coolant containers.

HYBRID ORGANIC ACID TECHNOLOGY

A newer variation of this technology is called **hybrid organic acid technology (HOAT).** It is similar to the OAT-type antifreeze as it uses organic acid salts (carboxylates) that are not abrasive to water pumps, yet provide the correct pH. The pH of the coolant is usually above 11. A pH of 7 is neutral, with lower numbers indicating an acidic solution and higher numbers indicating an alkaline solution. If the pH is too high, the coolant can cause scaling and reduce the heat transferability of the coolant. If the pH is too low, the resulting acidic solution could cause corrosion of the engine components exposed to the coolant.

HOAT coolants can be green, orange, yellow, gold, pink, red, or blue.

Samples of HOAT coolants include:

- **VW/Audi pink.** Contains some silicates and an organic acid, and is phosphate free
- **Mercedes/Ford yellow.** Contains low amounts of silicate and no phosphate
- **Ford yellow.** Contains low silicate, no phosphate, and is dyed yellow for identification
- **Honda blue.** Contains a special coolant with just one organic acid
- **European/Korean blue.** Contains low silicates and no phosphates
- **Asian red.** Contains no silicates but has some phosphate

PHOSPHATE HYBRID ORGANIC ACID TECHNOLOGY

Phosphate hybrid organic acid technology (PHOAT) is used in Mazda-based Fords (2008+), same as Mazda FL-22, and is ethylene glycol based. This coolant is available in a 55% coolant/45% water premix. ● **SEE FIGURE 20–4.**

- Concentration: 55%
- Boiling point (with 15 PSI pressure cap): 270°F (132°C)
- Freezing point: −47°F (−44°C)
- Color: Dark green
- Embittered (made to taste bitter so animals will not drink it)

The use of PHOAT coolant in these engines is required to be assured of proper protection of the material used in the engine. It is also only available in premix containers to ensure that the water used meets specifications.



FIGURE 20–4 Coolant used in Fords that use Mazda engines and in Mazda vehicles. It requires the use of a PHOAT coolant which is dark green.

FREQUENTLY ASKED QUESTION

What Is "Pet Friendly" Antifreeze?

Conventional ethylene glycol antifreeze used by all vehicle manufacturers is attractive to pets and animals because it has a sweet taste. Ethylene glycol is fatal to any animal if swallowed, so any spill should be cleaned up quickly. There are two types of coolant that are safer for use around pets than the conventional type.

- **Propylene glycol (PG).** This type of antifreeze is *less attractive* to pets and animals because it is not as sweet, but it is still harmful if swallowed. This type of coolant, including the Sierra brand, should not be mixed with any other ethylene glycol based coolant.

  CAUTION: Some vehicle manufacturers do not recommend the use of propylene glycol coolant. Check the recommendation in the owner manual or service information before using it in a vehicle.

- **Embittered coolant.** This coolant has a small amount of a substance that makes it taste bitter and therefore not appealing to animals. The embittering agent used in ethylene glycol (EG) antifreeze is usually denatonium benzoate, added at the rate of 30 ppm. Oregon and California require all coolant sold in these states since 2004 to be embittered. ● **SEE FIGURE 20–5.**

UNIVERSAL COOLANT

Universal coolant is usually a hybrid organic acid technology (HOAT), with extended life, and a low-silicate, phosphate-free antifreeze/coolant. It can be used in many vehicles, but cannot meet the needs for engines requiring a silicate-free formulation.



FIGURE 20–5 Not all embittered coolant is labeled embittered.

REAL WORLD FIX

If 50% Is Good, 100% Must Be Better

A vehicle owner said that the cooling system of his vehicle would never freeze or rust. He said that he used 100% antifreeze (ethylene glycol) instead of a 50/50 mixture with water.

However, after the temperature dropped to −20°F (−29°C), the radiator froze and cracked. (Pure antifreeze freezes at about 0°F [−18°C]). After thawing, the radiator had to be repaired. The owner was lucky that the engine block did not also crack.

For best freeze protection with good heat transfer, use a 50/50 mixture of antifreeze and water. A 50/50 mixture of antifreeze and water is the best compromise between temperature protection and the heat transfer that is necessary for cooling system operation. Do not exceed 70% antifreeze (30% water). As the percentage of antifreeze increases, the boiling temperature increases, and freezing protection increases (up to 70% antifreeze), but the heat transfer performance of the mixture decreases.

WATER

INTRODUCTION Water is half of the coolant and can have an effect on the corrosion protection of coolant due to variations in its quality, which is often unknown. As a result, many vehicle manufacturers, such as Honda and Toyota, are specifying the use of premix coolants only. The main reason is that not only can the water/coolant ratio be maintained, but also the quality of the water can be controlled.

PROPERTIES Water is about half of the coolant and is used because of the following qualities.

1. It is inexpensive.
2. It is an efficient heat exchange fluid because of its excellent thermal conductivity (the ability of a material to conduct heat).
3. It has good specific heat capacity, meaning it takes more heat energy to increase the temperature, versus one with low specific heat capacity.
4. The boiling point is 212°F (100°C) (at sea level).
5. The freezing point is 32°F (0°C).

FREQUENTLY ASKED QUESTION

What Makes Some Water Bad for Coolant?

City water is treated with chloride, which, if the levels are high enough, can cause corrosion problems when used in coolants. Well water may contain iron or other minerals that can affect the coolant and may increase the corrosion or cause electrolysis. Due to the fact that the water quality is often unknown and could affect the engine, many vehicle manufacturers are specifying the use of premixed coolant. In pre-mix coolant, the water is usually demineralized and meets the standards for use in coolant.

FREQUENTLY ASKED QUESTION

Why Is Most Coolant 50/50 with Water?

According to the freezing point, it appears that the lowest freezing point of coolant is achieved when 70% antifreeze is used with 30% water. While the freezing temperature is lower, the high concentrate of antifreeze reduces the heat transferability of the coolant. Therefore, most vehicle manufacturers specify a 50/50 mixture of antifreeze and water to achieve the best balance between freeze protection and heat conductivity.

COOLANT FREEZING/ BOILING TEMPERATURES

FREEZING POINT An antifreeze and water mixture is an example wherein the freezing point differs from the freezing point of either pure antifreeze or pure water.

	Freezing Point
Pure water	32°F (0°C)
Pure antifreeze*	0°F (−18°C)
50/50 mixture	−34°F (−37°C)
70% antifreeze/30% water	−84°F (−64°C)

*Pure antifreeze is usually 95% ethylene glycol, 2% to 3% water, and 2% to 3% additives.

Depending on the exact percentage of water used, antifreeze (not premixed), as sold in containers, freezes at about 0°F (−18°C). Premixed coolant will freeze at about −34°F (−37°C).

BOILING POINT The boiling point of antifreeze and water is also a factor of mixture concentrations.

	Boiling Point at Sea Level	Boiling Point with 15 PSI Pressure Cap
Pure water	212°F (100°C)	257°F (125°C)
50/50 mixture	218°F (103°C)	265°F (130°C)
70/30 mixture	225°F (107°C)	276°F (136°C)

COOLANT TESTING

Normal coolant tests include:

- **Visual inspection.** Coolant should be clean and bright.
- **Freeze/boiling point.** A high freezing point or low boiling point indicates dilution (too much water).
- **pH.** The wrong pH indicates buffer loss, which is used to help maintain the pH level.
- **Coolant voltage.** A high voltage indicates the wrong pH or a stray current flow.

Various methods are used to test coolant.

HYDROMETER TESTING Coolant can be checked using a coolant hydrometer. The hydrometer measures the density of the coolant. The higher the density is, the more concentration of antifreeze in the water. Most coolant hydrometers read the freezing and boiling points of the coolant. ● **SEE FIGURE 20–6**.



FIGURE 20–6 Checking the freezing temperature of the coolant using a hydrometer.

If the engine is overheating and the hydrometer reading is near −50°F (−60°C), suspect that pure 100% antifreeze is present. For best results, the coolant should have a freezing point lower than −20°F (−29°C) and a boiling point above 234°F (112°).

REFRACTOMETER A **refractometer** is a tester used to test the freezing point of coolant by placing a few drops of coolant on the prism surface. The technician then holds the unit up to light and looks through the eyepiece for the location of the shadow on the display.

A refractometer measures the extent to which light is bent (refracted) to determine the index of refraction of a liquid sample.

The refractive index is commonly used for the following:

- To identify or confirm the identity of a sample coolant
- To determine the purity of a coolant by comparing its refractive index to the value for the pure substance
- To determine the concentration of a solute in a solution by comparing the solution's refractive index to a standard curve

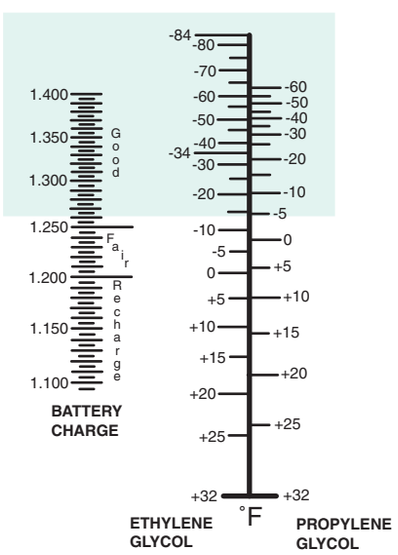
● **SEE FIGURE 20–7**.

TECH TIP

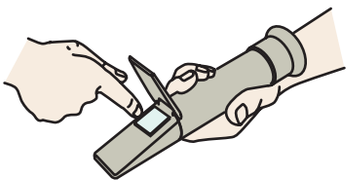
Ignore the Wind Chill Factor

The wind chill factor is a temperature that combines the actual temperature and the wind speed to determine the overall heat loss effect on open skin. Because it is the heat loss factor for open skin, the wind chill temperature is *not* to be considered when determining antifreeze protection levels.

Although moving air makes it feel colder, the actual temperature is not changed by the wind, and the engine coolant will not be affected by the wind chill. If you are not convinced, try placing a thermometer in a room and wait until a stable reading is obtained. Now turn on a fan and have the air blow across the thermometer. The temperature will not change.



1. PLACE A FEW DROPS OF THE SAMPLE FLUID ON THE MEASURING PRISM AND CLOSE THE COVER



2. HOLD UP TO A LIGHT AND READ THE SCALE



FIGURE 20–7 Using a refractometer is an accurate method to check the freezing point of coolant.



FIGURE 20–8 A meter that measures the actual pH of the coolant can be used for all coolants, unlike many test strips that cannot be used to test the pH of red or orange coolants.

PH

The term *pH* comes from a French word, meaning "power of hydrogen," and is a measure of acidity or alkalinity of a solution.

- Less than 7 pH is considered acidic.
- Greater than 7 pH is considered alkaline.

The pH of new coolant varies according to the type of coolant used. Typical pH values for new coolant include:

IAT: 9 to 10.5 new

OAT: 7.5 to 8.5 new (G30 and G34 designations)

HOAT: 7.5 to 8.5 new (G05, G48, G11, or G12 designation)

PHOAT: 7.5 to 8.5 new

When testing for pH, use either a test strip or a pH meter. If using a test strip be sure that it is calibrated to test the type of coolant being used in the vehicle.

Used coolant pH readings are usually lower than when the coolant is new and range from between 7.5 and 10 for IAT and lower for used OAT, HOAT, and PHOAT coolants. For best results use a pH tester that measures the actual pH of the coolant. ● **SEE FIGURE 20–8**.

GALVANIC ACTIVITY

Galvanic activity is the flow of an electrical current as a result of two different metals in a liquid, which acts like a battery. Galvanic activity does *not* require an outside source of voltage. The two different metals, usually iron and aluminum, become the plates of the battery and the coolant is the electrolyte. The higher the electrical conductivity of the coolant, the greater is the amount of corrosion. ● **SEE FIGURE 20–9**.

ELECTROLYSIS

Electrolysis requires the use of an outside voltage source. The source is usually due to a poor electrical ground connection.

- Electrical flow through the cooling system may cause metal to flow into the coolant.
- This metal transfer can eat holes in a heater core or radiator.
- Electrolysis holes will usually start from the inside and have a dark coloration.

TESTING FOR GALVANIC ACTIVITY AND ELECTROLYSIS

A voltmeter set to read DC volts is used to test for galvanic activity and electrolysis. To check for excessive voltage caused by galvanic activity or electrolysis, perform the following steps.

STEP 1 Allow the engine to cool and then carefully remove the pressure cap from the radiator.

STEP 2 Set the voltmeter to DC volts and connect the black meter lead to a good engine ground.

STEP 3 Place the red meter lead into the coolant.

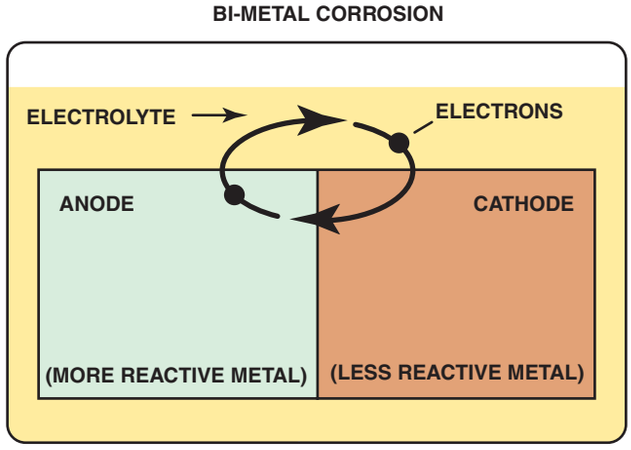


FIGURE 20–9 Galvanic activity is created by two dissimilar metals in contact with a liquid, in this case coolant.

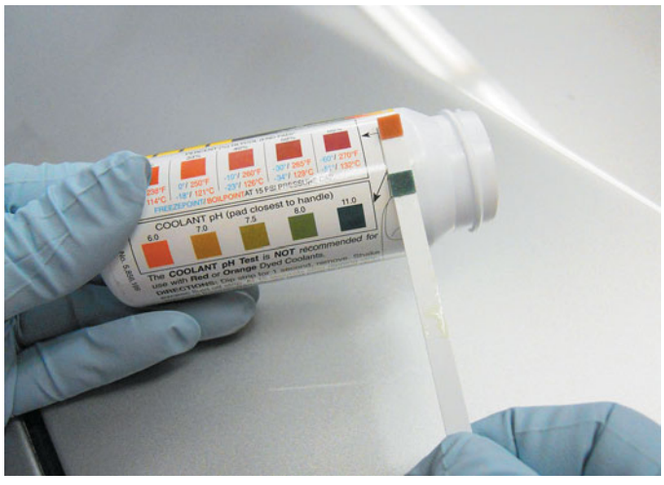


FIGURE 20–10 A test strip can be used to determine the pH and percentage of glycol of the coolant. The percentage of glycol determines the freezing and boiling temperatures, as shown on the bottle that contains the test strips.

STEP 4 Read the meter. If the voltage is above 0.5 V, this indicates excessive galvanic activity. Normal readings should be less than 0.2 V (200 mV). Flush and refill the cooling system.

STEP 5 To test for excessive electrolysis, start the engine and turn on all electrical accessories, including the headlights on high beam.

STEP 6 Read the voltmeter. If the reading is higher than 0.5 V, check for improper body ground wires or connections. Normal readings should be less than 0.3 V (300 mV).

TEST STRIP TESTING

Test strips can be used to check one or more of the following:

- Freeze point
- Boiling point
- Level of pH

Test strips will change color when they are dipped into the coolant, and the color change is compared to the container. Test strips are fairly accurate, easy to use, and inexpensive.

For best results, use test strips that are new and have been stored in a sealed bottle. Using older test strips may affect the accuracy. ● **SEE FIGURE 20–10**.

COOLANT REPLACEMENT ISSUES

INTERVALS Coolant should be replaced according to the vehicle manufacturer's recommended interval.

- For most new vehicles using OAT or HOAT type coolant, this interval may be every five years or 150,000 miles (241,000 km), whichever occurs first.
- Japanese brand vehicles usually have a replacement interval of three years or 36,000 miles (58,000 km), whichever occurs first.
- If the coolant is changed from a long life to a conventional IAT coolant, the replacement interval needs to be changed to every two years or 24,000 miles (39,000 km), whichever occurs first.

PASSIVATION **Passivation** is a chemical reaction that takes place between coolant additives and the metal that it protects. This means that a chemical barrier is created between the coolant and the metals of the engine. When changing coolants, passivation can take from a few days to a few weeks.

- Each chemical package does its own passivation.
- If you change chemical packages, passivation has to start over.

Therefore, because of passivation concerns, most experts agree that for best results do not change types of coolants. Always use what the vehicle manufacturer recommends. Always check service information for the exact recommended replacement interval for the vehicle being serviced.

RECYCLING COOLANT Coolant (antifreeze and water) should be recycled. Used coolant may contain heavy metals, such as lead, aluminum, and iron, which are absorbed by the coolant during its use in the engine.

Recycle machines filter out these metals and dirt and reinstall the depleted acids. The recycled coolant, restored to be like new, can be reinstalled into the vehicle.

CAUTION: Most vehicle manufacturers warn that coolant should not be reused unless it is recycled and the acids restored. However, Mercedes lifetime coolant is very expensive, and according to Mercedes can be drained, filtered, and reused.

REVIEW QUESTIONS

1. What types of coolant are used in vehicles?
2. Why is a 50/50 mixture of antifreeze and water commonly used as a coolant?
3. What are the differences among IAT, OAT, HOAT, and PHOAT coolants?
4. What are some of the heavy metals that can be present in used coolant?
5. What is the difference between galvanic activity and electrolysis?

CHAPTER QUIZ

1. Coolant is water and _____.
   a. Methanol **c.** Kerosene
   b. Glycerin **d.** Ethylene glycol
2. As the percentage of antifreeze in the coolant increases, _____.
   a. The freeze point decreases (up to a point)
   b. The boiling point decreases
   c. The heat transfer increases
   d. All of the above
3. Adding a chemical to make ethylene glycol coolant bitter to the taste is called _____.
   a. Passivation
   b. Embittered
   c. Refractometer
   d. Electrolysis
4. Asian red coolant is what type?
   a. IAT **c.** HOAT
   b. OAT **d.** PHOAT
5. DEX-COOL is what type of coolant?
   a. IAT **c.** HOAT
   b. OAT **d.** PHOAT
6. PHOAT coolant is what color?
   a. Dark green **c.** Orange
   b. Red **d.** Blue
7. DEX-COOL is _____.
   a. Propylene glycol
   b. Ethylene glycol
   c. Is silicate and phosphate free
   d. Both b and c
8. Two technicians are discussing testing coolant for proper pH. Technician A says that coolant has a pH above 7 when new and becomes lower with use in an engine. Technician B says that OAT and HOAT coolants have a lower pH when new compared to the old green IAT coolant. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
9. Reusing old coolant is generally not approved by vehicle manufacturers except _____.
   a. General Motors **c.** Chrysler
   b. Ford **d.** Mercedes
10. A voltmeter was used to check the coolant and a reading of 0.2 volt with the engine off was measured. A reading of 0.8 volt was measured with the engine running and all electrical accessories turned on. Technician A says that the coolant should be flushed to solve the galvanic activity. Technician B says that the ground wires and connections should be inspected and repaired to solve the electrolysis problem. Which technician is correct?
    a. Technician A only **c.** Both Technicians A and B
    b. Technician B only **d.** Neither Technician A nor B

chapter 21

COOLING SYSTEM OPERATION AND DIAGNOSIS

OBJECTIVES: **After studying Chapter 21, the reader should be able to:** • Prepare for ASE Engine Repair (A1) certification test content area "D" (Lubrication and Cooling Systems Diagnosis and Repair). • Describe how coolant flows through an engine. • Discuss the operation of the thermostat. • Explain the purpose and function of the radiator pressure cap. • Describe the operation and service of water pumps. • Discuss how to diagnose cooling system problems.

KEY TERMS: Bar 188 • Bleed holes 191 • Bypass 184 • Centrifugal pump 189 • Coolant recovery system 188 • Cooling fins 186 • Core tubes 186 • Impeller 189 • Parallel flow system 190 • Reverse cooling 189 • Scroll 189 • Series flow system 190 • Series-parallel flow system 191 • Silicone coupling 191 • Steam slits 191 • Surge tank 188 • Thermostatic spring 191

COOLING SYSTEM

PURPOSE AND FUNCTION

Satisfactory cooling system operation depends on the design and operating conditions of the system. The design is based on heat output of the engine, radiator size, type of coolant, size of water pump (coolant pump), type of fan, thermostat, and system pressure. The cooling system must allow the engine to warm up to the required operating temperature as rapidly as possible and then maintain that temperature.

Peak combustion temperatures in the engine run from 4,000°F to 6,000°F (2,200°C to 3,300°C). The combustion temperatures will *average* between 1,200°F and 1,700°F (650°C and 925°C). Continued temperatures as high as this would weaken engine parts, so heat must be removed from the engine. The cooling system keeps the head and cylinder walls at a temperature that is within the range for maximum efficiency. The cooling system removes about one-third of the heat created in the engine. Another third escapes to the exhaust system. ● **SEE FIGURE 21–1**.

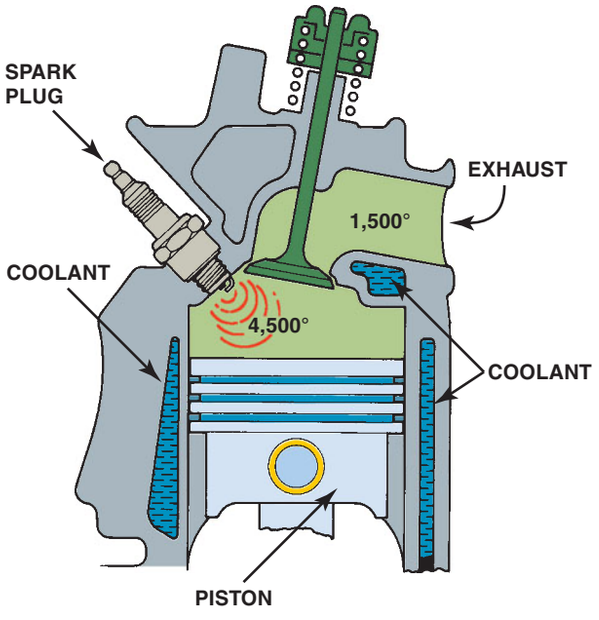


FIGURE 21–1 Typical combustion and exhaust temperatures.

LOW-TEMPERATURE ENGINE PROBLEMS

Engine operating temperatures must be above a minimum temperature for proper engine operation. If the coolant temperature does not reach the specified temperature as determined by the thermostat, then the following engine-related faults can occur.

- A P0128 diagnostic trouble code (DTC) can be set. This code indicates "coolant temperature below thermostat regulating temperature," which is usually caused by a defective thermostat staying open or partially open.
- Moisture created during the combustion process can condense and flow into the oil. *For each gallon of fuel used, moisture equal to a gallon of water is produced.* The condensed moisture combines with unburned hydrocarbons and additives to form carbonic acid, sulfuric acid, nitric acid, hydrobromic acid, and hydrochloric acid.

To reduce cold engine problems and to help start engines in cold climates, most manufacturers offer block heaters as an option. These

TECH TIP

Overheating Can Be Expensive

A faulty cooling system seems to be a major cause of engine failure. Engine rebuilders often have nightmares about seeing their rebuilt engine placed back in service in a vehicle with a clogged radiator. Most engine technicians routinely replace the water pump and all hoses after an engine overhaul or repair. The radiator should also be checked for leaks and proper flow whenever the engine is repaired or replaced. Overheating is one of the most common causes of engine failure.

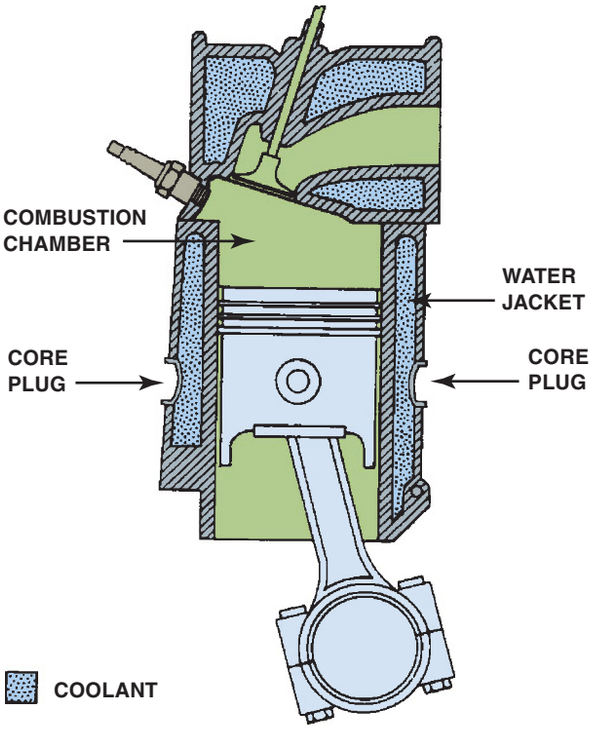


FIGURE 21–2 Coolant circulates through the water jackets in the engine block and cylinder head.

block heaters are plugged into household current (110 volts AC) and the heating element warms the coolant.

HIGH-TEMPERATURE ENGINE PROBLEMS Maximum temperature limits are required to protect the engine. Higher than normal temperatures can cause the following engine-related issues.

- High temperatures will oxidize the engine oil producing hard carbon and varnish. The varnish will cause the hydraulic valve lifter plungers to stick. Higher than normal temperatures will also cause the oil to become thinner (lower viscosity than normal). Thinned oil will also get into the combustion chamber by going past the piston rings and through valve guides to cause excessive oil consumption.
- The combustion process is very sensitive to temperature. High coolant temperatures raise the combustion temperatures to a point that may cause detonation (also called spark knock or ping) to occur.

COOLING SYSTEM OPERATION

PURPOSE AND FUNCTION Coolant flows through the engine, where it picks up heat. It then flows to the radiator, where the heat is given up to the outside air. The coolant continually recirculates through the cooling system, as illustrated in ● **FIGURES 21–2 AND 21–3**.

COOLING SYSTEM OPERATION The temperature of the coolant rises as much as 15°F (8°C) as it goes through the engine and cools as it goes through the radiator. *The coolant flow rate may be as high as 1 gallon (4 liters) per minute for each horsepower the engine produces.*

Hot coolant comes out of the thermostat housing on the top of the engine on most engines. The engine coolant outlet is connected

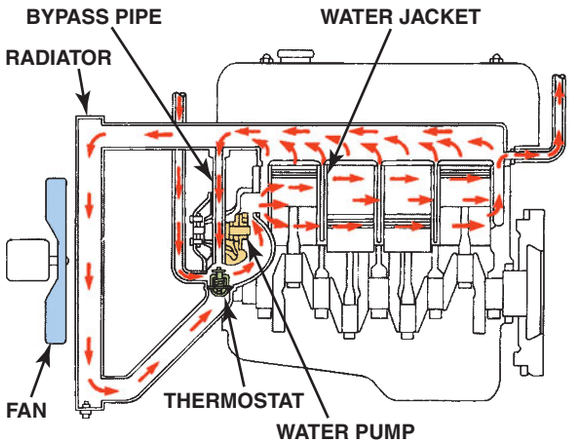


FIGURE 21–3 Coolant flow through a typical engine cooling system.

to the radiator by the upper radiator hose and clamps. The coolant in the radiator is cooled by air flowing through the radiator. As the coolant moves through the radiator, it cools. The cooler coolant leaves the radiator through an outlet and the lower radiator hose, and then flows to the inlet side of the water pump, where it is recirculated through the engine.

NOTE: Some newer engine designs such as Chrysler's 4.7 liter V-8 and General Motor's 4.8, 5.3, 5.7, and 6.0 liter V-8s place the thermostat on the inlet side of the water pump. As the cooled coolant hits the thermostat, the thermostat closes until the coolant temperature again causes it to open. Placing the thermostat in the inlet side of the water pump therefore reduces the rapid temperature changes that could cause stress in the engine, especially if aluminum heads are used with a cast iron block.

Radiators are designed for the maximum rate of heat transfer using minimum space. Cooling airflow through the radiator is aided by a belt- or electric motor–driven cooling fan.

THERMOSTATS

PURPOSE AND FUNCTION There is a normal operating temperature range between low-temperature and high-temperature extremes. The thermostat controls the minimum normal temperature. The thermostat is a temperature-controlled valve placed at the engine coolant outlet on most engines.

THERMOSTAT OPERATION An encapsulated wax-based plastic pellet heat sensor is located on the engine side of the thermostatic valve. As the engine warms, heat swells the heat sensor. ● **SEE FIGURE 21–4**.

A mechanical link, connected to the heat sensor, opens the thermostat valve. As the thermostat begins to open, it allows some coolant to flow to the radiator, where it is cooled. The remaining part of the coolant continues to flow through the bypass, thereby bypassing the thermostat and flowing back through the engine. ● **SEE FIGURE 21–5**.

The rated temperature of the thermostat indicates the temperature at which the thermostat starts to open. The thermostat is fully

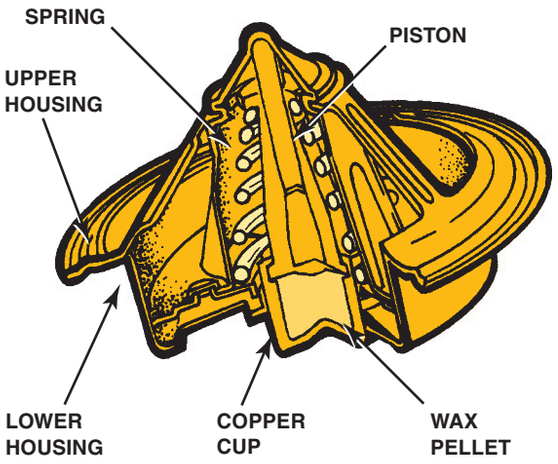


FIGURE 21–4 A cross section of a typical wax-actuated thermostat showing the position of the wax pellet and spring.

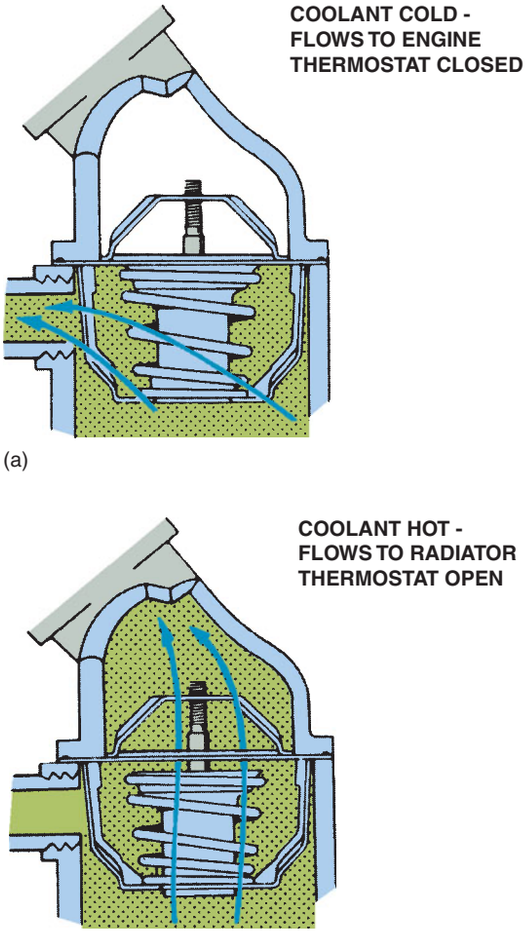


FIGURE 21–5 (a) When the engine is cold, the coolant flows through the bypass. (b) When the thermostat opens, the coolant can flow to the radiator.

open at about 20°F higher than its opening temperature. ● **SEE CHART 21–1**.

If the radiator, water pump, and coolant passages are functioning correctly, the engine should always be operating within the opening and fully open temperature range of the thermostat. ● **SEE FIGURE 21–6**.

THERMOSTAT TEMPERATURE RATING	STARTS TO OPEN	FULLY OPEN
180°F	180°F	200°F
195°F	195°F	215°F

CHART 21–1

The temperature of the coolant depends on the rating of the thermostat.



FIGURE 21–6 A thermostat stuck in the open position caused the engine to operate too cold. If a thermostat is stuck closed, this can cause the engine to overheat.

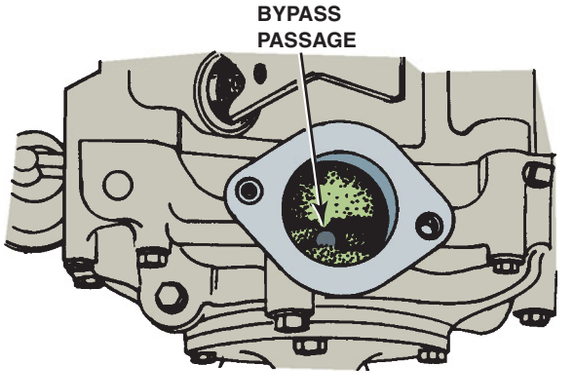


FIGURE 21–7 This internal bypass passage in the thermostat housing directs cold coolant to the water pump.

NOTE: A bypass around the closed thermostat allows a small part of the coolant to circulate within the engine during warm-up. It is a small passage that leads from the engine side of the thermostat to the inlet side of the water pump. It allows some coolant to bypass the thermostat even when the thermostat is open. The bypass may be cast or drilled into the engine and pump parts. ● **SEE FIGURES 21–7 AND 21–8**.

The bypass aids in uniform engine warm-up. Its operation eliminates hot spots and prevents the building of excessive coolant pressure in the engine when the thermostat is closed.

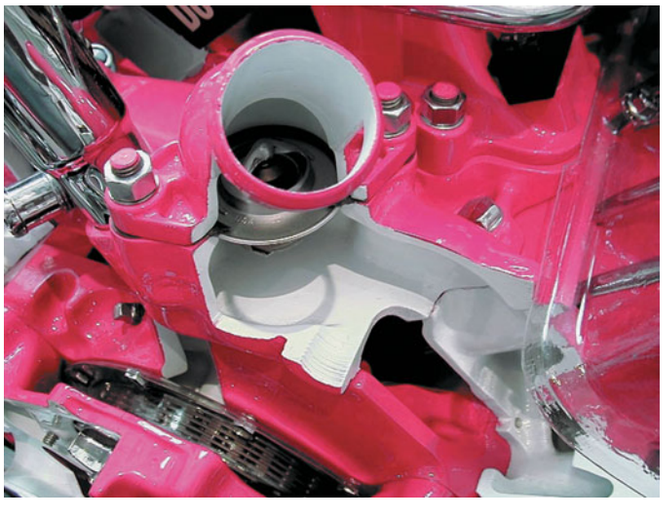


FIGURE 21–8 A cutaway of a small block Chevrolet V-8 showing the passage from the cylinder head through the front of the intake manifold to the thermostat.

THERMOSTAT TESTING

There are three basic methods used to check the operation of the thermostat.

1. **Hot water method.** If the thermostat is removed from the vehicle and is closed, insert a 0.015 in. (0.4 mm) feeler gauge in the opening so that the thermostat will hang on the feeler gauge. The thermostat should then be suspended by the feeler gauge in a container of water or coolant along with a thermometer. The container should be heated until the thermostat opens enough to release and fall from the feeler gauge. The temperature at which the thermostat falls is the opening temperature of the thermostat. If it is within 5°F (4°C) of the temperature stamped on the thermostat, the thermostat is satisfactory for use. If the temperature difference is greater, the thermostat should be replaced. ● **SEE FIGURE 21–9**.
2. **Infrared thermometer method.** An infrared thermometer (also called a pyrometer) can be used to measure the temperature of the coolant near the thermostat. The area on the engine side of the thermostat should be at the highest temperature that exists in the engine. A properly operating cooling system should cause the pyrometer to read as follows:
   - As the engine warms, the temperature reaches near thermostat opening temperature.
   - As the thermostat opens, the temperature drops just as the thermostat opens, sending coolant to the radiator.
   - As the thermostat cycles, the temperature should range between the opening temperature of the thermostat and 20°F (11°C) above the opening temperature.

   NOTE: If the temperature rises higher than 20°F (11°C) above the opening temperature of the thermostat, inspect the cooling system for a restriction or low coolant flow. A clogged radiator could also cause the excessive temperature rise.
3. **Scan tool method.** A scan tool can be used on many vehicles to read the actual temperature of the coolant as detected by the engine coolant temperature (ECT) sensor. Although the sensor or the wiring to and from the sensor may be defective, at least the scan tool can indicate what the computer "thinks" is the engine coolant temperature.

TECH TIP

Do Not Take Out the Thermostat!

Some vehicle owners and technicians remove the thermostat in the cooling system to "cure" an overheating problem. In some cases, removing the thermostat can *cause* overheating rather than stop it. This is true for three reasons.

1. Without a thermostat the coolant can flow more quickly through the radiator. The thermostat adds some restriction to the coolant flow, and therefore keeps the coolant in the radiator longer. This also allows additional time for the heat transfer between the hot engine parts and the coolant. The presence of the thermostat thus ensures a greater reduction in the coolant temperature before it returns to the engine.
2. Heat transfer is greater with a greater difference between the coolant temperature and air temperature. Therefore, when coolant flow rate is increased (no thermostat), the temperature difference is reduced.
3. Without the restriction of the thermostat, much of the coolant flow often bypasses the radiator entirely and returns directly to the engine.

If overheating is a problem, removing the thermostat will usually not solve the problem. Remember, the thermostat controls the temperature of the engine coolant by opening at a certain temperature and closing when the temperature falls below the minimum rated temperature of the thermostat.

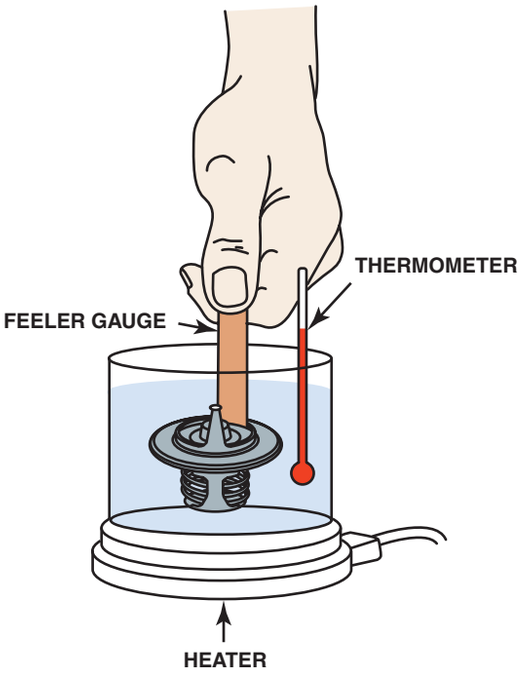


FIGURE 21–9 Checking the opening temperature of a thermostat.

THERMOSTAT REPLACEMENT

Two important things about a thermostat include:

1. An overheating engine *may* result from a faulty thermostat.
2. An engine that does not get warm enough *always* indicates a faulty thermostat.



FIGURE 21–10 Some thermostats are an integral part of the housing. This thermostat and radiator hose housing is serviced as an assembly. Some thermostats snap into the engine radiator fill tube underneath the pressure cap.

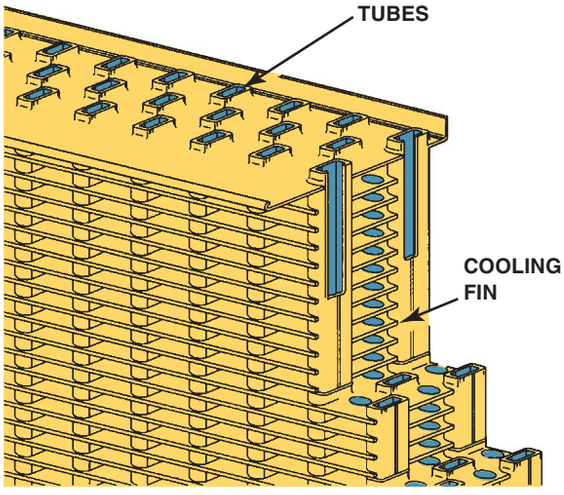
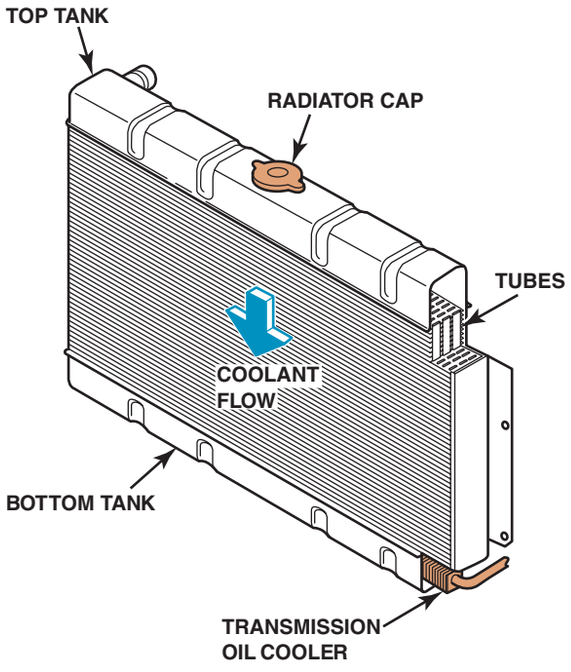


FIGURE 21–11 The tubes and fins of the radiator core.



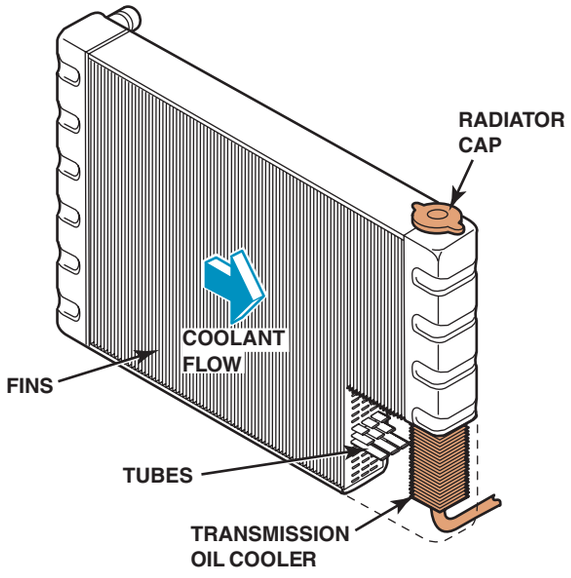


FIGURE 21–12 A radiator may be either a down-flow or a cross-flow type.

To replace the thermostat, coolant will have to be drained from the radiator drain petcock to lower the coolant level below the thermostat. It is not necessary to completely drain the system. The hose should be removed from the thermostat housing neck and then the housing removed to expose the thermostat. ● **SEE FIGURE 21–10**.

The gasket flanges of the engine and thermostat housing should be cleaned, and the gasket surface of the housing must be flat. The thermostat should be placed in the engine with the sensing pellet *toward* the engine. Make sure that the thermostat position is correct, and install the thermostat housing with a new gasket or O-ring.

CAUTION: Failure to set the thermostat into the recessed groove will cause the housing to become tilted when tightened. If this happens and the housing bolts are tightened, the housing will usually crack, creating a leak.

The upper hose should then be installed and the system refilled. Install the correct size of radiator hose clamp.

RADIATORS

TYPES The two types of radiator cores in common use in most vehicles are:

- Serpentine fin core
- Plate fin core

In each of these types, the coolant flows through oval-shaped **core tubes.** Heat is transferred through the tube wall and soldered joint to **cooling fins.** The fins are exposed to the air that flows through the radiator, which removes heat from the radiator and carries it away. ● **SEE FIGURES 21–11 AND 21–12**.

Older automobile radiators were made from yellow brass. Since the 1980s, most radiators have been made from aluminum with nylon-reinforced plastic side tanks. These materials are corrosion resistant, have good heat transferability, and are easily formed.

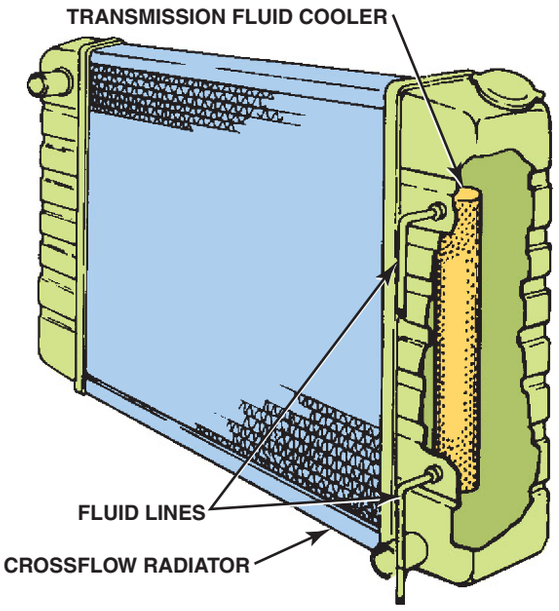


FIGURE 21–13 Many vehicles equipped with an automatic transmission use a transmission fluid cooler installed in one of the radiator tanks.

Core tubes are made from 0.0045 to 0.012 in. (0.1 to 0.3 mm) sheet brass or aluminum, using the thinnest possible materials for each application. The metal is rolled into round tubes and the joints are sealed with a locking seam.

The two basic designs of radiators include:

1. **Down-flow radiators.** This design was used mostly in older vehicles, where the coolant entered the radiator at the top and flowed downward, exiting the radiator at the bottom.
2. **Cross-flow radiators.** Most radiators use a cross-flow design, where the coolant flows from one side of the radiator to the opposite side.

HOW RADIATORS WORK

The main limitation of heat transfer in a cooling system is in the transfer from the radiator to the air. Heat transfers from the water to the fins as much as seven times faster than heat transfers from the fins to the air, assuming equal surface exposure. The radiator must be capable of removing an amount of heat energy approximately equal to the heat energy of the power produced by the engine. *Each horsepower is equivalent to 42 BTUs (10,800 calories) per minute.* As the engine power is increased, the heat-removing requirement of the cooling system is also increased.

With a given frontal area, radiator capacity may be increased by increasing the core thickness, packing more material into the same volume, or both. The radiator capacity may also be increased by placing a shroud around the fan so that more air will be pulled through the radiator.

NOTE: The lower air dam in the front of the vehicle is used to help direct the air through the radiator. If this air dam is broken or missing, the engine may overheat, especially during highway driving due to the reduced airflow through the radiator.

When a transmission oil cooler is used in the radiator, it is placed in the outlet tank, where the coolant has the lowest temperature. ● **SEE FIGURE 21–13**.

TECH TIP

Working Better Under Pressure

A problem that sometimes occurs with a high-pressure cooling system involves the water pump. For the pump to function, the inlet side of the pump must have a lower pressure than its outlet side. If inlet pressure is lowered too much, the coolant at the pump inlet can boil, producing vapor. The pump will then spin the coolant vapors and not pump coolant. This condition is called *pump cavitation.* Therefore, a radiator cap could be the cause of an overheating problem. A pump will not pump enough coolant if not kept under the proper pressure for preventing vaporization of the coolant.

PRESSURE CAPS

OPERATION

On most radiators the filler neck is fitted with a pressure cap. The cap has a spring-loaded valve that closes the cooling system vent. This causes cooling pressure to build up to the pressure setting of the cap. At this point, the valve will release the excess pressure to prevent system damage. Engine cooling systems are pressurized to raise the boiling temperature of the coolant.

- *The boiling temperature will increase by approximately 3°F (1.6°C) for each pound of increase in pressure.*
- At sea level, water will boil at 212°F (100°C). With a 15 PSI (100 kPa) pressure cap, water will boil at 257°F (125°C), which is a maximum operating temperature for an engine.

FUNCTIONS

The specified coolant system temperature serves two functions.

1. It allows the engine to run at an efficient temperature, close to 200°F (93°C), with no danger of boiling the coolant.
2. The higher the coolant temperature, the more heat the cooling system can transfer. The heat transferred by the cooling system is proportional to the temperature difference between the coolant and the outside air. This characteristic has led to the design of small, high-pressure radiators that are capable of handling large quantities of heat. For proper cooling, the system must have the right pressure cap correctly installed.

A vacuum valve is part of the pressure cap and is used to allow coolant to flow back into the radiator when the coolant cools down and contracts. ● **SEE FIGURE 21–14**.

NOTE: The proper operation of the pressure cap is especially important at high altitudes. The boiling point of water is lowered by about 1°F for every 550 ft increase in altitude. Therefore, in Denver, Colorado (altitude 5,280 ft), the boiling point of water is about 202°F, and at the top of Pike's Peak in Colorado (14,110 ft) water boils at 186°F.

METRIC RADIATOR CAPS

According to the *SAE Handbook,* all radiator caps must indicate their nominal (normal) pressure rating. Most original equipment radiator caps are rated at about 14 to 16 PSI (97 to 110 kPa).

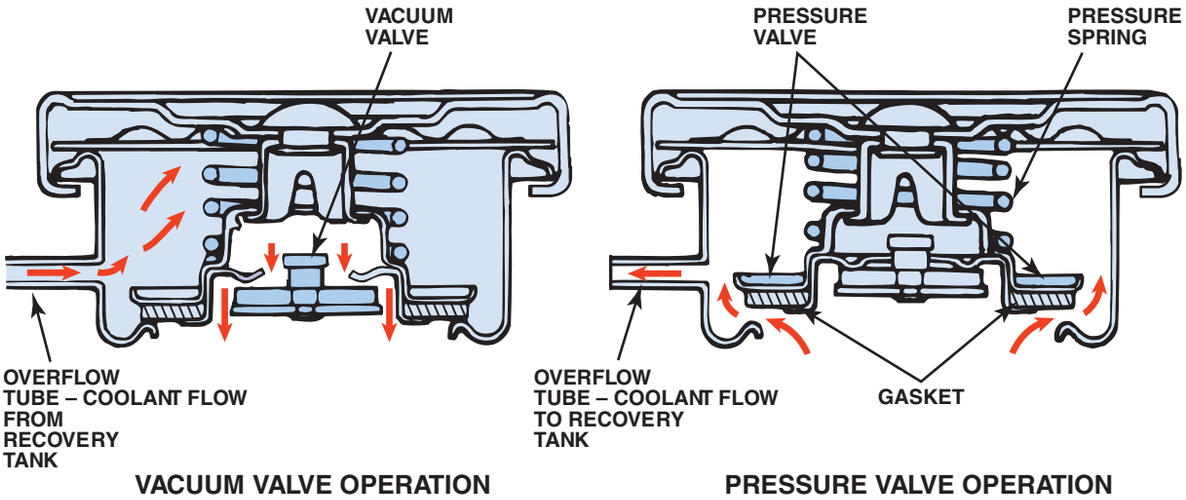


FIGURE 21–14 The pressure valve maintains the system pressure and allows excess pressure to vent. The vacuum valve allows coolant to return to the system from the recovery tank.

However, many vehicles manufactured in Japan or Europe use radiator pressure indicated in a unit called a **bar.** One bar is the pressure of the atmosphere at sea level, or about 14.7 PSI. The conversions in ● **CHART 21–2** can be used when replacing a radiator cap, to make certain it matches the pressure rating of the original.

NOTE: Many radiator repair shops use a 7 PSI (0.5 bar) radiator cap on a repaired radiator. A 7 PSI cap can still provide boil protection of 21°F (3°F × 7 PSI = 21°F) above the boiling point of the coolant. For example, if the boiling point of the antifreeze coolant is 223°F, then 21°F is added for the pressure cap, and boilover will not occur until about 244°F (223°F + 21°F = 244°F). Even though this lower pressure radiator cap provides some protection and will also help protect the radiator repair, the coolant can still boil *before* the "hot" dash warning light comes on and, therefore, should not be used. In addition, the lower pressure in the cooling system could cause cavitation to occur and damage the water pump. For best results, always follow the vehicle manufacturer's recommended radiator cap.

BAR OR ATMOSPHERES	POUNDS PER SQUARE INCH (PSI)
1.1	16
1.0	15
0.9	13
0.8	12
0.7	10
0.6	9
0.5	7

CHART 21–2

Comparison showing the metric pressure as shown on the top of the cap to pounds per square inch (PSI).

COOLANT RECOVERY SYSTEMS

PURPOSE AND FUNCTION Excess pressure usually forces some coolant from the system through an overflow. Most cooling systems connect the overflow to a plastic reservoir to hold excess coolant while the system is hot. ● **SEE FIGURE 21–15.**

When the system cools, the pressure in the cooling system is reduced and a partial vacuum forms. This vacuum pulls the coolant from the plastic container back into the cooling system, keeping the system full. Because of this action, the system is called a **coolant recovery system.** A vacuum valve allows coolant to reenter the system as the system cools so that the radiator parts will not collapse under the partial vacuum.

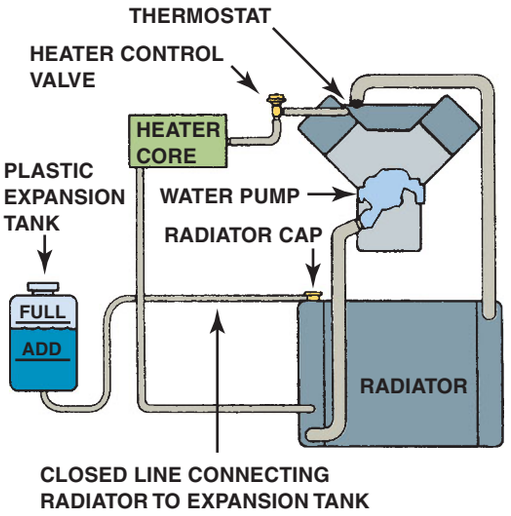


FIGURE 21–15 The level in the coolant recovery system raises and lowers with engine temperature.

SURGE TANK Some vehicles use a **surge tank,** which is located at the highest level of the cooling system and holds about 1 quart (1 liter) of coolant. A hose attaches to the bottom of the surge tank to the inlet side of the water pump. A smaller bleed hose attaches to the side of the surge tank to the highest point of the radiator. The bleed line allows some coolant circulation through the surge tank, and air in the system will rise below the radiator cap and be forced from the system if the pressure in the system exceeds the rating of the radiator cap. ● **SEE FIGURE 21–16.**



FIGURE 21–16 Some vehicles use a surge tank, which is located at the highest level of the cooling system, with a radiator cap.

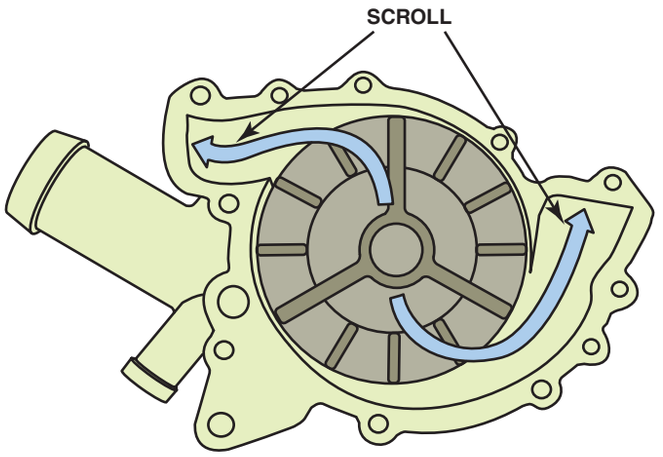


FIGURE 21–17 Coolant flow through the impeller and scroll of a coolant pump for a V-type engine.

REAL WORLD FIX

The Collapsed Radiator Hose Story

An automotive student asked the automotive instructor what brand of radiator hose is the best. Not knowing exactly what to say, the instructor asked if there was a problem with the brand hose used. The student had tried three brands and all of them collapsed when the engine cooled. The instructor then explained that the vehicle needed a new pressure cap and not a new upper radiator hose. The student thought that because the lower hose did not collapse that the problem *had* to be a fault with the hose. The instructor then explained that the lower radiator hose has a spring inside to keep the lower hose from collapsing due to the lower pressure created at the inlet to the water pump. The radiator cap was replaced and the upper radiator hose did not collapse when the engine cooled.



FIGURE 21–18 A demonstration engine running on a stand, showing the amount of coolant flow that actually occurs through the cooling system.

WATER PUMPS

OPERATION The water pump (also called a coolant pump) is driven by one of two methods.

- Crankshaft belt
- Camshaft

Coolant recirculates from the radiator to the engine and back to the radiator. Low-temperature coolant leaves the radiator by the bottom outlet. It is pumped into the warm engine block, where it picks up some heat. From the block, the warm coolant flows to the hot cylinder head, where it picks up more heat.

NOTE: Some engines use reverse cooling. This means that the coolant flows from the radiator to the cylinder head(s) before flowing to the engine block.

Water pumps are not positive displacement pumps. The water pump is a **centrifugal pump** that can move a large volume of coolant without increasing the pressure of the coolant. The pump pulls coolant in at the center of the **impeller.** Centrifugal force throws the coolant outward so that it is discharged at the impeller tips. ● **SEE FIGURE 21–17.**

FREQUENTLY ASKED QUESTION

How Much Coolant Can a Water Pump Move?

A typical water pump can move a maximum of about 7,500 gallons (28,000 liters) of coolant per hour, or recirculate the coolant in the engine over 20 times per minute. This means that a water pump could be used to empty a typical private swimming pool in an hour! The slower the engine speed, the less power is consumed by the water pump. However, even at 35 mph (56 km/h), the typical water pump still moves about 2,000 gallons (7,500 liters) per hour or 0.5 gallon (2 liters) per second! ● **SEE FIGURE 21–18.**

As engine speeds increase, more heat is produced by the engine and more cooling capacity is required. The pump impeller speed increases as the engine speed increases to provide extra coolant flow at the very time it is needed.

Coolant leaving the pump impeller is fed through a **scroll.** The scroll is a smoothly curved passage that changes the fluid flow



FIGURE 21–19 This severely corroded water pump could not circulate enough coolant to keep the engine cool. As a result, the engine overheated and blew a head gasket.

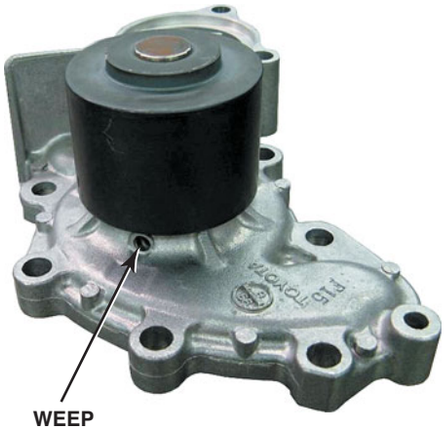


FIGURE 21–20 The bleed weep hole in the water pump allows coolant to leak out of the pump and not be forced into the bearing. If the bearing failed, more serious damage could result.

direction with minimum loss in velocity. The scroll is connected to the front of the engine so as to direct the coolant into the engine block. On V-type engines, two outlets are often used, one for each cylinder bank. Occasionally, diverters are necessary in the water pump scroll to equalize coolant flow between the cylinder banks of a V-type engine in order to equalize the cooling.

WATER PUMP SERVICE A worn impeller on a water pump can reduce the amount of coolant flow through the engine. ● **SEE FIGURE 21–19**.

If the seal of the water pump fails, coolant will leak out of the weep hole. The hole allows coolant to escape without getting trapped and forced into the water pump bearing assembly. ● **SEE FIGURE 21–20**.

The hole allows coolant to escape without getting trapped and forced into the water pump bearing assembly.

If the bearing is defective, the pump will usually be noisy and will have to be replaced. Before replacing a water pump that has failed because of a loose or noisy bearing, check all of the following:

1. Drive belt tension
2. Bent fan
3. Fan for balance

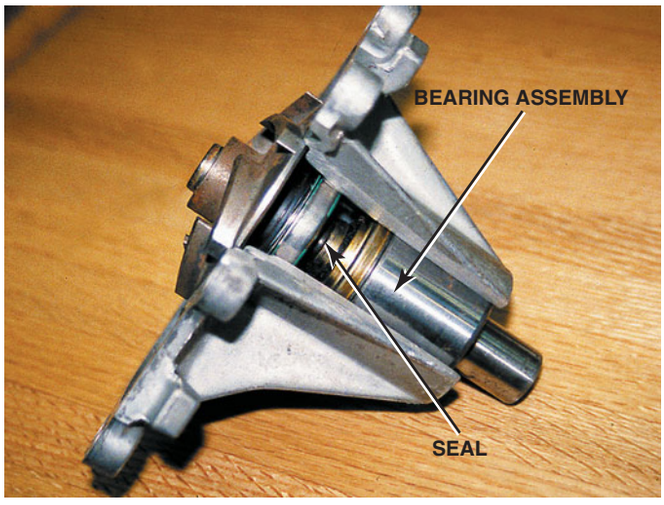


FIGURE 21–21 A cutaway of a typical water pump showing the long bearing assembly and the seal. The weep hole is located between the seal and the bearing. If the seal fails, then coolant flows out of the weep hole to prevent the coolant from damaging the bearing.

TECH TIP

Release the Belt Tension Before Checking a Water Pump

The technician should release water pump belt tension before checking for water pump bearing looseness. To test a water pump bearing, it is normal to check the fan for movement; however, if the drive belt is tight, any looseness in the bearing will not be felt.

If the water pump drive belt is too tight, excessive force may be exerted against the pump bearing. If the cooling fan is bent or out of balance, the resulting vibration can damage the water pump bearing. ● **SEE FIGURE 21–21**.

COOLANT FLOW IN THE ENGINE

TYPES OF SYSTEMS Coolant flows through the engine in one of the following ways.

- **Parallel flow system.** In the **parallel flow system,** coolant flows into the block under pressure and then crosses the head gasket to the head through main coolant passages beside *each* cylinder.
- **Series flow system.** In the **series flow system,** the coolant flows around all the cylinders on each bank. All the coolant flows to the *rear* of the block, where large main coolant passages allow the coolant to flow across the head gasket. The coolant then enters the rear of the heads. In the heads, the coolant flows forward to a crossover passage on the intake manifold outlet at the *highest point* in the engine cooling passage. This is usually located at the front of the engine. The outlet is either on the heads or in the intake manifold.

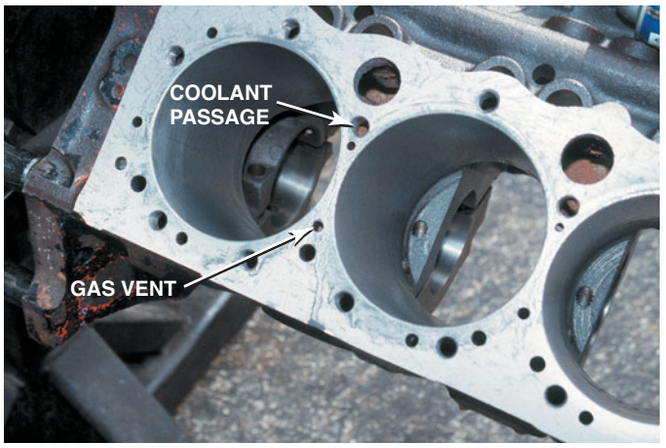


FIGURE 21–22 A Chevrolet V-8 block that shows the large coolant holes and the smaller gas vent or bleed holes that must match the head gasket when the engine is assembled.

- **Series-parallel flow system.** Some engines use a combination of these two coolant flow systems and call it a **series-parallel flow system.** Any steam that develops will go directly to the top of the radiator. In series flow systems, **bleed holes** or **steam slits** in the gasket, block, and head perform the function of letting out the steam.

COOLANT FLOW AND HEAD GASKET DESIGN

Most V-type engines use cylinder heads that are interchangeable side to side, but not all engines. Therefore, based on the design of the cooling system and flow through the engine, it is very important to double check that the cylinder head is matched to the block and that the head gasket is installed correctly (end for end) so that all of the cooling passages are open to allow the proper flow of coolant through the system. ● **SEE FIGURE 21–22.**

COOLING FANS

ELECTRONICALLY CONTROLLED COOLING FAN

Two types of electric cooling fans used on many engines include:

- One two-speed cooling fan
- Two cooling fans (one for normal cooling and one for high heat conditions)

The PCM commands low-speed fans on under the following conditions.

- Engine coolant temperature (ECT) exceeds approximately 223°F (106°C).
- A/C refrigerant pressure exceeds 190 PSI (1,310 kPa).
- After the vehicle is shut off, the engine coolant temperature at key-off is greater than 284°F (140°C) and system voltage is more than 12 volts. The fan(s) will stay on for approximately three minutes.

The PCM commands the high-speed fan on under the following conditions.

- Engine coolant temperature (ECT) reaches 230°F (110°C).
- A/C refrigerant pressure exceeds 240 PSI (1,655 kPa).
- Certain diagnostic trouble codes (DTCs) set.

To prevent a fan from cycling on and off excessively at idle, the fan may not turn off until the ignition switch is moved to the off position or the vehicle speed exceeds approximately 10 mph (16 km/h).

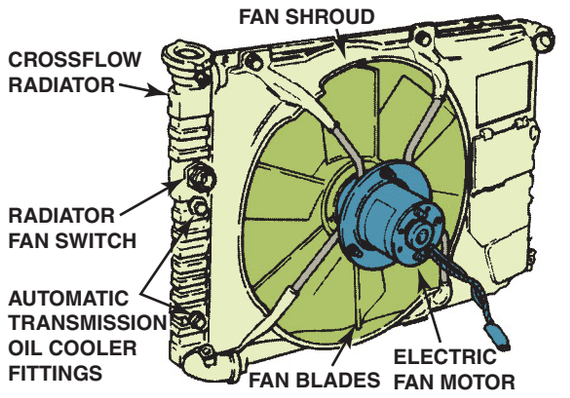


FIGURE 21–23 A typical electric cooling fan assembly showing the radiator and related components.

Many rear-wheel-drive vehicles and all transverse engines drive the fan with an electric motor. ● **SEE FIGURE 21–23.**

NOTE: Most electric cooling fans are computer controlled. To save energy, most cooling fans are turned off whenever the vehicle is traveling faster than 35 mph (55 km/h). The ram air caused by the vehicle speed is enough to keep the radiator cool. Of course, if the computer senses that the temperature is still too high, the computer will turn on the cooling fan, to "high," if possible, in an attempt to cool the engine to avoid severe engine damage.

WARNING

Some electric cooling fans can come on after the engine is off without warning. Always keep hands and fingers away from the cooling fan blades unless the electrical connector has been disconnected to prevent the fan from coming on. Always follow all warnings and cautions.

THERMOSTATIC FANS

On some rear-wheel-drive vehicles, a thermostatic cooling fan is driven by a belt from the crankshaft. It turns faster as the engine turns faster. Generally, the engine is required to produce more power at higher speeds. Therefore, the cooling system will also transfer more heat. Increased fan speed aids in the required cooling. Engine heat also becomes critical at low engine speeds in traffic where the vehicle moves slowly. The thermostatic fan is designed so that it uses little power at high engine speeds and minimizes noise. Two types of thermostatic fans include:

1. **Silicone coupling.** The **silicone coupling** fan drive is mounted between the drive pulley and the fan.

   HINT: When diagnosing an overheating problem, look carefully at the cooling fan. If silicone is leaking, then the fan may not be able to function correctly and should be replaced.

2. **Thermostatic spring.** A second type of thermal fan has a **thermostatic spring** added to the silicone coupling fan drive. The thermostatic spring operates a valve that allows the fan to freewheel when the radiator is cold. As the radiator warms to about 150°F (65°C), the air hitting the thermostatic spring will cause the spring to change its shape. The new shape of the

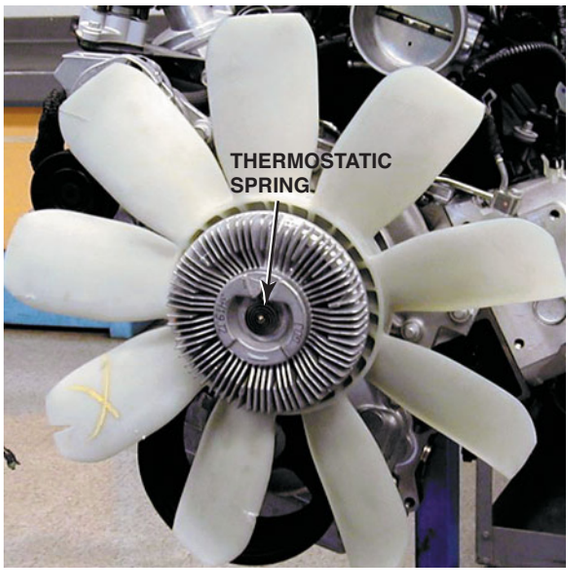


FIGURE 21–24 A typical engine-driven thermostatic spring cooling fan.

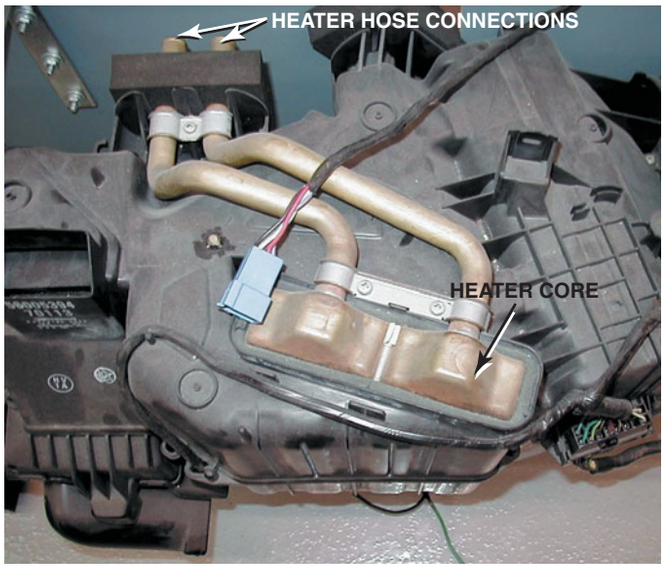


FIGURE 21–25 A typical heater core installed in a heating, ventilation, and air-conditioning (HVAC) housing assembly.

TECH TIP

Be Sure to Always Use a Fan Shroud

A fan shroud forces the fan to draw air through the radiator. If a fan shroud is not used, then air is drawn from around the fan and will reduce the airflow through the radiator. Many overheating problems are a result of not replacing the factory shroud after engine work or body repair work to the front of the vehicle.

spring opens a valve that allows the drive to operate like the silicone coupling drive. When the engine is very cold, the fan may operate at high speeds for a short time until the drive fluid warms slightly. The silicone fluid will then flow into a reservoir to let the fan speed drop to idle. ● **SEE FIGURE 21–24**.

The fan is designed to move enough air at the lowest fan speed to cool the engine when it is at its highest coolant temperature. The fan shroud is used to increase the cooling system efficiency.

HEATER CORES

PURPOSE AND FUNCTION Most of the heat absorbed from the engine by the cooling system is wasted. Some of this heat, however, is recovered by the vehicle heater. Heated coolant is passed through tubes in the small core of the heater. Air is passed across the heater fins and is then sent to the passenger compartment. In some vehicles, the heater and air conditioning work in series to maintain vehicle compartment temperature. ● **SEE FIGURE 21–25**.

HEATER PROBLEM DIAGNOSIS When the heater does not produce the desired amount of heat, many owners and technicians replace the thermostat before doing any other troubleshooting. It is true that a defective thermostat is the reason for the *engine* not to reach normal operating temperature, but there are many other causes besides a defective thermostat that can result in lack of heat from the heater. To determine the exact cause, follow this procedure.

STEP 1 After the engine has been operated, feel the upper radiator hose. If the engine is up to proper operating temperature, the upper radiator hose should be too hot to hold. The hose should also be pressurized.
- **a.** If the hose is not hot enough, replace the thermostat.
- **b.** If the hose is not pressurized, test or replace the radiator pressure cap if it will not hold the specified pressure.
- **c.** If okay, see step 2.

STEP 2 With the engine running, feel both heater hoses. (The heater should be set to the maximum heat position.) Both hoses should be too hot to hold. If both hoses are warm (not hot) or cool, check the heater control valve for proper operation (if equipped). If one hose is hot and the other (return) is just warm or cool, remove both hoses from the heater core or engine and flush the heater core with water from a garden hose.

STEP 3 If both heater hoses are hot and there is still a lack of heating concern, then the fault is most likely due to an airflow blend door malfunction. Check service information for the exact procedure to follow.

HINT: Heat from the heater that "comes and goes" is most likely the result of low coolant level. Usually with the engine at idle, there is enough coolant flow through the heater. At higher engine speeds, however, the lack of coolant through the heads and block prevents sufficient flow through the heater.

COOLING SYSTEM TESTING

VISUAL INSPECTION Many cooling system faults can be found by performing a thorough visual inspection. Items that can be inspected visually include:

- Water pump drive belt for tension or faults
- Cooling fan for faults
- Heater and radiator hoses for condition and leaks
- Coolant overflow or surge tank coolant level

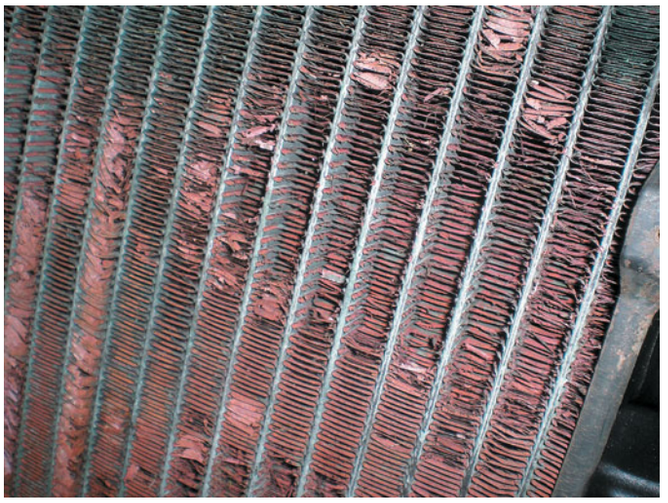


FIGURE 21–26 A heavily corroded radiator from a vehicle that was overheating. A visual inspection discovered that the corrosion had eaten away many of the cooling fins, yet did not leak. This radiator was replaced and it solved the overheating problem.



FIGURE 21–27 Pressure testing the cooling system. A typical hand-operated pressure tester applies pressure equal to the radiator cap pressure. The pressure should hold; if it drops, this indicates a leak somewhere in the cooling system. An adapter is used to attach the pump to the cap to determine if the radiator can hold pressure, and release it when pressure rises above its maximum rated pressure setting.

- Evidence of coolant loss
- Radiator condition ● **SEE FIGURE 21–26**.

PRESSURE TESTING Pressure testing using a hand-operated pressure tester is a quick and easy cooling system test. The radiator cap is removed (engine cold!) and the tester is attached in the place of the radiator cap. By operating the plunger on the pump, the entire cooling system is pressurized. ● **SEE FIGURE 21–27**.

CAUTION: Do not pump up the pressure beyond that specified by the vehicle manufacturer. Most systems should not be pressurized beyond 14 PSI (100 kPa). If a greater pressure is used, it may cause the water pump, radiator, heater core, or hoses to fail.

If the cooling system is free from leaks, the pressure should stay and not drop. If the pressure drops, look for evidence of leaks anywhere in the cooling system, including:

1. Heater hoses
2. Radiator hoses

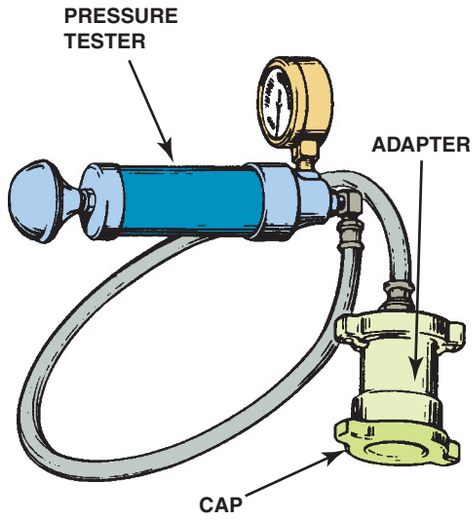


FIGURE 21–28 The pressure cap should be checked for proper operation using a pressure tester as part of the cooling system diagnosis.



FIGURE 21–29 Use dye specifically made for coolant when checking for leaks using a black light.

3. Radiator
4. Heater core
5. Cylinder head
6. Core plugs in the side of the block or cylinder head

Pressure testing should be performed whenever there is a leak or suspected leak. The pressure tester can also be used to test the radiator cap. An adapter is used to connect the pressure tester to the radiator cap. Replace any cap that will not hold pressure. ● **SEE FIGURE 21–28**.

COOLANT DYE LEAK TESTING One of the best methods to check for a coolant leak is to use a fluorescent dye in the coolant, one that is specifically designed for coolant. Operate the vehicle with the dye in the coolant until the engine reaches normal operating temperature. Use a black light to inspect all areas of the cooling system. When there is a leak, it will be easy to spot because the dye in the coolant will be seen as bright green. ● **SEE FIGURE 21–29**.



FIGURE 21–30 When an engine overheats, often the coolant overflow container boils.

COOLANT TEMPERATURE WARNING LIGHT

PURPOSE AND FUNCTION Most vehicles are equipped with a heat sensor for the engine operating temperature indicator light. If the warning light comes on during driving (or the temperature gauge goes into the red danger zone), then the coolant temperature is about 250°F to 258°F (120°C to 126°C), which is still *below* the boiling point of the coolant (assuming a properly operating pressure cap and system). ● **SEE FIGURE 21–30**.

PRECAUTIONS If the coolant temperature warning light comes on, follow these steps.

STEP 1 Shut off the air conditioning and turn on the heater. The heater will help rid the engine of extra heat. Set the blower speed to high.

STEP 2 If possible, shut the engine off and let it cool. (This may take over an hour.)

STEP 3 Never remove the radiator cap when the engine is hot.

STEP 4 Do *not* continue to drive with the hot light on, or serious damage to your engine could result.

STEP 5 If the engine does not feel or smell hot, it is possible that the problem is a faulty hot light sensor or gauge. Continue to drive, but to be safe, stop occasionally and check for any evidence of overheating or coolant loss.

COMMON CAUSES OF OVERHEATING Overheating can be caused by defects in the cooling system, such as the following:

1. Low coolant level
2. Plugged, dirty, or blocked radiator
3. Defective fan clutch or electric fan
4. Incorrect ignition timing (if adjustable)
5. Low engine oil level
6. Broken fan drive belt
7. Defective radiator cap
8. Dragging brakes
9. Frozen coolant (in freezing weather)
10. Defective thermostat
11. Defective water pump (the impeller slipping on the shaft internally)
12. Blocked cooling passages in the block or cylinder head(s)

REAL WORLD FIX

Highway Overheating

A vehicle owner complained of an overheating vehicle, but the problem occurred only while driving at highway speeds. The vehicle, equipped with a 4-cylinder engine, would run in a perfectly normal manner in city driving situations.

The technician flushed the cooling system and replaced the radiator cap and the water pump, thinking that restricted coolant flow was the cause of the problem. Further testing revealed coolant spray out of one cylinder when the engine was turned over by the starter with the spark plugs removed.

A new head gasket solved the problem. Obviously, the head gasket leak was not great enough to cause any problems until the engine speed and load created enough flow and heat to cause the coolant temperature to soar.

The technician also replaced the oxygen (O_2) sensor, because the IAT-type coolant contains phosphates and silicates that often contaminate the sensor. The deteriorated oxygen sensor could have contributed to the problem.

COOLING SYSTEM INSPECTION

COOLANT LEVEL The cooling system is one of the most maintenance-free systems in the engine. Normal maintenance involves an occasional check on the coolant level. It should also include a visual inspection for signs of coolant system leaks and for the condition of the coolant hoses and fan drive belts.

CAUTION: The coolant level should only be checked when the engine is cool. Removing the pressure cap from a hot engine will release the cooling system pressure while the coolant temperature is above its atmospheric boiling temperature. When the cap is removed, the pressure will instantly drop to atmospheric pressure level, causing the coolant to boil immediately. Vapors from the boiling liquid will blow coolant from the system. Coolant will be lost, and someone may be injured or burned by the high-temperature coolant that is blown out of the filler opening.

ACCESSORY DRIVE BELT TENSION Drive belt condition and proper installation are important for the proper operation of the cooling system.

There are four ways vehicle manufacturers specify that the belt tension is within factory specifications.

1. **Belt tension gauge.** A belt tension gauge is needed to achieve the specified belt tension. Install the belt and operate the engine with all of the accessories turned on, to run in the belt for at least five minutes. Adjust the tension of the accessory drive belt

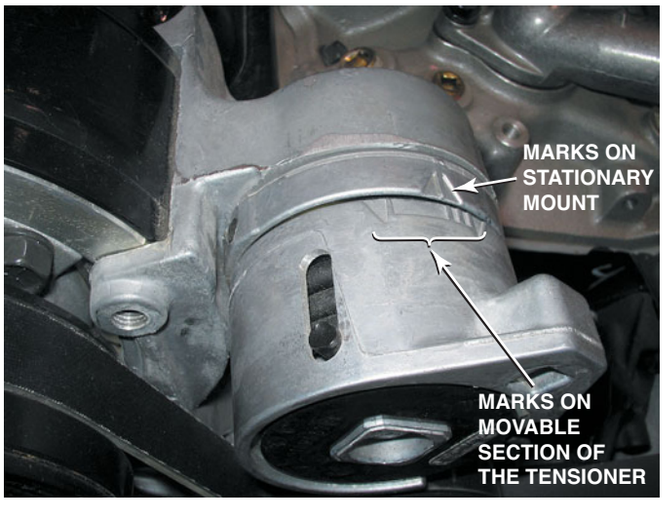


FIGURE 21–31 Typical marks on an accessory drive belt tensioner.

Number of Ribs Used	Tension Range (lb.)
3	45 to 60
4	60 to 80
5	75 to 100
6	90 to 125
7	105 to 145

CHART 21–3

The number of ribs determines the tension range of the belt.

TECH TIP

The Water Spray Trick

Lower-than-normal alternator output could be the result of a loose or slipping drive belt. All belts (V and serpentine multigroove) use an interference angle between the angle of the Vs of the belt and the angle of the Vs on the pulley. A belt wears this interference angle off the edges of the V of the belt. As a result, the belt may start to slip and make a squealing sound even if tensioned properly.

A common trick to determine if the noise is from the belt is to spray water from a squirt bottle at the belt with the engine running. If the noise stops, the belt is the cause of the noise. The water quickly evaporates and therefore, water just finds the problem—it does not provide a short-term fix.

to factory specifications or use **CHART 21–3** for an example of the proper tension based on the size of the belt. Replace any serpentine belt that has more than three cracks in any one rib that appears in a 3 in. span.

2. **Marks on the tensioner.** Many tensioners have marks that indicate the normal operating tension range for the accessory drive belt. Check service information for the location of the tensioner mark. ● **SEE FIGURE 21–31**.
3. **Torque wrench reading.** Some vehicle manufacturers specify that a beam-type torque wrench be used to determine the torque needed to rotate the tensioner. If the torque reading is below specifications, the tensioner must be replaced.
4. **Deflection.** Depress the belt between the two pulleys that are the farthest apart and the flex or deflection should be 1/2 in.

COOLING SYSTEM SERVICE

FLUSHING COOLANT Flushing the cooling system includes the following steps.

STEP 1 Drain the system (dispose of the old coolant correctly).

STEP 2 Fill the system with clean water and flushing/cleaning chemical.

STEP 3 Start the engine until it reaches operating temperature with the heater on.

STEP 4 Drain the system and fill with clean water.

STEP 5 Repeat until drain water runs clear (any remaining flush agent will upset pH).

STEP 6 Fill the system with 50/50 antifreeze/water mix or premixed coolant.

STEP 7 Start the engine until it reaches operating temperature with the heater on.

STEP 8 Adjust coolant level as needed.

Bleeding the air out of the cooling system is important because air can prevent proper operation of the heater and can cause the engine to overheat. Use a clear hose attached to the bleeder valve and the other end in a "suitable" container. This prevents coolant from getting on the engine and gives the technician a visual clue as to the color of coolant. ● **SEE FIGURE 21–32**.

Check service information for specific bleeding procedures and location of the air bleeder fittings.

COOLANT EXCHANGE MACHINE Many coolant exchange machines are able to perform one or more of the following operations.

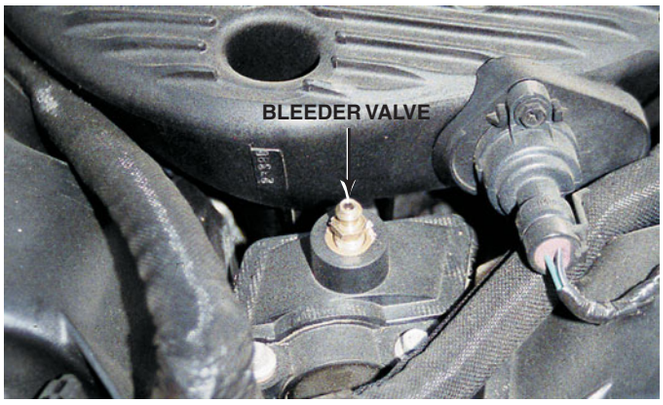
- Exchange old coolant with new coolant
- Flush the cooling system
- Pressure or vacuum check the cooling system for leaks

The use of a coolant exchange machine pulls a vacuum on the cooling system which helps illuminate air pockets from forming during coolant replacement. If an air pocket were to occur, the following symptoms may occur.

1. **Lack of heat from the heater.** Air rises and can form in the heater core, which will prevent coolant from flowing.
2. **Overheating.** The engine can overheat due to the lack of proper coolant flow through the system.

Always follow the operating instructions for the coolant exchange machine being used. ● **SEE FIGURE 21–33**.

HOSE INSPECTION Coolant system hoses are critical to engine cooling. As the hoses get old, they become either soft or brittle and sometimes swell in diameter. Their condition depends on their material and on the engine service conditions. If a hose breaks while the engine is running, all coolant will be lost. A hose should be replaced any time it appears to be abnormal. ● **SEE FIGURE 21–34**.



(a)



(b)

FIGURE 21–32 (a) Many vehicle manufacturers recommend that the bleeder valve be opened whenever refilling the cooling system. (b) Chrysler recommends that a clear plastic hose (1/4 in. ID) be attached to the bleeder valve and directed into a suitable container to keep from spilling coolant onto the ground and on the engine and to allow the technician to observe the flow of coolant for any remaining oil bubbles.



FIGURE 21–33 Using a coolant exchange machine helps eliminate the problem of air getting into the system which can cause overheating or lack of heat due to air pockets getting trapped in the system.

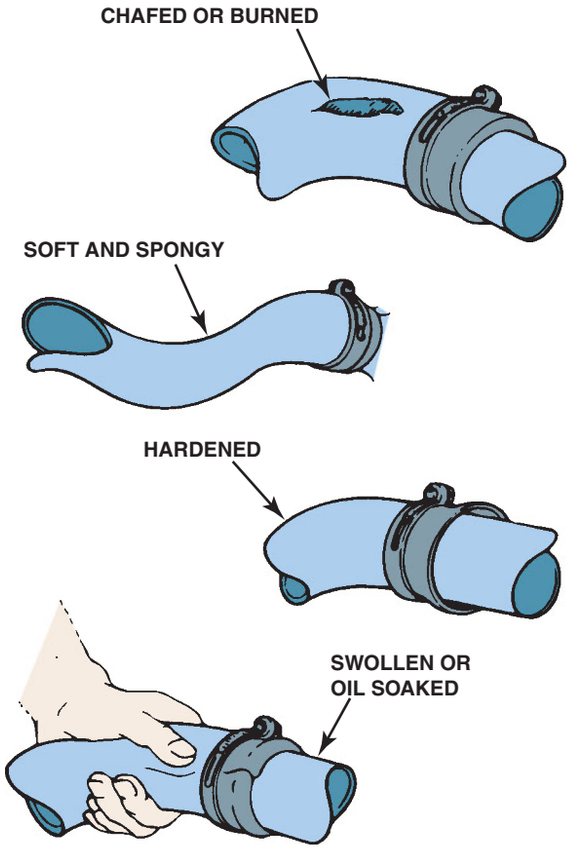


FIGURE 21–34 All cooling system hoses should be checked for wear or damage.

TECH TIP

Always Replace the Pressure Cap

Replace the old radiator cap with a new cap with the same pressure rating. The cap can be located on the following:

1. Radiator
2. Coolant recovery reservoir
3. Upper radiator hose

WARNING

Never remove a pressure cap from a hot engine. When the pressure is removed from the system, the coolant will immediately boil and will expand upward, throwing scalding coolant in all directions. Hot coolant can cause serious burns.

HINT: To make hose removal easier and to avoid possible damage to the radiator, use a utility knife and slit the hose lengthwise. Then simply peel the hose off.

The hose and hose clamp should be positioned so that the clamp is close to the bead on the neck. This is especially important on aluminum hose necks to avoid corrosion. When the hoses are in place and the drain petcock is closed, the cooling system can be refilled with the correct coolant mixture.

TECH TIP

Always Use Heater Hoses Designed for Coolant

Many heater hoses are sizes that can also be used for other purposes such as oil lines. Always check and use hose that states it is designed for heater or cooling system use. ● **SEE FIGURE 21–35.**

TECH TIP

Quick and Easy Cooling System Problem Diagnosis

1. If overheating occurs in slow stop-and-go traffic, the usual cause is low airflow through the radiator. Check for airflow blockages or cooling fan malfunction.
2. If overheating occurs at highway speeds, the cause is usually a radiator or coolant circulation problem. Check for a restricted or clogged radiator.

DISPOSING OF USED COOLANT Used coolant drained from vehicles should be disposed of according to state or local laws. Some communities permit draining into the sewer. Ethylene glycol will easily biodegrade. There could be problems with groundwater contamination, however, if coolant is spilled on open ground. Check with recycling companies authorized by local or state governments for the exact method recommended for disposal in your area.

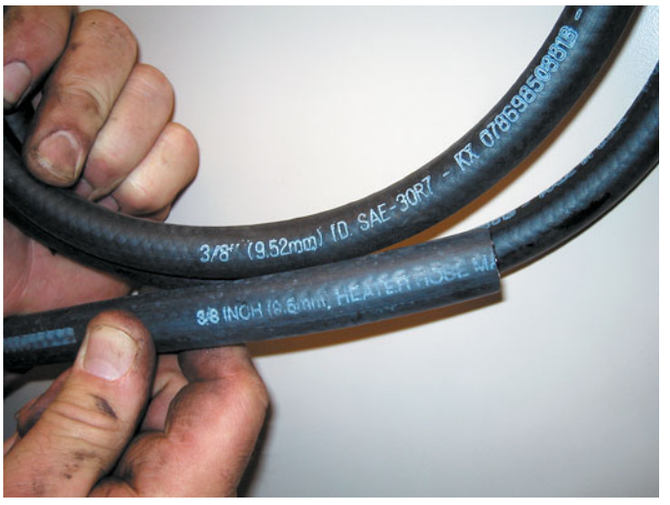


FIGURE 21–35 The top 3/8 in. hose is designed for oil and similar liquids, whereas the 3/8 in. hose below is labeled "heater hose" and is designed for coolant.

CLEANING THE RADIATOR EXTERIOR Overheating can result from exterior and interior radiator plugging. External plugging is caused by dirt and insects. This type of plugging can be seen if you look straight through the radiator while a light is held behind it. It is most likely to occur on off-road vehicles. The plugged exterior of the radiator core can usually be cleaned with water pressure from a hose. The water is aimed at the *engine side* of the radiator. The water should flow freely through the core at all locations. If this does not clean the core, the radiator should be removed for cleaning at a radiator shop.

REVIEW QUESTIONS

1. What is normal operating coolant temperature?
2. Explain the flow of coolant through the engine and radiator.
3. Why is a cooling system pressurized?
4. What is the purpose of the coolant system bypass?
5. Describe how to perform a drain, flush, and refill procedure on a cooling system.
6. Explain the operation of a thermostatic cooling fan.
7. Describe how to diagnose a heater problem.
8. What are 10 common causes of overheating?

CHAPTER QUIZ

1. The upper radiator collapses when the engine cools. What is the most likely cause?
   a. Defective upper radiator hose
   b. Missing spring from the upper radiator hose, which is used to keep it from collapsing
   c. Defective thermostat
   d. Defective pressure cap
2. What can be done to prevent air from getting trapped in the cooling system when the coolant is replaced?
   a. Pour the coolant into the radiator slowly.
   b. Use a coolant exchange machine that draws a vacuum on the system.
   c. Open the air bleeder valves while adding coolant.
   d. Either b or c
3. Heat transfer is improved from the coolant to the air when the _____.
   a. Temperature difference is great
   b. Temperature difference is small
   c. Coolant is 95% antifreeze
   d. Both a and c
4. A water pump is a positive displacement type of pump.
   a. True **b.** False
5. Water pumps _____.
   a. Only work at idle and low speeds and are disengaged at higher speeds
   b. Use engine oil as a lubricant and coolant
   c. Are driven by the engine crankshaft or camshaft
   d. Disengage during freezing weather to prevent radiator failure

6. What diagnostic trouble code (DTC) could be set if the thermostat is defective?
   a. P0300 **c.** P0171
   b. P0440 **d.** P0128
7. Which statement is *true* about thermostats?
   a. The temperature marked on the thermostat is the temperature at which the thermostat should be fully open.
   b. Thermostats often cause overheating.
   c. The temperature marked on the thermostat is the temperature at which the thermostat should start to open.
   d. Both a and b
8. Technician A says that the radiator should always be inspected for leaks and proper flow before installing a rebuilt engine. Technician B says that overheating during slow city driving can only be due to a defective electric cooling fan. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. A customer complains that the heater works sometimes, but sometimes only cold air comes out while driving. Technician A says that the water pump is defective. Technician B says that the cooling system could be low on coolant. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. The normal operating temperature (coolant temperature) of an engine equipped with a 195°F thermostat is _____.
   a. 175°F to 195°F
   b. 185°F to 205°F
   c. 195°F to 215°F
   d. 175°F to 215°F

chapter 22 ENGINE OIL

OBJECTIVES: **After studying Chapter 22, the reader should be able to:** • Prepare for ASE Engine Repair (A1) certification test content area "D" (Lubrication and Cooling Systems Diagnosis and Repair). • Describe the importance and the role of engine oil. • Describe the various oil specifications. • Discuss the importance of the vehicle manufacturer's requirements. • Discuss how to change oil.

KEY TERMS: Additive package 201 • American Petroleum Institute (API) 199 • Antidrainback valve 204 • Association des Constructeurs Européens d'Automobiles (ACEA) 200 • Bypass valve 204 • HTHS 201 • International Lubricant Standardization and Approval Committee (ILSAC) 200 • Japanese Automobile Standards Organization (JASO) 201 • Miscible 198 • Pour point 198 • SAPS 201 • Society of Automotive Engineers (SAE) 199 • Viscosity index (VI) 198 • zinc dialkyl dithiophosphate (ZDDP or ZDP) 202

INTRODUCTION

Engine oil has a major effect on the proper operation and life of any engine. Engine oil provides the following functions in every engine.

- Lubricates moving parts
- Helps cool engine parts
- Helps seal piston rings
- Helps to neutralize acids created by the by-products of combustion
- Reduces friction in the engine
- Helps to prevent rust and corrosion

As a result of these many factors, the specified engine oil must be used and replaced at the specified mileage or time intervals.

PROPERTIES OF ENGINE OIL

The most important engine oil property is its thickness or viscosity.

- As oil is cooled, it gets thicker.
- As oil is heated, it gets thinner.

Therefore, its viscosity changes with temperature. The oil must not be too thick at low temperatures to allow the engine to start. The lowest temperature at which oil will pour is called its **pour point.** An index of the change in viscosity between the cold and hot extremes is called the **viscosity index (VI).** All oils with a high viscosity index thin less with heat than do oils with a low viscosity index. Oils must also be **miscible,** meaning they are capable of mixing with other oils (brands and viscosities, for example) without causing any problems such as sludge.



FIGURE 22–1 The SAE viscosity rating required is often printed on the engine oil filler cap.



FIGURE 22–2 API doughnut for a SAE 5W-30, SN engine oil. When compared to a reference oil, the "energy conserving" designation indicates a 1.1% better fuel economy for SAE 10W-30 oils and 0.5% better fuel economy for SAE 5W-30 oils.

SAE RATING

TERMINOLOGY Engine oils are sold with a **Society of Automotive Engineers (SAE)** grade number, which indicates the viscosity range into which the oil fits. Oils tested at 212°F (100°C) have a number with no letter following. For example, SAE 30 indicates that the oil has only been checked at 212°F (100°C). This oil's viscosity falls within the SAE 30 grade number range when the oil is hot. Oils tested at 0°F (−18°C) are rated with a number and the letter *W,* which means *winter* and indicates that the viscosity was tested at 0°F, such as SAE 20W.

MULTIGRADE ENGINE OIL An SAE 5W-30 multigrade oil meets the SAE 5W viscosity specification when cooled to 0°F (−18°C), and meets the SAE 30 viscosity specification when tested at 212°F (100°C).

Most vehicle manufacturers recommend the following multiviscosity engine oils.

- SAE 5W-30
- SAE 10W-30

● **SEE FIGURE 22–1**.

Oil with a high viscosity has a higher resistance to flow and is thicker than lower viscosity oil. Thick oil is not necessarily good oil and thin oil is not necessarily bad oil. Generally, the following items can be considered in the selection of engine oil within the recommended viscosity range.

- Thinner oil
  1. Improved cold engine starting
  2. Improved fuel economy
- Thicker oil
  1. Improved protection at higher temperatures
  2. Reduced fuel economy

NOTE: Always use the specified viscosity engine oil.

API RATING

DEFINITION The **American Petroleum Institute (API),** working with the engine manufacturers and oil companies, has established an engine oil performance classification. Oils are tested and rated in production automotive engines. The oil container is printed with the API classification of the oil. The API performance or service classification and the SAE grade marking are the only information available to help determine which oil is satisfactory for use in an engine. ● **SEE FIGURE 22–2** for a typical API oil container "doughnut."

GASOLINE ENGINE RATINGS In gasoline engine ratings, the letter *S* means *service,* but can also indicate spark ignition engines. The rating system is open ended so that newer, improved ratings can be readily added as necessary (the letter *I* is skipped to avoid confusion with the number one).

SA	Straight mineral oil (no additives), not suitable for use in any engine
SB	Nondetergent oil with additives to control wear and oil oxidation
SC	Obsolete (1964)
SD	Obsolete (1968)
SE	Obsolete (1972)
SF	Obsolete (1980)
SG	Obsolete (1988)
SH	Obsolete (1993–1997)
SJ	Obsolete (1997–2001)
SL	2001–2003
SM	2004–2010
SN	2011+

REAL WORLD FIX

The Case of the Wrong Oil Viscosity

A 2007 Dodge Durango 5.7 liter Hemi with a multiple displacement system (MDS) had the oil changed at a shop. SAE 10W-30 was used as this was the "standard" bulk oil in the shop. After the oil change, the vehicle was returned to the customer. Within a few minutes, however, the "check engine" light came on. The technician checked for diagnostic trouble codes (DTCs) and found a P0521 DTC stored. The technician checked service information and discovered that the code could be set if the incorrect viscosity engine oil had been used. The description of the P0521 read:

"Oil pressure not reaching specified at 1250 RPM."

The technician changed the oil and used the specified SAE 5W-20, then cleared the DTC. A test drive confirmed that the change to the correct viscosity oil solved the problem.

NOTE: Vehicles built since about 1996 that use roller valve lifers can use the newer, higher rated engine oil classifications where older, now obsolete ratings were specified. Newly overhauled antique cars or engines also can use the newer, improved oils, as the appropriate SAE viscosity grade is used for the anticipated temperature range. Engines older than an about 1996 or those using flat-bottom lifters should use a zinc additive if using newer rated oil.

DIESEL ENGINE RATINGS Diesel classifications begin with the letter *C,* which stands for *commercial,* but can also indicate compression ignition or diesel engines.

CA	Obsolete
CB	Obsolete
CC	Obsolete
CD	Minimum rating for use in a diesel engine service
CE	Designed for certain turbocharged or supercharged heavy-duty diesel engine service
CF	For off-road indirect injected diesel engine service
CF-2	Two-stroke diesel engine service
CF-4	High-speed four-stroke cycle diesel engine service
CG-4	Severe-duty high-speed four-stroke diesel engine service
CI-4	Severe-duty high-speed four-stroke diesel engine service
CJ-4	Required for use in all 2007 and newer diesels using ultra-low-sulfur diesel (ULSD) fuel

ILSAC OIL RATING

DEFINITION The **International Lubricant Standardization and Approval Committee (ILSAC)** developed an oil rating that consolidates the SAE viscosity rating and the API quality rating. If an engine oil meets the standards, a "starburst" symbol is displayed on the *front* of the oil container. If the starburst is present, the vehicle owner and technician know that the oil is suitable for use in almost any gasoline engine. ● **SEE FIGURE 22–3**.



FIGURE 22–3 The International Lubricant Standardization and Approval Committee (ILSAC) starburst symbol. If this symbol is on the front of the container of oil, then it is acceptable for use in almost any gasoline engine.

TECH TIP

Three Oil Change Facts

Three facts that are important to know when changing oil are:

1. *Recommended SAE viscosity* (thickness) for the temperature range that is anticipated before the next oil change (such as SAE 5W-30)
2. *Quality rating* as recommended by the engine or vehicle manufacturer such as API SM and other specified rating such as the ILSAC and vehicle manufacturer's specifications
3. *Recommended oil change interval* (time or mileage) (usually every 5,000 miles or every six months)

ILSAC RATINGS

- The original GF-1 (gasoline fueled) rating in 1993
- Updated to GF-2 in 1997
- Updated to GF-3 in 2000
- Updated to GF-4 in 2004
- Updated to GF-5 in 2010

For more information, visit www.gf-5.com.

EUROPEAN OIL RATING SYSTEM

DEFINITION The **Association des Constructeurs Européens d'Automobiles (ACEA)** rates the oil according to the following:

- Gasoline engine oils

ACEA A1	Low-friction low-viscosity oil (not suitable for some engines)
ACEA A2	General-purpose oil intended for normal oil change intervals; not suitable for some engines or extended oil drain intervals in any engine



FIGURE 22–4 ACEA ratings are included on the back of the oil container if it meets any of the standards. ACEA ratings apply to European vehicles only such as BMW, Mercedes, Audi, and VW.

ACEA A3	Designed for high-performance engines and/or extended oil drain intervals and under all temperature ranges
ACEA A4	Designed to meet the requirements for gasoline direct injection (GDI) engines
ACEA A5	Low-viscosity low-friction oil not suitable for some engines

- Diesel engine oils

ACEA B1	Low-viscosity oil designed for use in a passenger vehicle diesel engine that is equipped with an indirect injection system; not suitable for some diesel engines
ACEA B2	Designed for use in passenger vehicle diesel engines using indirect injection and using normal oil drain intervals
ACEA B3	Intended for use in a high-performance indirect injected passenger vehicle diesel engine and under extended oil drain interval conditions
ACEA B4	Intended for year-round use in direct injected passenger vehicle diesel engines; can be used in an indirect injected diesel engine
ACEA B5	Designed for extended oil drain intervals; not suitable for some engines
ACEA C1,	Specifications for catalyst compatible oils, C2, C3 which have limits on the amount of sulfur, zinc, and other additives that could harm the catalytic converter

Starting in 2004, the ACEA began using combined ratings such as A1/B1, A3/B3, A3/B4, and A5/B5.

- ACEA oil also requires low levels of sulfated ash, phosphorous, and sulfur, abbreviated **SAPS,** and has a high temperature/high shear rate viscosity, abbreviated **HTHS.**
- C ratings are catalytic converter compatible oils and include:

C1: basically A5/B5 oil with low SAPS, low HTHS

C2: A5/B5 with low HTHS and mid-level SAPS

C3: A5/B5 with high HTHS and mid-level SAPS

C4: low SAPS; high HTHS

● **SEE FIGURE 22–4.**



FIGURE 22–5 Viscosity index (VI) improver is a polymer and feels like finely ground foam rubber. When dissolved in the oil, it expands when hot to keep the oil from thinning.

JAPANESE OIL RATINGS

The **Japanese Automobile Standards Organization (JASO)** also publishes oil standards. The JASO tests use small Japanese engines, and their ratings require more stringent valve train wear standards than oil ratings in other countries. However, most Japanese brand vehicles specify SAE, API, and ILSAC rating standards for use in the engine.

ENGINE OIL ADDITIVES

Oil producers are careful to check the compatibility of the oil additives they use. A number of chemicals that will help each other can be used for each of the additive requirements. The balanced additives are called an **additive package.**

ADDITIVES TO IMPROVE THE BASE OIL

- **Viscosity index (VI) improver.** Modifies the viscosity of the base fluid so that it changes less as the temperature rises; allows the lubricant to operate over a wider temperature range (● **SEE FIGURE 22–5.**)
- **Pour point depressant.** Keeps the lubricant flowing at low temperatures
- **Antifoam agents.** Foam reduces the effectiveness of a lubricant. The antifoam agents reduce/stop foaming when the oil is agitated or aerated.

ADDITIVES TO PROTECT THE BASE OIL

- **Antioxidants.** Slow the breakdown of the base fluid caused by oxygen (air) and heat (Oxidation is the main cause of lubricant degradation in service.)
- **Oxidants.** Prevent acid formation (corrosion) in the form of sludges, varnishes
- **Total base number (TBN).** The reserve alkalinity used to neutralize the acids created during the combustion process (Typical TBN levels are between 60 and 100, which is dependent on the fuel sulfur level. The higher the sulfur percentage in the fuel, the higher the TBN required. The higher the total base

TECH TIP

Dirty Engine Oil Can Cause Oil Burning

Service technicians have known for a long time that some of their customers never change the engine oil. Often these customers believe that because their engine uses oil and they add a new quart every week, they are doing the same thing as changing the oil. But dirty, oxidized engine oil could cause piston rings to stick and not seal the cylinder. Therefore, when the oil and filter are changed, the clean oil may free the piston rings, especially if the vehicle is driven on a long trip during which the oil is allowed to reach the normal operating temperature. An engine that is mechanically sound, but burning oil, may be "fixed" by simply changing the oil and filter.

number of oil, the longer it can be used in an engine. Long-life oils usually have higher total base numbers than other oils.)

ADDITIVES TO PROTECT THE ENGINE

- **Rust inhibitor.** Inhibits the action of water on ferrous metal such as steel
- **Corrosion inhibitor.** Protects nonferrous metals such as copper
- **Antiwear additive.** Forms a protective layer on metal surfaces to reduce friction and prevent wear when no lubricant film is present
- **Extreme pressure additive.** Functions only when heavy loads and temperatures are occurring

OIL BRAND COMPATIBILITY

Many technicians and vehicle owners have their favorite brand of engine oil. The choice is often made as a result of marketing and advertising, as well as comments from friends, relatives, and technicians. If your brand of engine oil is not performing up to your expectations, then you may wish to change brands. For example, some owners experience lower oil pressure with a certain brand than they do with other brands with the same SAE viscosity rating.

- Most experts agree that the oil changes are the most important regularly scheduled maintenance for an engine.
- It is also wise to check the oil level regularly and add oil when needed.
- According to SAE standard J-357, all engine oils must be miscible (compatible) with all other brands of engine oil.
- Therefore, any brand of engine oil can be used as long as it meets the viscosity and API standards recommended by the vehicle manufacturer. Even though many people prefer a particular brand, be assured that, according to API and SAE, any major brand name engine oil can be used.

SYNTHETIC OIL

DEFINITION Synthetic engine oils have been available for years for military, commercial, and general public use. The term *synthetic* means that it is a manufactured product and not refined from a naturally occurring substance, as engine oil (petroleum base) is refined from crude oil. Synthetic oil is processed from several different base stocks using several different methods.



FIGURE 22–6 Using a zinc additive is important when using SM or SN-rated oil in an engine equipped with a flat-bottom lifter, especially during the break-in period.

FREQUENTLY ASKED QUESTION

Can Newer Engine Oils Be Used in Engines That Use Flat-Bottom Lifters

No. Newer oil standards are designed to reduce phosphates in the engine oil that may leak past piston rings and end up in the exhaust system. These additives found in oil can then damage the catalytic converter. The levels of phosphate and zinc, commonly referred to as **zinc dialkyl dithiophosphate** (**ZDDP** or **ZDP**), have been reduced because they can cause damage to the catalytic converter. Even though engines consume very little oil, if the oil contains zinc, the efficiency of the catalytic converter is reduced. The use of ZDDP was intended to reduce sliding friction in an engine. Sliding friction is usually found in engines that use flat-bottom lifters. Most, if not all, engines produced over the past 15 years have used roller lifters or cam followers, so using the new oil without ZDDP is not a concern. Even diesel oils have reduced amounts of the zinc, so many camshaft manufacturers are recommending the use of an additive. Older oils had up to 0.15% ZDDP and now SM-rated oils list the zinc at just 0.08% or 800 parts per million.

- Engine oil had about 1,200 ppm zinc prior to 2001.
- In 2001, the zinc was reduced to 1,000 ppm; and in 2005, reduced again to the current 800 ppm.
- API ratings do not specify the zinc content, just oil performance.

If driving a vehicle with flat-bottom lifters, use engine oil specifically designed for older engines, such as Shell Rotella T, or use an additive, such as General Motor's engine oil supplement (EOS), part number 1052367 or 88862586, or a zinc additive. Check with camshaft manufacturers for their recommended oil or additive to use. **SEE FIGURE 22–6.**

API GROUPS According to the American Petroleum Institute, engine oil is classified into the following groups.



FIGURE 22–7 Mobil 1 synthetic engine oil is used by several vehicle manufacturers in new engines.

- **Group I.** Mineral, nonsynthetic base oil with few if any additives; suitable for light lubricating needs and rust protection, not for use in an engine
- **Group II.** Mineral oil with quality additive packages; includes most conventional engine oils
- **Group III.** Hydrogenated (hydroisomerized) synthetic compounds commonly referred to as hydrowaxes or hydrocracked oil; the lowest costing synthetic engine oil; includes Castrol Syntec
- **Group IV.** Synthetic oils made from mineral oil and monomolecular oil called polyalpholefin (POA); includes Mobil 1 (● **SEE FIGURE 22–7**.)
- **Group V.** Nonmineral sources such as alcohol from corn called diesters or polyolesters; includes Red Line synthetic oil

Groups III, IV, and V are considered to be synthetic because the molecular structure of the finished product does not occur naturally, but is man-made through chemical processes. All synthetic engine oils perform better than group II (mineral) oils, especially when tested according to the Noack Volatility Test ASTM D-5800. This test procedure measures the ability of an oil to stay in grade after it has been heated to 300°F (150°C) for one hour. The oil is then measured for percentage of weight loss. As the lighter components boil off, the oil's viscosity will increase.

ADVANTAGES OF SYNTHETICS The major advantage of using synthetic engine oil is its ability to remain fluid at very low temperatures. ● **SEE FIGURE 22–8**.

This characteristic of synthetic oil makes it popular in colder climates where cold-engine cranking is important.

DISADVANTAGES OF SYNTHETICS The major disadvantage is cost. The cost of synthetic engine oils can be four to five times the cost of petroleum-based engine oils.

SYNTHETIC BLENDS A synthetic blend indicates that some synthetic oil is mixed with petroleum base engine oil; however, the percentage of synthetic used in the blend is unknown.

VEHICLE-SPECIFIC SPECIFICATIONS

BACKGROUND Some oils can meet industry specifications, such as SAE, API, and/or ILSAC ratings, but not pass the tests specified by the vehicle manufacturer.

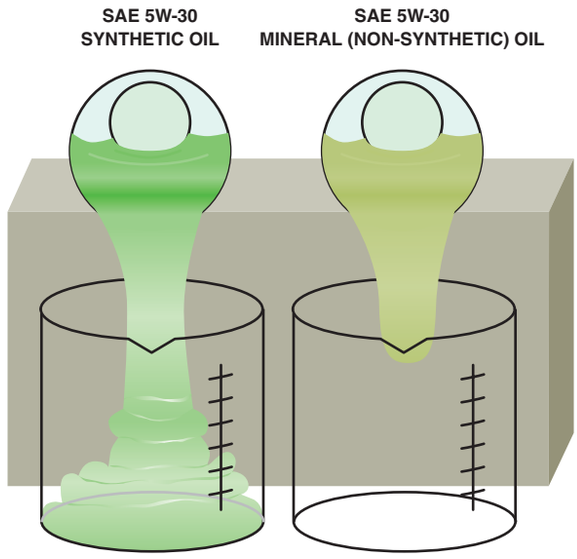


FIGURE 22–8 Both oils have been cooled to −20°F (−29°C). Notice that the synthetic oil on the left flows more freely than the mineral oil on the right even though both are SAE 5W-30.

TECH TIP

Use Synthetic Engine Oil in Lawn and Garden Equipment

Most four-cycle lawn and garden equipment engines are air cooled and operate hotter than many liquid-cooled engines. Lawn mowers and other small engines are often operated near or at maximum speed and power output for hours at a time. These operating conditions are hard on any engine oil. Try using synthetic oil. The cost is not as big a factor because most small four-cycle lawn mower engines require only about 1/2 quart (1/2 liter) of oil. The synthetic oil is able to perform under high temperatures better than conventional mineral oils.

VEHICLE MANUFACTURER–SPECIFIC OIL SPECIFICATIONS The oil used should meet the specifications of the vehicle manufacturer, which include the following:

- **BMW**
  Longlife-98 and longlife-01 (abbreviated LL-01), LL-04
- **General Motors**
  GM 6094M
  GM 4718M (synthetic oil specification)
  Dexos 1 (all GM gasoline engines, 2011+)
  Dexos 2 (all GM diesel engines, 2011+)
- **Ford**
  WSS-M2C153-H
  WSS-M2C929-A (low viscosity rating, SAE 5W-20)
  WSS-M2C930-A
  WSS-M2C931-A
  WSS-M2C934-A
- **Chrysler**
  MS-6395 (2005+ vehicles)
  MS-10725 (2004 and older)
- **Honda/Acura**
  HTO-06 (turbocharged engine only)



FIGURE 22–9 European vehicle manufacturers usually specify engine oil with a broad viscosity range, such as SAE 5W-40, and their own unique standards, such as the Mercedes specification 229.51. Always use the oil specified by the vehicle manufacturer.

- **Mercedes**

  229.3, 229.5, 229.1, 229.3, 229.31, 229.5, and 229.51 (● **SEE FIGURE 22–9**.)

- **Volkswagen (VW and Audi)**

  502.00, 505.00, 505.01, 503, 503.01, 505, 506 diesel, 506.1 diesel, and 507 diesel

Be sure to use the oil that meets all of the specifications, especially during the warranty period.

NOTE: Most Asian brand vehicle manufacturers do not specify any specifications other than SAE, API, and ILSAC. These vehicles include:

- Acura/Honda
- Toyota/Lexus/Scion
- Kia
- Hyundai
- Nissan/Infinity
- Mitsubishi
- Mazda
- Suzuki

HIGH MILEAGE OILS

DEFINITION A "high mileage oil" is sold for use in vehicles that have over 75,000 miles and are, therefore, nearing the eight-year, 80,000-mile catalytic converter warranty period.

Usually higher viscosity and lack of friction-reducing additives mean that most high mileage oils cannot meet ILSAC GF-4 rating and are, therefore, not recommended for use in most engines.

DIFFERENCES

- Esters are added to swell oil seals (main and valve-stem seals).
- The oil is used only in engines with higher than 75,000 miles.
- The oil usually does not have the energy rating of conventional oils (i.e., will not meet the specifications for use according to the owner manual in most cases).

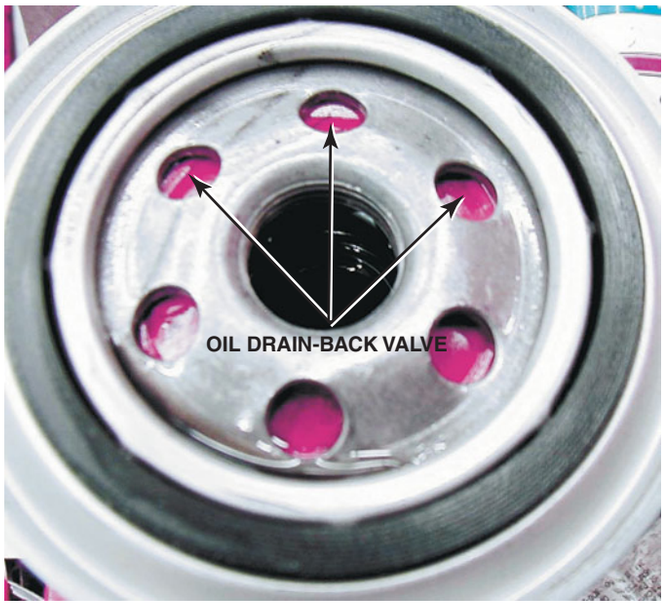


FIGURE 22–10 A rubber diaphragm acts as an antidrainback valve to keep the oil in the filter when the engine is stopped and the oil pressure drops to zero.

OIL FILTERS

CONSTRUCTION The oil within the engine is pumped from the oil pan through the filter before it goes into the engine lubricating system passages. The filter is made from either closely packed cloth fibers or a porous paper. Large particles are trapped by the filter. Microscopic particles will flow through the filter pores. These particles are so small that they can flow through the bearing oil film and not touch the surfaces, so they do no damage.

OIL FILTER VALVES Many oil filters are equipped with an **antidrainback valve** that prevents oil from draining out of the filter when the engine is shut off. ● **SEE FIGURE 22–10**.

This valve keeps oil in the filter and allows the engine to receive immediate lubrication as soon as the engine starts.

Either the engine or the filter is provided with a **bypass valve** that will allow the oil to go around the filter element. ● **SEE FIGURE 22–11**.

The bypass allows the engine to be lubricated with dirty oil, rather than having no lubrication, if the filter becomes plugged. The oil also goes through the bypass when the oil is cold and thick.

OIL FILTER DISPOSAL Oil filters should be crushed and/or drained of oil before discarding. After the oil has been drained, the filter can usually be disposed of as regular metal scrap. Always check and follow local, state, or regional oil filter disposal rules, regulations, and procedures. ● **SEE FIGURE 22–12**.

OIL CHANGE

INTERVALS All vehicle and engine manufacturers recommend a maximum oil change interval. The recommended intervals are almost always expressed in terms of mileage or elapsed time (or hours of operation), whichever milestone is reached first.

Most vehicle manufacturers recommend an oil change interval of 7,500 to 12,000 miles (12,000 to 19,000 km) or every six months. If,



FIGURE 22–11 A cutaway of a typical spin-on oil filter. Engine oil enters the filter through the small holes around the center of the filter and flows through the pleated paper filtering media and out the large hole in the center of the filter. The center metal cylinder with holes is designed to keep the paper filter from collapsing under the pressure. The bypass valve can be built into the center on the oil filter or is part of the oil filter housing and located in the engine.

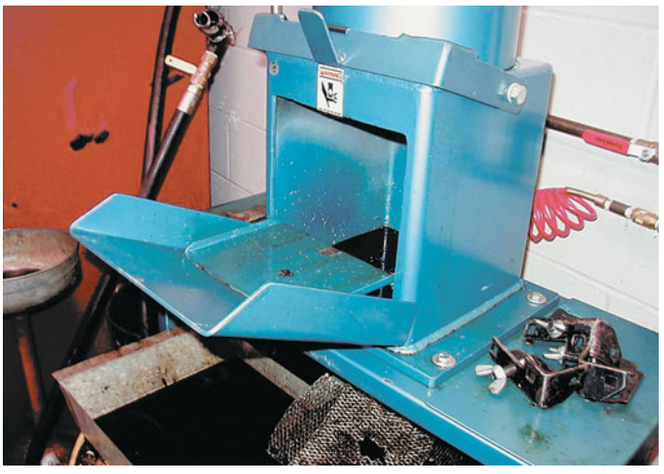


FIGURE 22–12 A typical filter crusher. The hydraulic ram forces out most of the oil from the filter. The oil is trapped underneath the crusher and is recycled.

however, *any one* of the conditions in the following list exists, the oil change interval recommendation drops to a more reasonable 2,000 to 3,000 miles (3,000 to 5,000 km) or every three months. The important thing to remember is that these are recommended *maximum* intervals and they should be shortened substantially if any of the following operating conditions exist.

1. Operating in dusty areas
2. Towing a trailer
3. Short-trip driving, especially during cold weather (The definition of a short trip varies among manufacturers, but it is usually defined as 4 to 15 miles (6 to 24 km) each time the engine is started.)
4. Operating in temperatures below freezing (32°F, 0°C)
5. Operating at idle speed for extended periods of time (such as normally occurs in police or taxi service)

Because most vehicles driven during cold weather are driven on short trips, technicians and automotive experts recommend changing the oil every 2,000 to 3,000 miles or every two to three months, whichever occurs first.

? FREQUENTLY ASKED QUESTION

Why Change Oil If the Oil Filter Can Trap All the Dirt?

Many persons believe that oil filters will remove all dirt from the oil being circulated through the filtering material. Most oil filters will filter particles that are about 10 to 20 microns in size. A micron is one-millionth of a meter or 0.000039 in. Most dirt and carbon particles that turn engine oil black are less than a micron in size. In other words, it takes about 3 million of these carbon particles to cover a pin head. To help visualize the smallness of a micron, consider that a typical human hair is 60 microns in diameter. In fact, anything smaller than 40 microns is not visible to the human eye.

The dispersants added to engine oil prevent dirt from adhering together to form sludge. It is the same dispersant additive that prevents dirt from being filtered or removed by other means. If an oil filter could filter particles down to 1 micron, it would be so restrictive that the engine would not receive sufficient oil through the filter for lubrication. Oil recycling companies use special chemicals to break down the dispersants, which permit the dirt in the oil to combine into larger units that can be filtered or processed out of the oil.

OIL LIFE MONITORS

Most vehicles built since the mid-1990s are equipped with a warning light that lets the driver know when the engine oil should be changed. The two basic types of oil change monitoring systems include:

- **Mileage only.** The service light will come on based on mileage only and may include a service "A" or "B" based on what service needs to be performed. The interval can be every 3,750 to 7,500 miles, or even longer in some cases where specialized engine oil is required.
- **Algorithm.** Computer programs contain algorithms that specify instructions a computer should perform (in a specific order) to carry out a task. This program uses the number of cold starts, the run time of the engine, and inputs from the engine coolant temperature (ECT) sensor to determine when the oil should be changed.

● **SEE FIGURE 22–13.**

OIL CHANGE PROCEDURE

An oil change includes the following steps.

STEP 1 Check the oil level on the dipstick before hoisting the vehicle. Document the work order and notify the owner if the oil level is low before changing the oil.

STEP 2 Safely hoist the vehicle.

STEP 3 Position a drain pan under the drain plug, then remove the plug with care to avoid contact with hot oil.

CAUTION: Used engine oil has been determined to be harmful. Rubber gloves should be worn to protect the skin. If used engine oil gets on the skin, wash thoroughly with soap and water.

STEP 4 Allow the oil to drain freely so that the contaminants come out with the oil. It is not critically important to get every last drop of oil from the engine oil pan, because a quantity of used oil still remains in the engine oil passages and oil pump.

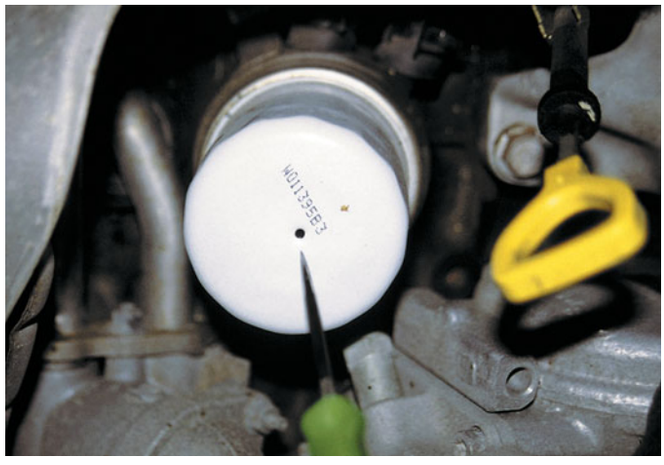
STEP 5 While the engine oil is draining, the oil plug gasket should be examined. If it appears to be damaged, it should be replaced.



FIGURE 22–13 Many vehicle manufacturers can display the percentage of oil life remaining, whereas others simply turn on a warning lamp when it has been determined that an oil change is required.



(a)



(b)

FIGURE 22–14 (a) A pick is pushed through the top of an oil filter that is positioned vertically. (b) When the pick is removed, a small hole allows air to get into the top of the filter which then allows the oil to drain out of the filter and back into the engine.

TECH TIP

Follow the Seasons

Vehicle owners often forget when they last changed the oil. This is particularly true of the person who owns or is responsible for several vehicles. A helpful method for remembering when the oil should be changed is to change it at the start of each season of the year.

- Fall (September 21)
- Winter (December 21)
- Spring (March 21)
- Summer (June 21)

Remembering that the oil needs to be changed on these dates helps owners budget for the expense and the time needed.

TECH TIP

The Pick Trick

Removing an oil filter that is installed upside down can be a real mess. When this design filter is loosened, oil flows out from around the sealing gasket. To prevent this from happening, use a pick to poke a hole in the top of the filter, as shown in ● **FIGURE 22–14**.

This small hole allows air to get into the filter, thereby allowing the oil to drain back into the engine rather than remain in the filter. After punching a hole in the filter, be sure to wait several minutes to allow time for the trapped oil to drain down into the engine before loosening the filter.

NOTE: Honda/Acura recommends that the oil drain plug gasket be replaced at every oil change on many of their vehicles. The aluminum sealing gasket does not seal once it has been tightened. Always follow the vehicle manufacturer's recommendations.

STEP 6 When the oil stops running and starts to drip, reinstall and tighten the drain plug. Replace the oil filter.

TECH TIP

Change Oil Every Friday?

A vehicle less than one year old came back to the dealer for some repair work. While writing the repair order, the service advisor noted that the vehicle had 88,000 miles on the odometer and was, therefore, out of warranty for the repair. Because the owner approved the repair anyway, the service advisor asked how he had accumulated so many miles in such a short time. The owner said that he was a traveling salesperson with a territory of "east of the Mississippi River."

Because the vehicle looked to be in new condition, the technician asked the salesperson how often he had the oil changed. The salesperson smiled and said proudly, "Every Friday."

Many fleet vehicles put on over 2,000 miles per week. How about changing their oil based on the time since last changed instead of by mileage?

STEP 7 Refill the engine with the proper type, grade, and quantity of oil. Restart the engine and allow the engine to idle until it develops oil pressure; then check the engine for leaks, especially at the oil filter.



1 Before entering the customer's car for the first time, be sure to install a seat cover as well as a steering wheel cover to protect the vehicle's interior.



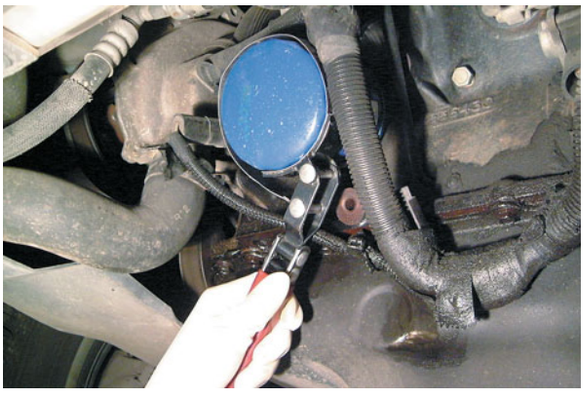
2 Run the engine until it is close to operating temperature. This will help the used oil drain more quickly and thoroughly.



3 Raise the vehicle on a hoist, and place the oil drain container in position under the oil drain plug. Be sure to wear protective gloves.



4 Remove the plug and allow the hot oil to drain from the engine. Use caution during this step as hot oil can cause painful burns!



5 While the engine oil continues to drain, remove the engine oil filter using a filter wrench. Some oil will drain from the filter, so be sure to have the oil drain container underneath when removing it.



6 Compare the new oil filter with the old one to be sure that it is the correct replacement.

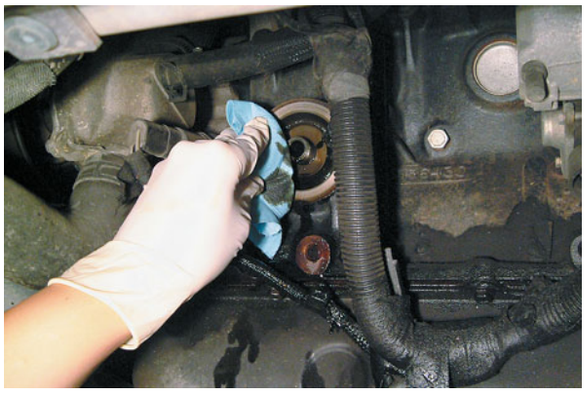
CONTINUED ▶



7 The wise service technician adds oil to the oil filter whenever possible. This provides faster filling of the filter during start-up and a reduced amount of time that the engine does not have oil pressure.



8 Apply a thin layer of clean engine oil to the gasket of the new filter. This oil film will allow the rubber gasket to slide and compress as the oil filter is being tightened.



9 Clean the area where the oil filter gasket seats to be sure that no part of the gasket remains that could cause an oil leak if not fully removed.



10 Install the new oil filter and tighten it by hand. Do not use an oil filter wrench to tighten the filter! Most filters should be tightened 3/4 of a turn after the gasket contacts the engine.



11 Carefully inspect the oil drain plug and gasket. Replace the gasket as needed. Install the drain plug and tighten firmly but do not overtighten!



12 Lower the vehicle and clean around the oil fill cap before removing it.



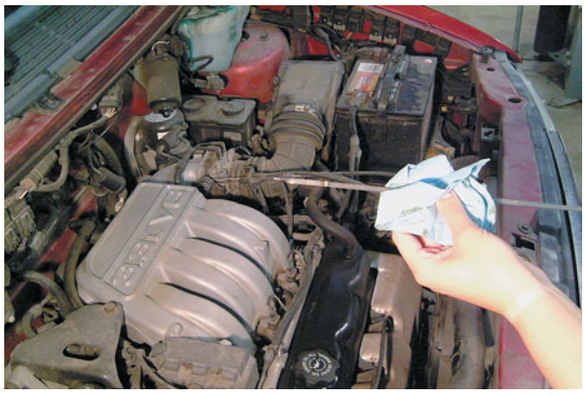
13 Use a funnel to add the specified amount of oil to the engine at the oil fill opening. When finished, replace the oil fill cap.



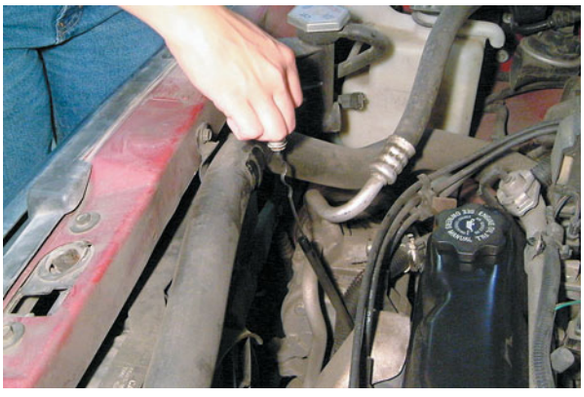
14 Start the engine and allow it to idle while watching the oil pressure gauge and/or oil pressure warning lamp. Oil pressure should be indicated within 15 seconds of starting the engine.



15 Stop the engine and let it sit for a few minutes to allow the oil to drain back into the oil pan. Look underneath the vehicle to check for any oil leaks at the oil drain plug(s) or oil filter.



16 Remove the oil-level dipstick and wipe it clean with a shop cloth.



17 Reinstall the oil-level dipstick. Remove the dipstick a second time and read the oil level.



18 The oil level should be between the MIN and the MAX lines. In this case, the oil level should be somewhere in the cross-hatched area of the dipstick.

REVIEW QUESTIONS

1. What property of oil does the SAE ratings reflect?
2. List the vehicle manufacturer's oil specifications.
3. Why is the oil filter bypassed when the engine oil is cold and thick?
4. What are the steps in performing an oil change?

CHAPTER QUIZ

1. The "W" in SAE 5W-20 means _____.
   a. Weight **c.** With
   b. Winter **d.** Without
2. Oil change intervals as specified by the vehicle manufacturer _____.
   a. Are *maximum* time and mileage intervals
   b. Are *minimum* time and mileage intervals
   c. Only include miles driven between oil changes
   d. Generally only include time between oil changes
3. Most conventional (mineral) oil is made from what API group?
   a. Group I **c.** Group III
   b. Group II **d.** Group IV or V
4. Which rating is the ACEA rating specified for use by many European vehicle manufacturers?
   a. SAE **c.** SM
   b. A3/B3 **d.** GF-4
5. Technician A says that the engine oil used should meet the vehicle manufacturer's standards. Technician B says that the specified viscosity of oil be used. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. Technician A says that some vehicle manufacturers recommend an ILSAC grade be used in the engine. Technician B says that an oil with the specified API rating *and* SAE viscosity rating should be used in an engine. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. Two technicians are discussing oil filters. Technician A says that the oil will remain perfectly clean if just the oil filter is changed regularly. Technician B says that oil filters can filter particles smaller than the human eye can see. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. The purpose of the oil filter bypass valve is to _____.
   a. Allow oil to bypass the filter if the filter becomes clogged
   b. Keep the oil from draining out of the filter when the engine is off and the oil pressure drops to zero
   c. Allows oil to bypass the oil filter when the oil is hot, to help cool the oil
   d. Both a and b
9. Different brands of oil can be used in a vehicle from one oil change to another if they meet the vehicle specifications, because all oil is _____.
   a. The same API group
   b. Miscible
   c. Of the same viscosity
   d. Both a and c
10. Older engines that use flat-bottom lifers should use oil (or an additive) that has enough _____.
    a. Viscosity
    b. ZDDP (zinc)
    c. Polyalpholefin (POA)
    d. Diesters

chapter 23

LUBRICATION SYSTEM OPERATION AND DIAGNOSIS

OBJECTIVES: After studying Chapter 23, the reader should be able to: • Prepare for ASE Engine Repair (A1) certification test content area "D" (Lubrication and Cooling Systems Diagnosis and Repair). • Explain hydrodynamic lubrication. • Describe how the oil pump and engine lubrication work. • Discuss how oil flows to the valve train components. • Explain how to inspect an oil pump for wear.

KEY TERMS: Boundary lubrication 211 • Cavitate 213 • Dry sump 217 • Gallery 215 • Gerotor 213 • Hydrodynamic lubrication 211 • Positive displacement pumps 212 • Pressure regulating valve 213 • Sump 217 • Wet sump 217 • Windage tray 217

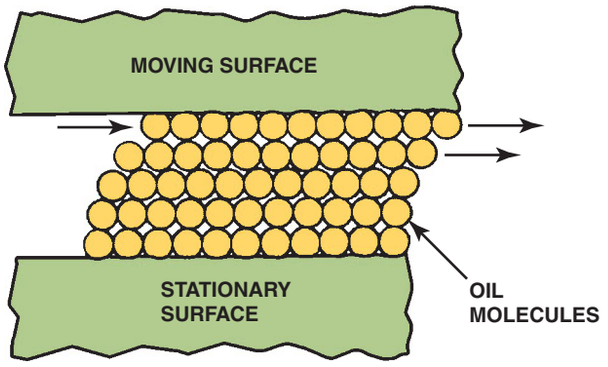


FIGURE 23–1 Oil molecules cling to metal surfaces but easily slide against each other.

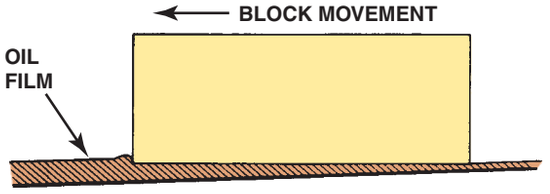


FIGURE 23–2 Wedge-shaped oil film developed below a moving block.

INTRODUCTION

Engine oil is the lifeblood of any engine. The purposes of a lubrication system include the following:

1. Lubricating all moving parts to prevent wear
2. Helping to cool the engine
3. Helping to seal piston rings
4. Cleaning, and holding dirt in suspension in the oil until it can be drained from the engine
5. Neutralizing acids that are formed as the result of the combustion process
6. Reducing friction
7. Preventing rust and corrosion

LUBRICATION PRINCIPLES

PURPOSE AND FUNCTION Lubrication between two moving surfaces results from an oil film that separates the surfaces and supports the load. ● **SEE FIGURE 23–1**.

Although oil does not compress, it does leak out around the oil clearance between the shaft and the bearing. In some cases, the oil film is thick enough to keep the surfaces from seizing, but can allow some contact to occur. This condition is called **boundary lubrication.** The specified oil viscosity and oil clearances must be adhered to during service to help prevent boundary lubrication and wear from occurring, which usually happens when the engine is under a heavy load and low speeds. The movement of the shaft helps prevent contact with the bearing. If oil were put on a flat surface and a heavy block were pushed across the surface, the block would slide more easily than if it were pushed across a dry surface. The reason for this is that a wedge-shaped oil film is built up between the moving block and the surface, as illustrated in ● **FIGURE 23–2**.

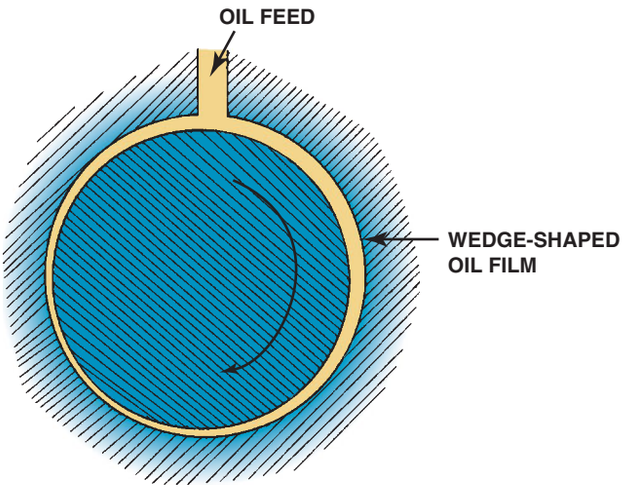


FIGURE 23–3 Wedge-shaped oil film curved around a bearing journal.

HYDRODYNAMIC LUBRICATION This wedging action is called **hydrodynamic lubrication,** and depends on the force applied to the rate of speed between the objects and the thickness of the oil. Thickness of oil is called the *viscosity,* and is defined as the ability of the oil to resist flow. High-viscosity oil is thick and low-viscosity oil is thin.

- The prefix *hydro-* refers to liquids, as in hydraulics.
- The term *dynamic* refers to moving materials.

Hydrodynamic lubrication occurs when a wedge-shaped film of lubricating oil develops between two surfaces that have relative motion between them. ● **SEE FIGURE 23–3**.

The engine oil pressure system feeds a continuous supply of oil into the lightly loaded part of the bearing oil clearance. Hydrodynamic lubrication takes over as the shaft rotates in the bearing to produce a wedge-shaped hydrodynamic oil film that is curved around the bearing. The pressure between the bearings and the crankshaft can exceed 1,000 PSI (6,900 kPa) due to hydrodynamic lubrication, as created by the wedging action between the bearing and the crankshaft journal. Most bearing wear occurs during the initial start-up, and continues until a hydrodynamic film is established.

ENGINE LUBRICATION SYSTEMS

PURPOSE AND FUNCTION The primary function of the engine lubrication system is to maintain a positive and continuous oil supply to the bearings. Engine oil pressure must be high enough to get the oil to the bearings with enough force to cause the oil flow that is required for proper cooling.

NORMAL OIL PRESSURE The normal engine oil pressure range is from 10 to 60 PSI (200 to 400 kPa) or 10 PSI per 1000 engine RPM. It is normal to see the following:

- Higher oil pressure when the engine is cold due to the oil being cold and at a higher viscosity
- Lower oil pressure when the engine is at normal operating temperature due to the oil becoming thinner even though it is multiviscosity oil



FIGURE 23–4 The dash oil pressure gauge may be a good indicator of engine oil pressure. If there is any concern about the oil pressure, always use a mechanical gauge to be sure.

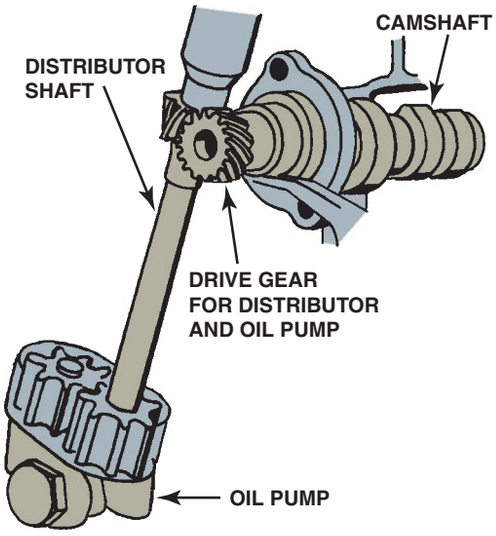


FIGURE 23–5 An oil pump driven by the camshaft.

- Lower oil pressures at idle and higher pressures at higher engine speeds because oil pumps are "positive displacement" pumps

The relatively low engine oil pressures obviously could not support these high bearing loads without hydrodynamic lubrication. Oil pressure measurements only show the oil pump pressure and not the pressure created between the bearings and the crankshaft journal due to hydrodynamic forces. ● **SEE FIGURE 23–4**.

OIL TEMPERATURE Excessive temperatures, either too low or too high, are harmful to any engine. If the oil is too cold, it could be too thick to flow through the oil passages and lubricate all engine parts. If the oil is too hot, it could become too thin to provide the film strength necessary to prevent metal-to-metal contact and wear. Estimated oil temperature can be determined with the following formula.

Estimated oil temperature = Outside air temperature + 120°F

For example, 90°F outside air temperature + 120°F = 210°F estimated oil temperature.

During hard acceleration (or high-power demand activities such as trailer towing), the oil temperature will quickly increase. Oil temperature should not exceed 300°F (150°C).

OIL PUMPS

PURPOSE AND FUNCTION All production automobile engines have a full-pressure oil system. The oil pump is required to:

- Provide 3 to 6 gallons per minute of engine oil to lubricate the engine
- Maintain pressure, by forcing the oil into the lubrication system under pressure

PARTS AND OPERATION In most engines that use a distributor, the distributor drive gear meshes with a gear on the camshaft, as shown in ● **FIGURE 23–5**.

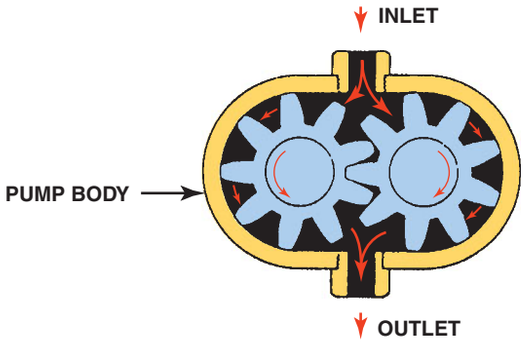


FIGURE 23–6 In an external gear-type oil pump, the oil flows through the pump around the outside of each gear. This is an example of a positive displacement pump, wherein everything entering the pump must leave the pump.

The oil pump is driven from the end of the distributor shaft, often with a hexagon-shaped shaft. Some engines have a short shaft with a gear that meshes with the cam gear to drive both the distributor and oil pump. With a distributor-driven oil pump, the pump turns at one-half engine speed. On crankshaft-driven oil pump systems, the oil pump assembly is often made as part of the engine's front cover so that it turns at the same speed as the crankshaft.

TYPES OF OIL PUMPS All oil pumps are called **positive displacement pumps,** and each rotation of the pump delivers the same volume of oil; therefore, everything that enters must exit. Also a positive displacement pump will deliver more oil and higher pressure as the speed of the pump increases. Most automotive engines use one of two types of oil pumps, either gear or rotor.

- **External gear type.** A gear-type oil pump is usually driven by a shaft from the distributor, which is driven by the camshaft. As a result, this type of pump rotates at half engine (crankshaft) speed. The gear-type oil pump consists of two spur gears in a close-fit housing—one gear is driven while the other idles. As the gear teeth come out of mesh, they tend to leave a space, which is filled by oil drawn through the pump inlet. When the pump is pumping, oil is carried around the *outside* of each gear in the space between the gear teeth and the housing. As the teeth mesh in the center, oil is forced from the teeth into an oil passage, thus producing oil pressure. ● **SEE FIGURE 23–6**.

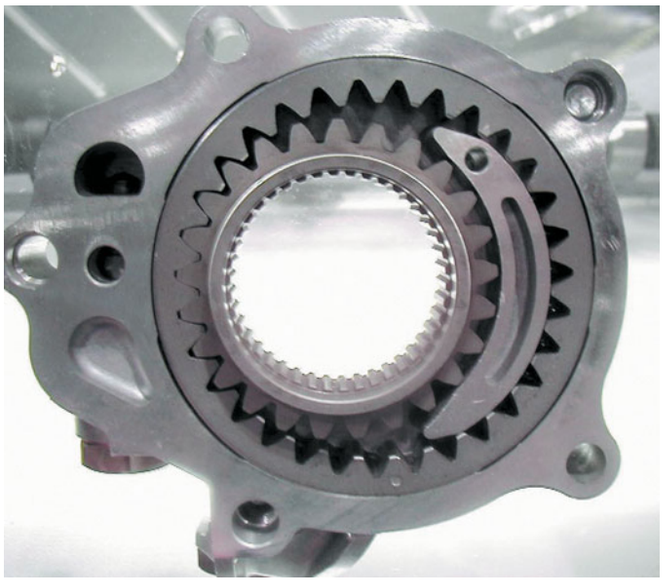
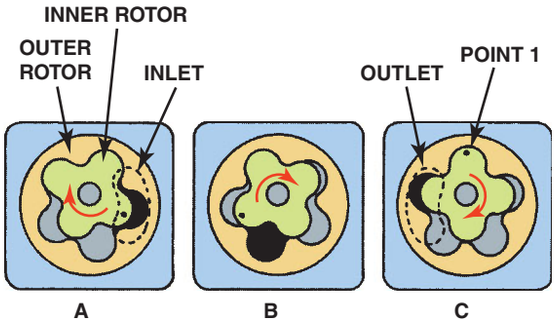


FIGURE 23–7 A typical internal/external oil pump mounted in the front cover of the engine that is driven by the crankshaft.



A. OIL IS PICKED UP IN LOBE OF OUTER ROTOR.
B. OIL IS MOVED IN LOBE OF OUTER ROTOR TO OUTLET.
C. OIL IS FORCED OUT OF OUTLET BECAUSE THE INNER AND OUTER ROTORS MESH TOO TIGHTLY AT POINT 1 AND THE OIL CANNOT PASS THROUGH.

FIGURE 23–8 The operation of a rotor-type oil pump.

- **Internal/external gear type.** This type of oil pump is driven by the crankshaft and operates at engine speed. In this style of oil pump, two gears and a crescent stationary element are used. ● **SEE FIGURE 23–7**.
- **Rotor type.** This rotor-type oil pump is driven by the crankshaft and uses a special lobe-shape gear meshing with the inside of a lobed rotor. The center lobed section is driven and the outer section idles. As the lobes separate, oil is drawn in just as it is drawn into gear-type pumps. As the pump rotates, it carries oil around and between the lobes. As the lobes mesh, they force the oil out from between them under pressure in the same manner as the gear-type pump. The pump is sized so that it will maintain a pressure of at least 10 PSI (70 kPa) in the oil gallery when the engine is hot and idling. Pressure will increase because the engine-driven pump also rotates faster. ● **SEE FIGURE 23–8**.
- **Gerotor type.** This type of positive displacement oil pump uses an inner and an outer rotor. The term is derived from two words: "*ge*nerated *rotor,*" or **gerotor.** The inner rotor has one fewer teeth than the outer rotor and both rotate. ● **SEE FIGURE 23–9**.

OIL PRESSURE REGULATION

In engines with a full-pressure lubricating system, maximum pressure is limited with a pressure

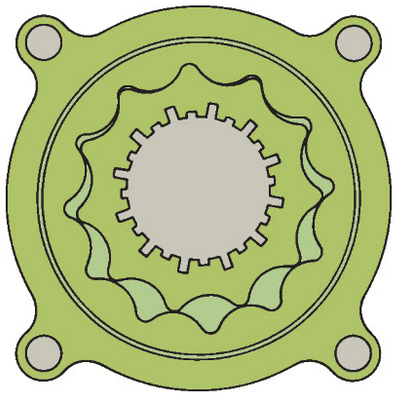


FIGURE 23–9 Gerotor-type oil pump driven by the crankshaft.

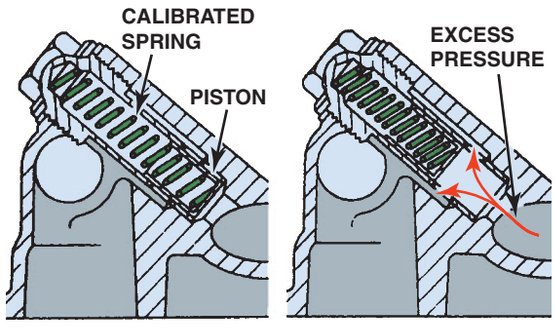


FIGURE 23–10 Oil pressure relief valves are spring loaded. The stronger the spring tension, the higher the oil pressure.

relief valve. The relief valve (sometimes called the **pressure regulating valve**) is located at the outlet of the pump. The relief valve controls maximum pressure by bleeding off oil to the inlet side of the pump. ● **SEE FIGURE 23–10**.

The relief valve spring tension determines the maximum oil pressure. If a pressure relief valve is not used, the engine oil pressure will continue to increase as the engine speed increases. Maximum pressure is usually limited to the lowest pressure that will deliver enough lubricating oil to all engine parts that need to be lubricated.

The oil pump is made so that it is large enough to provide pressure at low engine speeds and small enough that it will not **cavitate** at high speed. Cavitation occurs when the pump tries to pull oil faster than it can flow from the pan to the pickup. When it cannot get enough oil, it will pull air. This puts air pockets or cavities in the oil stream. A pump is cavitating when it is pulling air or vapors.

NOTE: The reason for sheet metal covers over the pickup screen is to prevent cavitation. Oil is trapped under the cover, which helps prevent the oil pump from drawing in air, especially during sudden stops or during rapid acceleration.

After the oil leaves the pump, it first flows through the oil filter and then is delivered to the moving parts through drilled oil passages. ● **SEE FIGURE 23–11**.

FACTORS AFFECTING OIL PRESSURE

Oil pressure can only be produced when the oil pump has a capacity larger than all the "leaks" in the engine.

- **Leaks.** The leaks are the clearances at end points of the lubrication system. The end points are at the edges of bearings, the rocker arms, the connecting rod spit holes, and so on. These clearances are designed into the engine and are necessary for its proper operation. As the engine parts wear

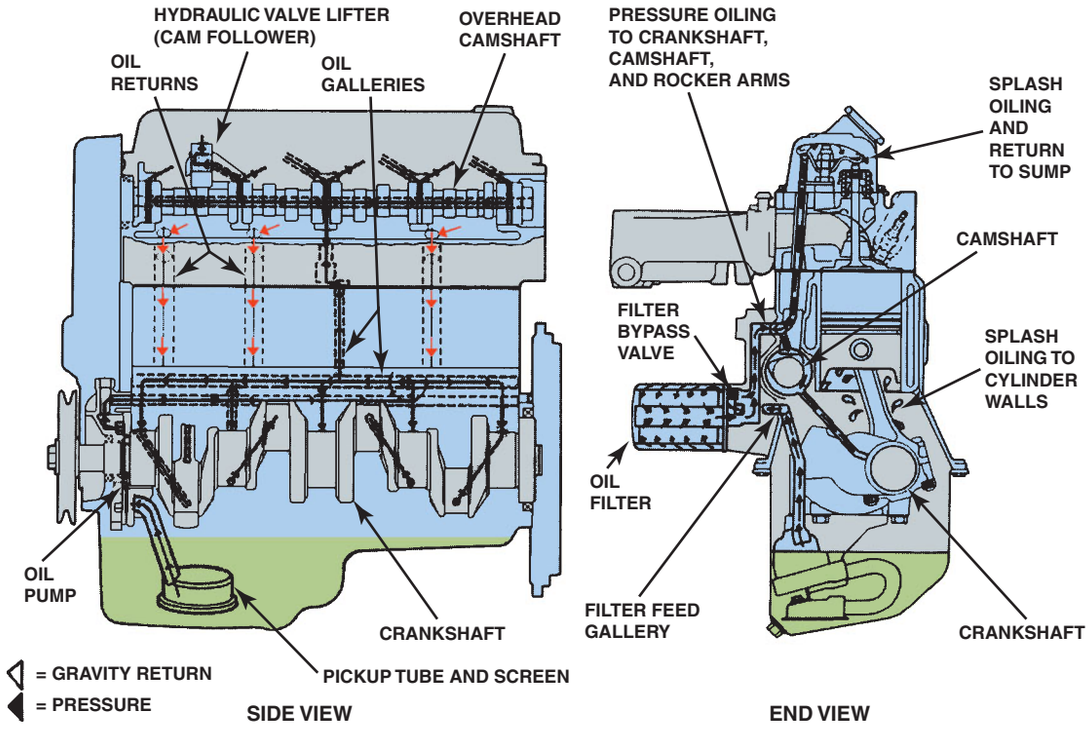


FIGURE 23–11 A typical engine design that uses both pressure and splash lubrication. Oil travels under pressure through the galleries (passages) to reach the top of the engine. Other parts are lubricated as the oil flows back down into the oil pan or is splashed onto parts.

? FREQUENTLY ASKED QUESTION

Is a High-Pressure or High-Volume Oil Pump Needed?

No. Engine parts need pressure after the oil reaches the parts that are to be lubricated. The oil film between the parts is developed and maintained by hydrodynamic lubrication. Excessive oil pressure requires more horsepower and provides no better lubrication than the minimum effective pressure. A high-volume pump is physically larger and pumps more oil with each revolution. A high-volume pump is used mostly in race engines where the main and rod bearing clearances are much greater than normal and therefore would need a great volume of oil to make up for the oil leaking from the wide clearances.

and clearance becomes greater, more oil will leak out. In other words, worn main or rod bearings are often the cause of lower than normal oil pressure.

- **Oil pump capacity.** The oil pump must supply extra oil for any leaks. The capacity of the oil pump results from its size, rotating speed, and physical condition. When the pump is rotating slowly as the engine idles, oil pump capacity is low. *If the leaks are greater than the pump capacity, engine oil pressure is low.* As the engine speed increases, the pump capacity increases and the pump tries to force more oil out of the leaks. This causes the pressure to rise until it reaches the regulated maximum pressure.

NOTE: A clogged oil pump pickup screen can cause lower than normal oil pressure because the amount of oil delivered by the pump is reduced by the clogged screen.

- **Viscosity of the engine oil.** The viscosity of the oil affects both the pump capacity and the oil leakage. Thin oil or oil of very low viscosity slips past the edges of the pump and flows freely from the leaks. Hot oil has a low viscosity, and therefore, a hot engine often has low oil pressure. Cold oil is more viscous (thicker) than hot oil. This results in higher pressures, even with the cold engine idling. High oil pressure occurs with a cold engine, because the oil relief valve must open farther to release excess oil than is necessary with a hot engine. This larger opening increases the spring compression force, which in turn increases the oil pressure. Putting higher viscosity oil in an engine will raise the engine oil pressure to the regulated setting of the relief valve at a lower engine speed.

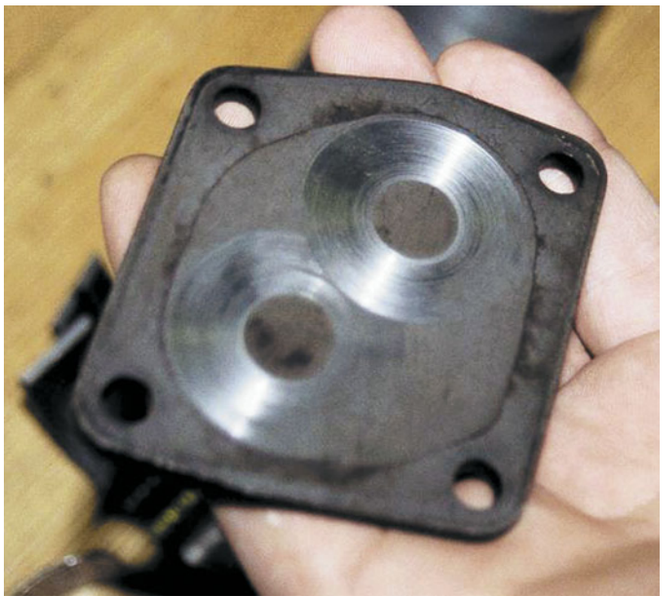
OIL PUMP CHECKS

The cover is removed to check the condition of the oil pump.

- **Visual inspection.** The gears and housing are examined for scoring. If the gears and housing are heavily scored, the entire pump should be replaced. ● **SEE FIGURE 23–12.**
- **Measurements.** If they are lightly scored, the clearances in the pump should be measured. These clearances include the space between the gears and housing, the space between the teeth of the two gears, and the space between the side of the gear and the pump cover. A feeler gauge is often used to make these measurements. Gauging plastic can be used to measure the space between the side of the gears and the cover. The oil pump should be replaced when excessive clearance or scoring is found.

On most engines, the oil pump should be replaced as part of any engine work, especially if the cause for the repair is lack of lubrication.

NOTE: The oil pump is the "garbage pit" of the entire engine. Any and all debris is often forced through the gears and housing of an oil pump. ● **SEE FIGURE 23–13.**



(a)



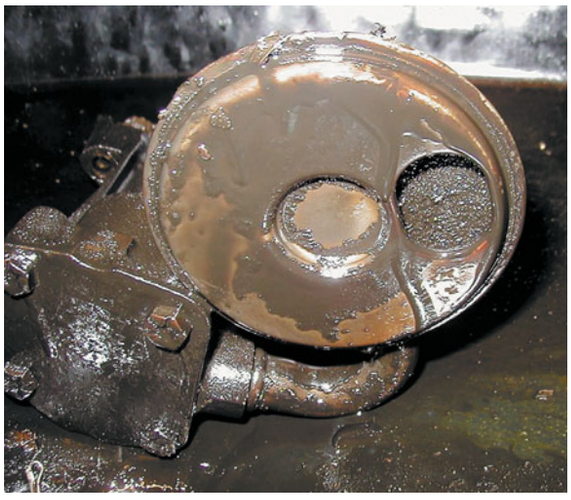
(b)

FIGURE 23–12 (a) A visual inspection indicated that this pump cover was worn. (b) An embedded particle of something was found on one of the gears, making this pump worthless except for scrap metal.

Always refer to the manufacturer's specifications when checking the oil pump for wear. Typical oil pump clearances include the following:

1. End plate clearance: 0.0015 in. (0.04 mm)
2. Side (rotor) clearance: 0.012 in. (0.30 mm)
3. Rotor tip clearance: 0.010 in. (0.25 mm)
4. Gear end play clearance: 0.004 in. (0.10 mm)

All parts should also be inspected closely for wear. Check the relief valve for scoring and check the condition of the spring. When installing the oil pump, coat the sealing surfaces with engine assembly lubricant. This lubricant helps draw oil from the oil pan on initial start-up.



(a)



(b)

FIGURE 23–13 (a) The oil pump is the only part in an engine that gets unfiltered engine oil. The oil is drawn up from the bottom of the oil pan and is pressurized before flowing to the oil filter. (b) If debris gets into an oil pump, the drive or distributor shaft can twist and/or break. When this occurs, the engine will lose all oil pressure.

OIL PASSAGES

PURPOSE AND FUNCTION Oil from the oil pump first flows through the oil filter then goes through a drilled hole that intersects with a drilled main oil **gallery,** or longitudinal header. This is a long hole drilled from the front of the block to the back.

- Inline engines use one oil gallery.
- V-type engines may use two or three galleries.

Passages drilled through the block bulkheads allow the oil to go from the main oil gallery to the main and cam bearings. ● **SEE FIGURE 23–14**.

In some engines, oil goes to the cam bearings first, and then to the main bearings. It is important that the oil holes in the bearings match with the drilled passages in the bearing saddles so that the bearing can be properly lubricated. Over a long period of use, bearings will wear. This wear causes excess clearance. The excess clearance will allow too much oil to leak from the side of the bearing. When this happens, there will be little or no oil left for bearings located farther downstream in the lubricating system. This is a major cause of bearing failure. To aid in bearing failure diagnosis, on most engines, the last rod bearing to receive oil pressure is typically the bearing farthest from the oil pump. If this bearing fails, then suspect low oil pressure as the probable cause.

TECH TIP

The New Hemi Engine Oiling System

The Chrysler Hemi V-8 engine uses a unique oiling system because the valve lifters are fed oil from the top of the cylinder heads and through the pushrods. While it is normal to have oil flowing through hollow pushrods, it is unique that in the Hemi V-8 the oil flows backward from normal and from the head *down* the hollow pushrods to the lifters. Be sure to use the specified viscosity of oil, as this is critical for proper lubrication of the valve lifters.

VALVE TRAIN LUBRICATION

The oil gallery may intersect or have drilled passages to the valve lifter bores to lubricate the lifters. When hydraulic lifters are used, the oil pressure in the gallery keeps refilling them. On some engines, oil from the lifters goes up the center of a hollow pushrod to lubricate the pushrod ends, the rocker arm pivot, and the valve stem tip. In other engines, an oil passage is drilled from either the gallery or a cam bearing to the block deck, where it matches with a head gasket hole and a hole drilled in the head to carry the oil to a rocker arm shaft. Some engines use an enlarged bolt hole to carry lubrication oil around the rocker shaft cap screw to the rocker arm shaft.

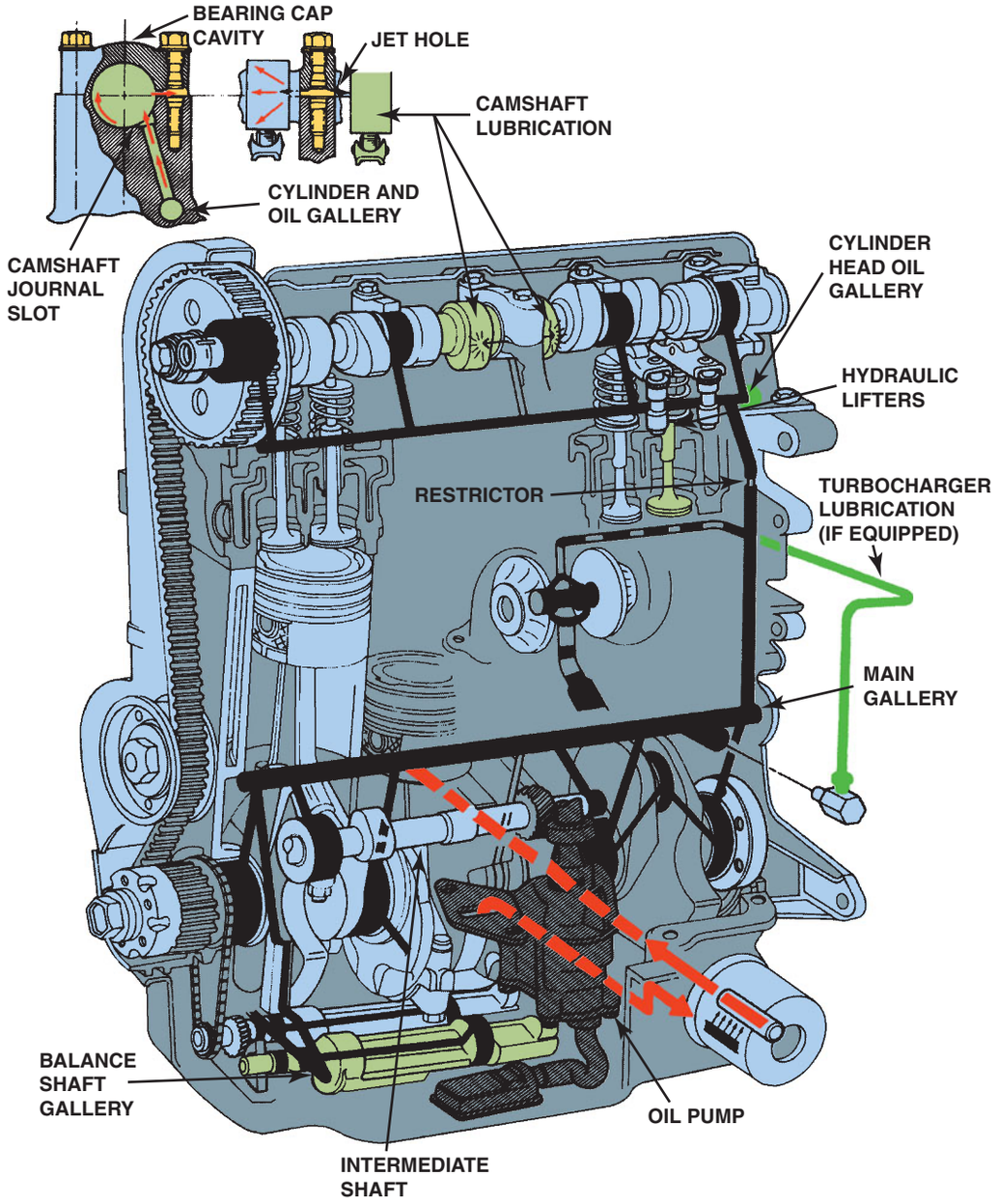


FIGURE 23–14 An intermediate shaft drives the oil pump on this overhead camshaft engine. Note the main gallery and other drilled passages in the block and cylinder head.

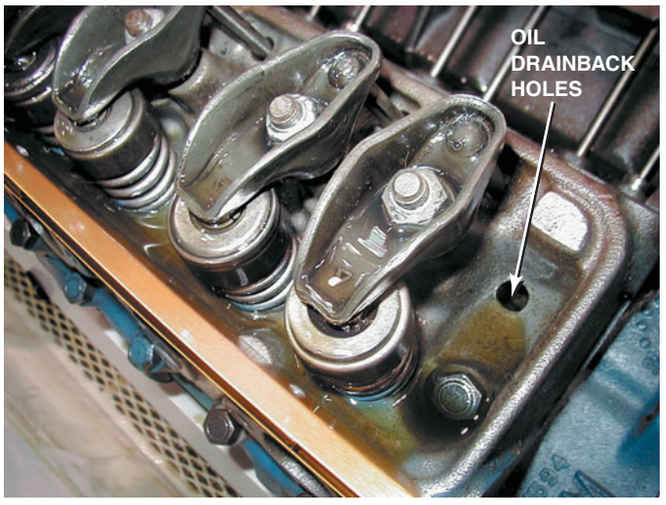


FIGURE 23–15 Oil is sent to the rocker arms on this Chevrolet V-8 engine through the hollow pushrods. The oil returns to the oil pan through the oil drainback holes in the cylinder head.

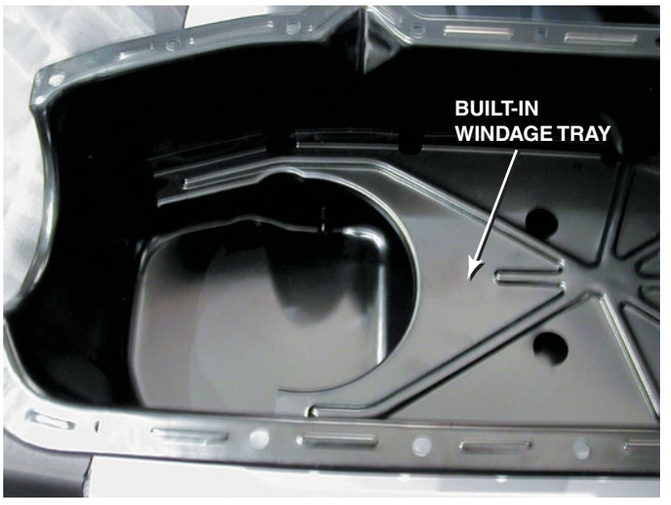


FIGURE 23–16 A typical oil pan with a built-in windage tray used to keep oil from being churned up by the rotating crankshaft.

Holes in the bottom of the rocker arm shaft allow lubrication of the rocker arm pivot. Rocker arm assemblies need only a surface coating of oil, so the oil flow to the rocker assembly is minimized using restrictions or metered openings. The restriction or metering disk is in the lifter when the rocker assembly is lubricated through the pushrod. Oil that seeps from the rocker assemblies is returned to the oil pan through drain holes. These oil drain holes are often placed so that the oil drains on the camshaft or cam drive gears to lubricate them. Oil drain holes can be either machined or cast into the cylinder heads and block. ● **SEE FIGURE 23–15**.

Some engines have means of directing a positive oil flow to the cam drive gears or chain. This may include either of the following:

- Nozzle
- Chamfer on a bearing parting surface, which allows oil to spray on the loaded portion of the cam drive mechanism

OIL PANS

PURPOSE AND FUNCTION

The oil pan is where engine oil is used for lubricating the engine. Another name for the oil pan is a **sump**. As the vehicle accelerates, brakes, or turns rapidly, the oil tends to move around in the pan. Pan baffles and oil pan shapes are often used to keep the oil inlet under the oil at all times. As the crankshaft rotates, it acts like a fan and causes air within the crankcase to rotate with it. This can cause a strong draft on the oil, churning it so that air bubbles enter the oil, which then causes oil foaming. Oil with air will not lubricate like liquid oil, so oil foaming can cause bearings to fail. A baffle or **windage tray** is sometimes installed in engines to eliminate the oil churning problem. This may be an added part, as shown in ● **FIGURE 23–16,** or it may be a part of the oil pan.

Windage trays have the good side effect of reducing the amount of air disturbed by the crankshaft, so that less power is drained from the engine at high crankshaft speeds.

DRY SUMP SYSTEM

CONSTRUCTION AND OPERATION

The term *sump* is used to describe a location where oil is stored or held. In most engines, oil is held in the oil pan and the oil pump draws the oil from the bottom. This type of system is called a **wet sump** oil system. In a **dry sump** system, the oil pan is shallow and the oil is pumped into a remote reservoir. In this reservoir, the oil is cooled and any trapped air is allowed to escape before being pumped back to the engine. A dry sump system uses an externally mounted oil reservoir.

? FREQUENTLY ASKED QUESTION

Why Is It Called a Windage Tray?

A windage tray is a plate or baffle installed under the crankshaft and is used to help prevent aeration of the oil. Where does the wind come from? Pistons push air down into the crankcase as they move from top dead center to bottom dead center. The pistons also draw air and oil upward when moving from bottom dead center to top dead center. At high engine speeds, this causes a great deal of airflow, which can easily aerate the oil. Therefore, a windage tray is used to help prevent this movement of air (wind) from affecting the oil in the pan. Try the following:

- Take an oil pan and add a few quarts (liters) of oil.
- Then take an electric hair dryer and use it to blow air into the oil pan.

Oil will be thrown everywhere, which helps illustrate why windage trays are used in all newer engines.

ADVANTAGES

The advantages of a dry sump system are as follows:

1. A shallow oil pan allows the engine to be mounted lower in the vehicle to improve cornering.
2. The oil capacity can be greatly expanded because the size of the reservoir is not limited. A larger quantity of oil means that the oil temperature can be controlled.
3. A dry sump system allows the vehicle to corner and brake for long periods, which is not able to be done with a wet sump system due to the oil being thrown to one side and away from the oil pickup.
4. A dry sump system also allows the engine to develop more power as the oil is kept away from the moving crankshaft.

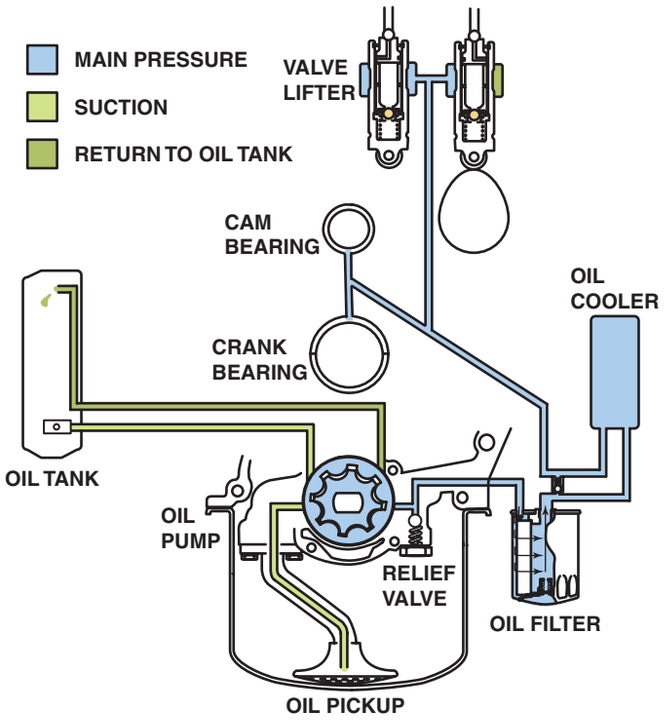


FIGURE 23–17 A dry sump system as used in a Chevrolet Corvette.

DISADVANTAGES A dry sump system has the following disadvantages.

1. The system is expensive as it requires components and plumbing not needed in a wet sump system.
2. The system is complex because the plumbing and connections, plus the extra components, result in more places where oil leaks can occur and change the way routine maintenance is handled. A dry sump oil system is used in most motor sport vehicles and is standard on certain high-performance production vehicles, such as some models of the Chevrolet Corvette, Porsche, and BMW. ● **SEE FIGURE 23–17**.

OIL COOLERS

Oil temperature must be controlled on many high-performance or turbocharged engines. A larger capacity oil pan helps to control oil temperature. Some engines use remote mounted oil coolers. Coolant flows through the oil cooler to help warm the oil when the engine is cold and cool the oil when the engine is hot. Oil temperature should be:

- Above 212°F (100°C) to boil off any accumulated moisture
- Below 280°F to 300°F (138°C to 148°C)

● **SEE FIGURE 23–18**.

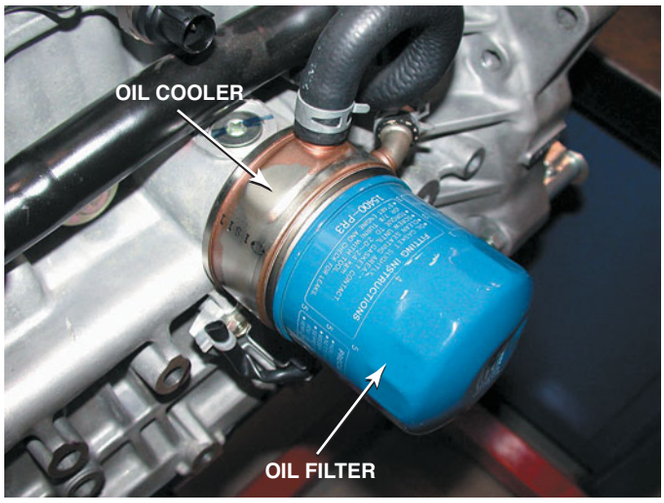


FIGURE 23–18 Oil is cooled by the flow of coolant through the oil filter adapter.

? FREQUENTLY ASKED QUESTION

What Is Acceptable Oil Consumption?

There are a number of opinions regarding what is acceptable oil consumption. Most vehicle owners do not want their engine to use *any* oil between oil changes even if they do not change it more often than every 7,500 miles (12,000 km). Engineers have improved machining operations and piston ring designs to help eliminate oil consumption.

Many stationary or industrial engines are not driven on the road, so they do not accumulate miles but still may consume excessive oil.

A general rule for "acceptable" oil consumption is that it should be about 0.002 to 0.004 pound per horsepower per hour. To figure, use the following:

$$\frac{1.82 \times \text{Quarts used}}{\text{Operating hp} \times \text{Total hours}} = \text{Pound/hp/hr}$$

Therefore, oil consumption is based on the amount of work an engine performs. Although the formula may not be viable for vehicle engines used for daily transportation, it may be for the marine or industrial engine builder. Generally, oil consumption that is greater than 1 quart for every 600 miles (1 liter per 1,000 km) is considered to be excessive with a motor vehicle.

REVIEW QUESTIONS

1. What causes a wedge-shaped film to form in the oil?
2. What is hydrodynamic lubrication?
3. Explain why internal engine leakage affects oil pressure.
4. Describe how the oil flows from the oil pump, through the filter and main engine bearings, to the valve train.
5. What is the purpose of a windage tray?

CHAPTER QUIZ

1. Normal oil pump pressure in an engine is _____ PSI.
   a. 3 to 7 **c.** 100 to 150
   b. 10 to 60 **d.** 180 to 210
2. Two technicians are discussing oil pumps. Technician A says that many oil pumps are driven directly off the front of the crankshaft. Technician B says that some are driven from the distributor if the engine uses a distributor-type ignition system. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
3. A typical oil pump can pump how many gallons per minute?
   a. 3 to 6 gallons
   b. 6 to 10 gallons
   c. 10 to 60 gallons
   d. 50 to 100 gallons
4. In typical engine lubrication systems, what components are the last to receive oil and the first to suffer from a lack of oil or oil pressure?
   a. Main bearings **c.** Valve train components
   b. Rod bearings **d.** Oil filters
5. Hydrodynamic lubrication is created by the wedging action of oil between the crankshaft journal and the bearing, can be as high as _____ PSI.
   a. 60 **c.** 500
   b. 120 **d.** 1,000
6. What type of oil pump is driven by the crankshaft?
   a. Gerotor **c.** External gear
   b. Internal/external gear **d.** Both a and b
7. Lower than specified oil pressure is measured on a high mileage engine. Technician A says that worn main or rod bearings could be the cause. Technician B says that a clogged oil pump pickup screen could be the cause. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
8. Oil passages in an engine block are usually called _____.
   a. Galleries **c.** Runners
   b. Holes **d.** Pathways
9. Why is a dry sump system used in some high-performance vehicles?
   a. It allows the vehicle to corner or brake for long periods
   b. It allows the engine to develop more power
   c. It allows for a greater oil capacity so that oil temperatures can be controlled
   d. All of the above
10. An engine oil cooler uses what to cool the oil?
    a. Coolant
    b. Air
    c. Air-conditioning evaporator output
    d. Automatic transmission fluid after it flows through the radiator

chapter 24 INTAKE AND EXHAUST SYSTEMS

OBJECTIVES: **After studying Chapter 24, the reader should be able to:** • Prepare for ASE Engine Performance (A8) certification test content area "C" (Air Induction and Exhaust Systems Diagnosis and Repair). • Discuss the purpose and function of intake air system components. • Explain the differences between throttle-body fuel-injection manifolds and port fuel-injection manifolds. • List the materials used in exhaust manifolds and exhaust systems. • Describe the purpose and function of the exhaust system components.

KEY TERMS: EGR 223 • Hangers 226 • Helmholtz resonator 221 • Micron 220 • Plenum 223

AIR INTAKE FILTRATION

NEED FOR AIR FILTERING Gasoline must be mixed with air to form a combustible mixture. Air movement into an engine occurs due to low pressure (vacuum) being created in the engine. ● **SEE FIGURE 24–1**.

Air contains dirt and other materials that cannot be allowed to reach the engine. Just as fuel filters are used to clean impurities from gasoline, an air cleaner and filter are used to remove contaminants from the air. The three main jobs of the air cleaner and filter include:

1. Clean the air before it is mixed with fuel
2. Silence intake noise
3. Act as a flame arrester in case of a backfire

The automotive engine uses about 9,000 gallons (34,000 liters) of air for every gallon of gasoline burned at an air-fuel ratio of 14.7:1 by weight. Without proper filtering of the air before it enters the engine, dust and dirt in the air can seriously damage engine parts and shorten engine life.

Abrasive particles can cause wear any place inside the engine where two surfaces move against each other, such as piston rings against the cylinder wall. The dirt particles then pass by the piston rings and into the crankcase. From the crankcase, the particles

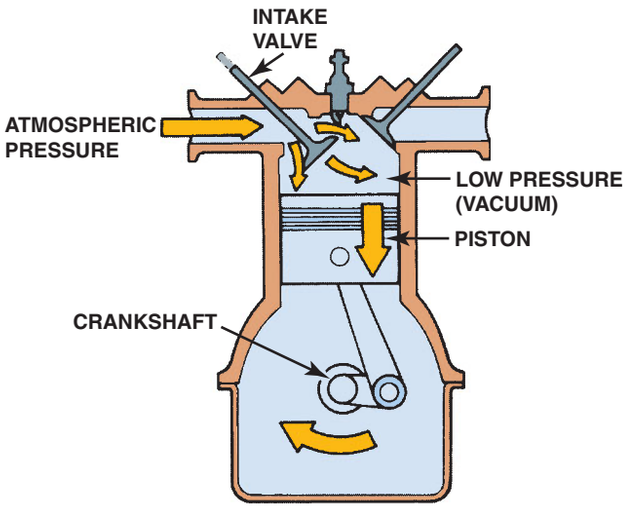


FIGURE 24–1 Downward movement of the piston lowers the air pressure inside the combustion chamber. The pressure differential between the atmosphere and the inside of the engine forces air into the engine.

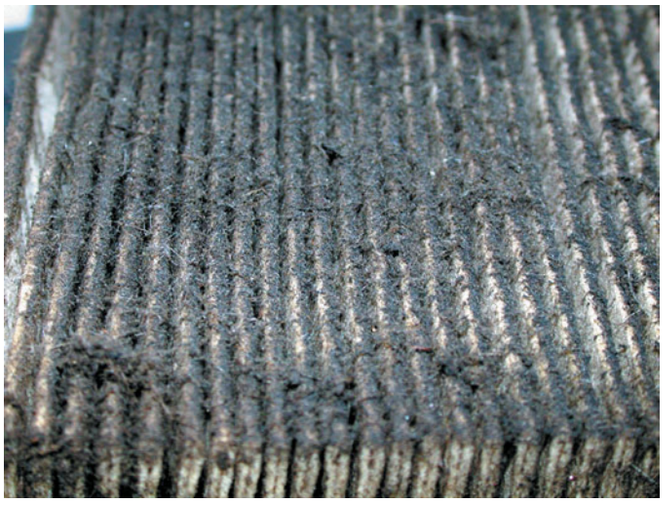


FIGURE 24–2 Dust and dirt in the air are trapped in the air filter so they do not enter the engine.

circulate throughout the engine in the oil. Large amounts of abrasive particles in the oil can damage other moving engine parts.

The filter that cleans the intake air is in a two-piece air cleaner housing made either of:

- Stamped steel or
- Composite (usually nylon reinforced plastic) materials.

AIR FILTER ELEMENTS The paper air filter element is the most common type of filter. It is made of a chemically treated paper stock that contains tiny passages in the fibers. These passages form an indirect path for the airflow to follow. The airflow passes through several fiber surfaces, each of which traps microscopic particles of dust, dirt, and carbon. Most air filters are capable of trapping dirt and other particles larger than 10 to 25 microns in size. One **micron** is equal to 0.000039 in.

NOTE: A person can only see objects that are 40 microns or larger in size. A human hair is about 50 microns in diameter.

● **SEE FIGURE 24–2.**

FILTER REPLACEMENT Manufacturers recommend cleaning or replacing the air filter element at periodic intervals, usually listed in terms of distance driven or months of service. The distance and time intervals are based on so-called normal driving. More frequent air filter replacement is necessary when the vehicle is driven under dusty, dirty, or other severe conditions.

It is best to replace a filter element before it becomes too dirty to be effective. A dirty air filter that passes contaminants can cause engine wear.



FIGURE 24–3 Most air filter housings are located on the side of the engine compartment and use flexible rubber hose to direct the airflow into the throttle body of the engine.

REMOTELY MOUNTED AIR FILTERS AND DUCTS Air cleaner and duct design depend on a number of factors such as the size, shape, and location of other engine compartment components, as well as the vehicle body structure.

Port fuel-injection systems generally use a horizontally mounted throttle body.

Some systems also have a mass airflow (MAF) sensor between the throttle body and the air cleaner. Because placing the air cleaner housing next to the throttle body would cause engine and vehicle design problems, it is more efficient to use this remote air cleaner placement. ● **SEE FIGURE 24–3.**

Turbocharged engines present a similar problem. The air cleaner connects to the air inlet elbow at the turbocharger. However, the tremendous heat generated by the turbocharger makes it impractical to place the air cleaner housing too close to the turbocharger. Remote air cleaners are connected to the turbocharger air inlet elbow or fuel-injection throttle body by composite ducting that is usually retained by clamps. The ducting used may be rigid or flexible, but all connections must be airtight.

AIR FILTER RESTRICTION INDICATOR Some vehicles, especially pickup trucks that are often driven in dusty conditions, are equipped with an air filter restriction indicator. The purpose of this device is to give a visual warning when the air filter is restricted and needs to be replaced. The device operates by detecting the slight drop in pressure that occurs when an air filter is restricted. The calibration before the red warning bar or "replace air filter" message appears varies, but is usually:

- 15 to 20 in. of water (in. H_2O) for gasoline engines
- 20 to 30 in. of water (in. H_2O) for diesel engines

The unit of inches of water is used to measure the difference in air pressure before and after the air filter. The unit is very small, because 28 in. of water is equal to a pound per square inch (PSI).

Some air filter restriction indicators, especially on diesel engines, include an electrical switch used to light a dash-mounted warning lamp when the air filter needs to be replaced. ● **SEE FIGURE 24–4.**

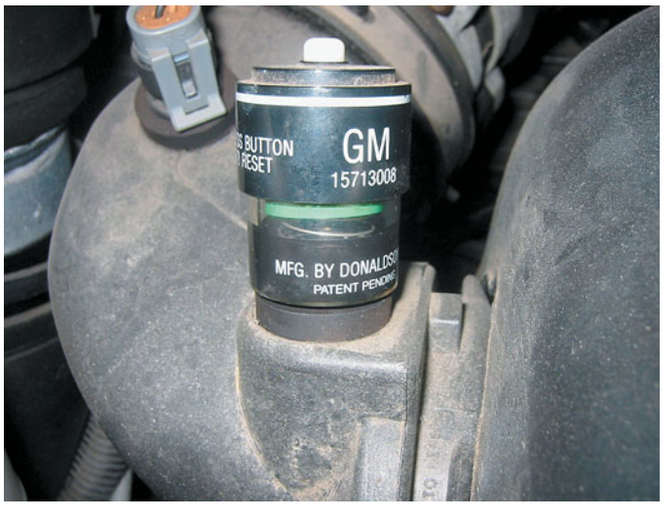
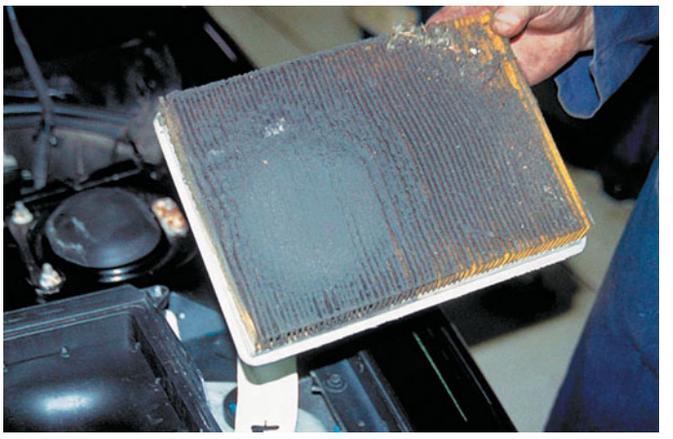


FIGURE 24–4 A typical air filter restriction indicator used on a General Motors truck engine. The indicator turns red when it detects enough restriction to require a filter replacement.



(a)



(b)

FIGURE 24–5 (a) Note the discovery as the air filter housing was opened during service on a Pontiac. The nuts were obviously deposited by squirrels (or some other animal). (b) Not only was the housing filled with nuts, but also this air filter was extremely dirty, indicating that this vehicle had not been serviced for a long time.

TECH TIP

Always Check the Air Filter

Always inspect the air filter and the air intake system carefully during routine service. Debris or objects deposited by animals can cause a restriction to the airflow and can reduce engine performance. ● **SEE FIGURE 24–5**.

FREQUENTLY ASKED QUESTION

What Does This Tube Do?

What is the purpose of the odd-shape tube attached to the inlet duct between the air filter and the throttle body, as seen in ● **FIGURE 24–6?**

The tube shape is designed to dampen out certain resonant frequencies that can occur at specific engine speeds. The length and shape of this tube are designed to absorb shock waves that are created in the air intake system and to provide a reservoir for the air that will then be released into the airstream during cycles of lower pressure. This resonance tube is often called a **Helmholtz resonator,** named for the discoverer of the relationship between shape and value of frequency, Herman L. F. von Helmholtz (1821–1894) of the University of Hönizsberg in East Prussia. The overall effect of these resonance tubes is to reduce the noise of the air entering the engine.



FIGURE 24–6 A resonance tube, called a Helmholtz resonator, is used on the intake duct between the air filter and the throttle body to reduce air intake noise during engine acceleration.

THROTTLE-BODY INJECTION INTAKE MANIFOLDS

TERMINOLOGY The *intake manifold* is also called an *inlet manifold.* Smooth engine operation can only occur when each combustion chamber produces the same pressure as every other chamber in the engine. For this to be achieved, each cylinder must receive an intake charge exactly like the charge going into the other cylinders in quality and quantity. The charges must have the same physical properties and the same air-fuel mixture.

A throttle-body fuel injector forces finely divided droplets of liquid fuel into the incoming air to form a combustible air-fuel mixture. ● **SEE FIGURE 24–7** for an example of a typical throttle-body injection (TBI) unit.



FIGURE 24–7 A throttle-body injection (TBI) unit used on a GM V-6 engine.

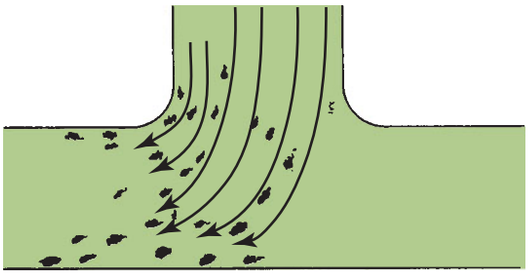


FIGURE 24–8 Heavy fuel droplets separate as they flow around an abrupt bend in an intake manifold.

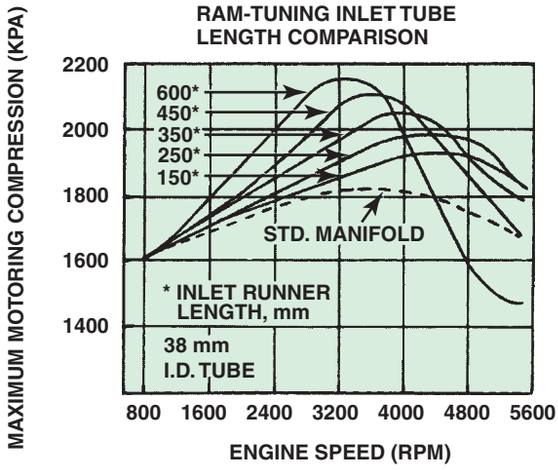


FIGURE 24–9 The graph shows the effect of sonic tuning of the intake manifold runners. The longer runners increase the torque peak and move it to a lower RPM. The 600 mm intake runner is about 24 in. long.

INTAKE AIR SPEEDS

These droplets start to evaporate as soon as they leave the throttle-body injector nozzles. *The droplets stay in the charge as long as the charge flows at high velocities.* At maximum engine speed, these velocities may reach 300 ft per second. Separation of the droplets from the charge as it passes through the manifold occurs when the velocity drops below 50 ft per second. Intake charge velocities at idle speeds are often below this value. When separation occurs—at low engine speeds—extra fuel must be supplied to the charge in order to have a combustible mixture reach the combustion chamber.

Manifold sizes and shapes represent a compromise.

- They must have a cross section large enough to allow charge flow for maximum power.
- The cross section must be small enough that the flow velocities of the charge will be high enough to keep the fuel droplets in suspension. This is required so that equal mixtures reach each cylinder. Manifold cross-sectional size is one reason why engines designed especially for racing will not run at low engine speeds.
- Racing manifolds must be large enough to reach maximum horsepower. This size, however, allows the charge to move slowly, and the fuel will separate from the charge at low engine speeds. Fuel separation leads to poor accelerator response. ● **SEE FIGURE 24–8**.

Standard passenger vehicle engines are primarily designed for economy during light-load, partial-throttle operation. Their manifolds, therefore, have a much smaller cross-sectional area than do those of racing engines. This small size will help keep flow velocities of the charge high throughout the normal operating speed range of the engine.

PORT FUEL-INJECTION INTAKE MANIFOLDS

TERMINOLOGY

The size and shape of port fuel-injected engine intake manifolds can be optimized because the only thing in the manifold is air. The fuel injector is located in the intake manifold about 3 to 4 in. (70 to 100 mm) from the intake valve. Therefore, the runner length and shape are designed for tuning only. There is no need to keep an air-fuel mixture thoroughly mixed (homogenized) throughout its trip from the TBI unit to the intake valve. Intake manifold runners are tuned to improve engine performance.

- Long runners build low-RPM torque.
- Shorter runners provide maximum high-RPM power.

● **SEE FIGURES 24–9 AND 24–10**.

VARIABLE INTAKES

Some engines with four valve heads utilize a dual or variable intake runner design. At lower engine speeds, long intake runners provide low-speed torque. At higher engine speeds, shorter intake runners are opened by means of a computer-controlled valve to increase high-speed power.

Many intake manifolds are designed to provide both short runners best for higher engine speed power and longer runners best for lower engine speed torque. The valve(s) that control the flow of air through the passages of the intake manifold are computer controlled. ● **SEE FIGURE 24–11**.

PLASTIC INTAKE MANIFOLDS

Most intake manifolds are made from thermoplastic molded from fiberglass-reinforced nylon by either casting or by injection molding. Some manifolds are molded in two parts and bonded together. Plastic intake manifolds are lighter than aluminum manifolds and can better insulate engine heat from the fuel injectors.

Plastic intake manifolds have smoother interior surfaces than do other types of manifolds, resulting in greater airflow. ● **SEE FIGURE 24–12**.

UPPER AND LOWER INTAKE MANIFOLDS

Many intake manifolds are constructed in two parts.

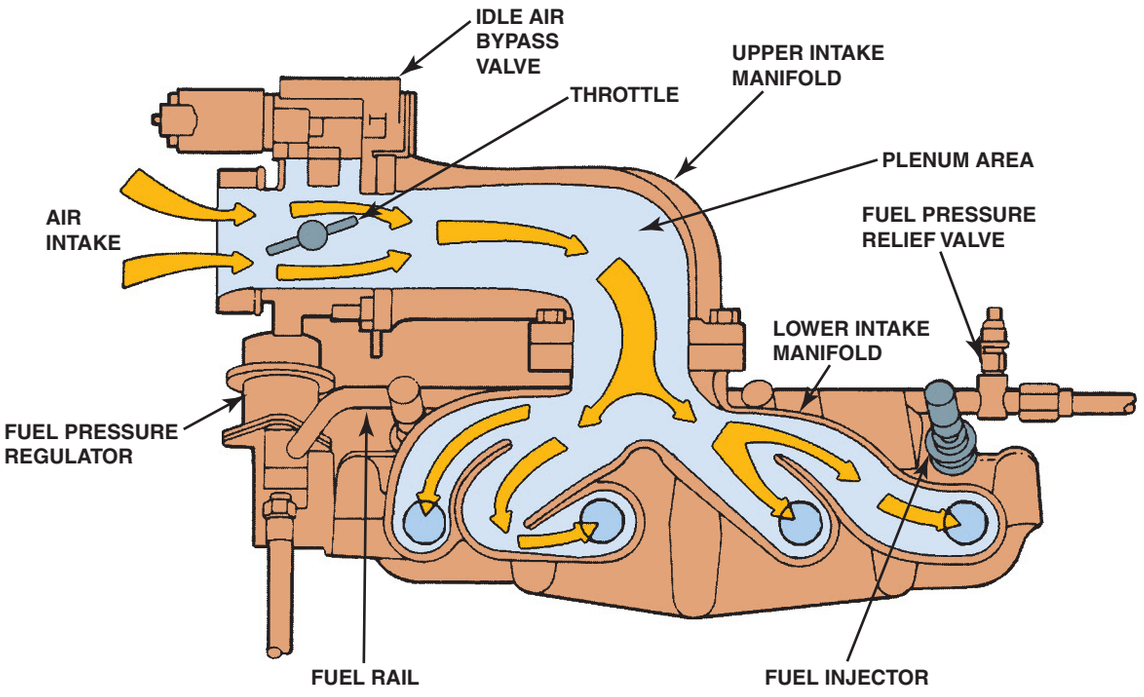


FIGURE 24–10 Airflow through the large diameter upper intake manifold is distributed to smaller diameter individual runners in the lower manifold in this two-piece manifold design.

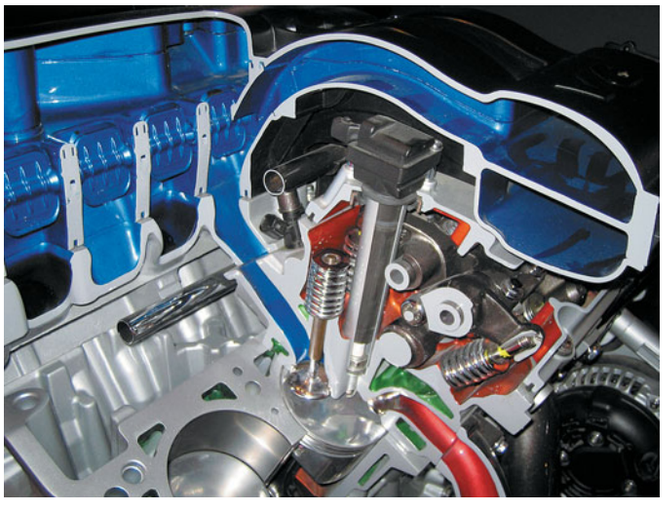


FIGURE 24–11 The air flowing into the engine can be directed through long or short runners for best performance and fuel economy.

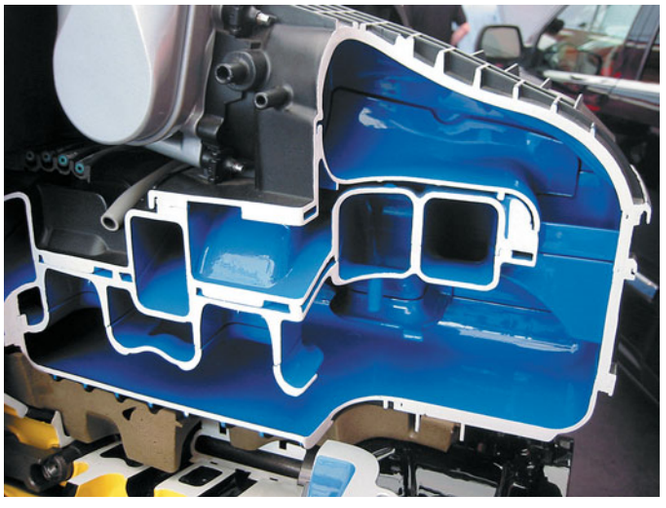


FIGURE 24–12 Many plastic intake manifolds are constructed using many parts glued together to form complex passages for airflow into the engine.

- A lower section attaches to the cylinder heads and includes passages from the intake ports.
- An upper manifold, usually called the **plenum,** connects to the lower unit and includes the long passages needed to help provide the ram effect that helps the engine deliver maximum torque at low engine speeds. The throttle body attaches to the upper intake.

The use of a two-part intake manifold allows for easier manufacturing as well as assembly, but can create additional locations for leaks.

If the lower intake manifold gasket leaks, not only could a vacuum leak occur affecting the operation of the engine, but a coolant leak or an oil leak can also occur if the manifold has coolant flowing through it. A leak at the gasket(s) of the upper intake manifold usually results in a vacuum (air) leak only.

EXHAUST GAS RECIRCULATION PASSAGES

PURPOSE AND FUNCTION To reduce the emission of oxides of nitrogen (NOx), engines have been equipped with **exhaust gas recirculation (EGR)** valves. From 1973 until recently, they were used on almost all vehicles. Most EGR valves are mounted on the intake manifold. Because of the efficiency of computer-controlled fuel injection, some newer engines do not require an EGR system to meet emission standards. These engines' variable valve timing to close the exhaust valve sooner than normal, trapping some exhaust in the cylinder, is an alternative to using an EGR valve.

On engines with EGR systems, the EGR valve opens at speeds above idle on a warm engine. When open, the valve allows a small portion of the exhaust gas (5% to 10%) to enter the intake manifold.

The EGR system has some means of interconnecting of the exhaust and intake manifolds. The EGR valve controls the gas flow through the passages.

- On V-type engines, the intake manifold crossover is used as a source of exhaust gas for the EGR system. A cast passage connects the exhaust crossover to the EGR valve.

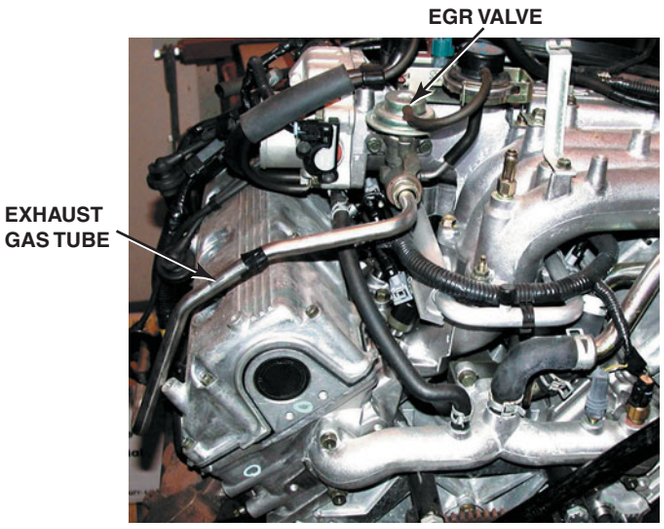


FIGURE 24–13 A typical long exhaust gas line used to cool the exhaust gases before being recirculated back into the intake manifold.

- On inline-type engines, an external tube is generally used to carry exhaust gas to the EGR valve.

EXHAUST GAS COOLERS The exhaust gases are more effective in reducing oxide of nitrogen (NOx) emissions if the exhaust is cooled before being drawn into the cylinders. This tube is often designed to be long so that the exhaust gas is cooled before it enters the EGR valve. ● **SEE FIGURE 24–13**.

EXHAUST MANIFOLDS

PURPOSE AND FUNCTION The exhaust manifold is designed to collect high-temperature spent gases from the individual head exhaust ports and direct them into a single outlet connected to the exhaust system. ● **SEE FIGURE 24–14**.

The hot gases are sent to an exhaust pipe, then to a catalytic converter, to the muffler, to a resonator, and on to the tailpipe, where they are vented to the atmosphere. The exhaust system is designed to meet the following needs.

- Provide the least possible amount of restriction or backpressure
- Keep the exhaust noise at a minimum

Exhaust gas temperature will vary according to the power produced by the engine. The manifold must be designed to operate at both engine idle and continuous full power. Under full-power conditions, the exhaust manifold can become red-hot, causing a great deal of expansion.

The temperature of an exhaust manifold can exceed 1,500°F (815°C).

CONSTRUCTION Most exhaust manifolds are made from the following:

- Cast iron
- Steel tubing

During vehicle operation, manifold temperatures usually reach the high-temperature extremes. The manifold is bolted to the head in a way that will allow expansion and contraction. In some cases, hollow-headed bolts are used to maintain a gas-tight seal while still allowing normal expansion and contraction.

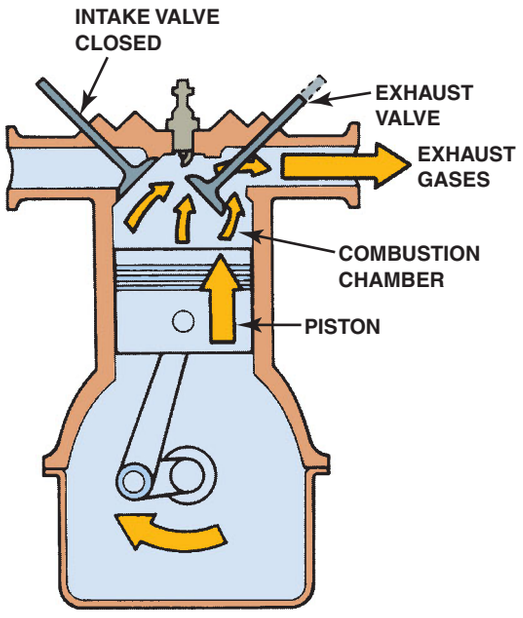


FIGURE 24–14 The exhaust gases are pushed out of the cylinder by the piston on the exhaust stroke.



FIGURE 24–15 This exhaust manifold (red area) is equipped with a heat shield to help retain heat and reduce exhaust emissions.

Many exhaust manifolds have heat shields to help keep exhaust heat off the spark plug wires and to help keep the heat from escaping to improve exhaust emissions. ● **SEE FIGURE 24–15**.

Exhaust systems are especially designed for the engine-chassis combination. The exhaust system length, pipe size, and silencer are designed, where possible, to make use of the tuning effect within the exhaust system. Tuning occurs when the exhaust pulses from the cylinders are emptied into the manifold between the pulses of other cylinders. ● **SEE FIGURE 24–16**.

EXHAUST MANIFOLD GASKETS Exhaust heat will expand the manifold more than it will expand the head. The heat causes the exhaust manifold to slide on the sealing surface of the head. The heat also causes thermal stress. When the manifold is removed from the engine for service, the stress is relieved, which may cause the manifold to warp slightly. Exhaust manifold gaskets are included in gasket sets to seal slightly warped exhaust manifolds. These gaskets *should* be used, even if the engine did not originally use exhaust manifold gaskets. When an exhaust manifold gasket has facing on one side only, put the facing side against the head and put the manifold against the perforated metal core. The manifold can slide on the metal of the gasket just as it slid on the sealing surface of the head.



FIGURE 24–16 Many exhaust manifolds are constructed of steel tubing and are free flowing to improve engine performance.

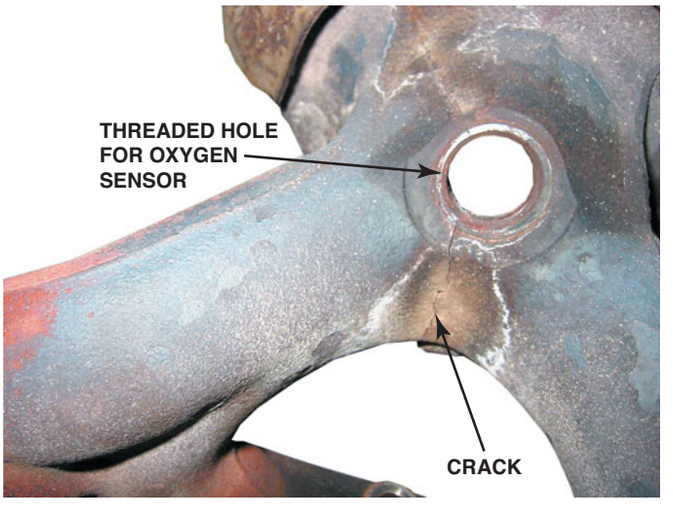


FIGURE 24–17 A crack in an exhaust manifold is often not visible because a heat shield usually covers the area. A crack in the exhaust manifold upstream of the oxygen sensor can fool the sensor and affect engine operation.

FREQUENTLY ASKED QUESTION

How Can a Cracked Exhaust Manifold Affect Engine Performance?

Cracks in an exhaust manifold will not only allow exhaust gases to escape and cause noise, but also allow air to enter the exhaust manifold. ● **SEE FIGURE 24–17**.

Exhaust flows from the cylinders as individual puffs or pressure pulses. Behind each of these pressure pulses, a low pressure (below atmospheric pressure) is created. Outside air at atmospheric pressure is then drawn into the exhaust manifold through the crack. This outside air contains 21% oxygen and is measured by the oxygen sensor (O2S). The air passing the O2S signals the engine computer that the engine is operating too lean (excess oxygen) and the computer, not knowing that the lean indicator is false, adds additional fuel to the engine. The result is that the engine will be operating richer (more fuel than normal) and spark plugs could become fouled by fuel, causing poor engine operation.

Gaskets are used on new engines with tubing- or header-type exhaust manifolds. They may have several layers of steel for high-temperature sealing. The layers are spot welded together. Some are embossed where special sealing is needed. ● **SEE FIGURE 24–18**.

Many new engines do not use gaskets with cast exhaust manifolds. The flat surface of the new cast-iron exhaust manifold fits tightly against the flat surface of the new head.

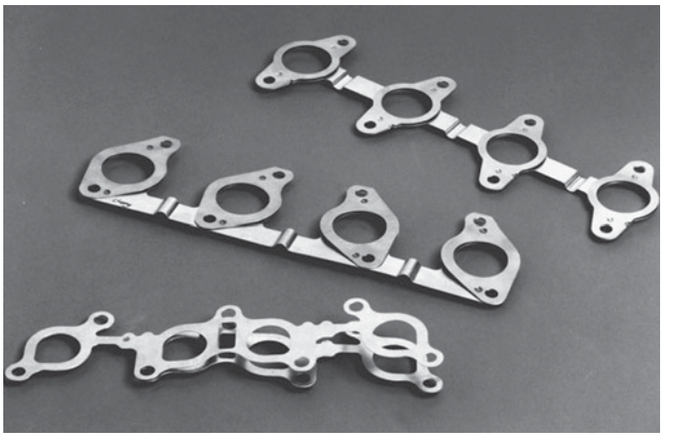


FIGURE 24–18 Typical exhaust manifold gaskets. Note how they are laminated to allow the exhaust manifold to expand and contract due to heating and cooling.

TECH TIP

Using the Correct Tool Saves Time

When cast-iron exhaust manifolds are removed, the stresses built up in the manifolds often cause the manifolds to twist or bend. This distortion even occurs when the exhaust manifolds have been allowed to cool before removal. Attempting to reinstall distorted exhaust manifolds is often a time-consuming and frustrating exercise.

However, special spreading jacks can be used to force the manifold back into position so that the fasteners can be lined up with the cylinder head. ● **SEE FIGURE 24–19**.

MUFFLERS

PURPOSE AND FUNCTION When the exhaust valve opens, it rapidly releases high-pressure gas. This sends a strong air pressure wave through the atmosphere inside the exhaust system, which produces a sound we call an explosion. It is the same sound produced when the high-pressure gases from burned gunpowder are released from a gun. In an engine, the pulses are released one after another. The explosions come so fast that they blend together in a steady roar.

Sound is air vibration. When the vibrations are large, the sound is loud. The muffler catches the large bursts of high-pressure exhaust gas from the cylinder, smoothing out the pressure pulses and allowing them to be released at an even and constant rate. It does this through the use of perforated tubes within the muffler chamber. The smooth-flowing gases are released to the tailpipe. In this way, the muffler silences engine exhaust noise. ● **SEE FIGURE 24–20**.

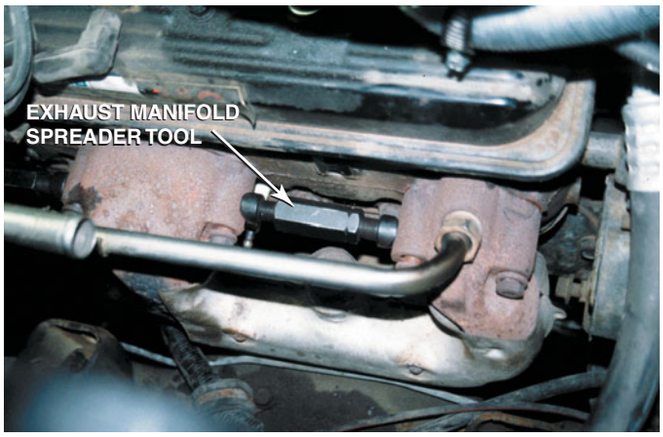


FIGURE 24–19 An exhaust manifold spreader tool is absolutely necessary when reinstalling exhaust manifolds. When they are removed from the engine, the manifolds tend to warp slightly even though the engine is allowed to cool before being removed. The spreader tool allows the technician to line up the bolt holes without harming the manifold.

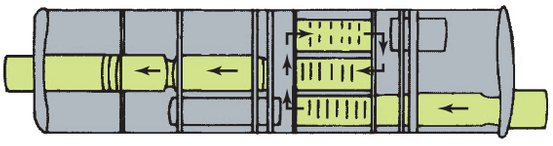


FIGURE 24–20 Exhaust gases expand and cool as they travel through passages in the muffler.

FREQUENTLY ASKED QUESTION

Why Is There a Hole in My Muffler?

Many mufflers are equipped with a small hole in the lower rear part to drain accumulated water. About 1 gallon of water is produced in the form of steam for each gallon of gasoline burned. The water is formed when gasoline is burned in the cylinder. Water consists of two molecules of hydrogen and one of oxygen (H_2O). The hydrogen (H) comes from the fuel and the oxygen (O) comes from the air. During combustion, the hydrogen from the fuel combines with some of the oxygen in the air to form water vapor. The water vapor condenses on the cooler surfaces of the exhaust system, especially in the muffler, until the vehicle has been driven long enough to fully warm the exhaust above the boiling point of water (212°F [100°C]). ● **SEE FIGURE 24–21.**

CONSTRUCTION Most mufflers have a larger inlet diameter than outlet diameter. As the exhaust enters the muffler, it expands and cools. The cooler exhaust is denser and occupies less volume. The diameter of the outlet of the muffler and the diameter of the tailpipe can be reduced with no decrease in efficiency.

Sometimes resonators are used in the exhaust system and the catalytic converter also acts as a muffler. They provide additional expansion space at critical points in the exhaust system to smooth out the exhaust gas flow.

The tailpipe carries the exhaust gases from the muffler to the air, away from the vehicle. In most cases, the tailpipe exit is at the rear of the vehicle, below the rear bumper. In some cases, the exhaust is released at the side of the vehicle, just ahead of or just behind the rear wheel.

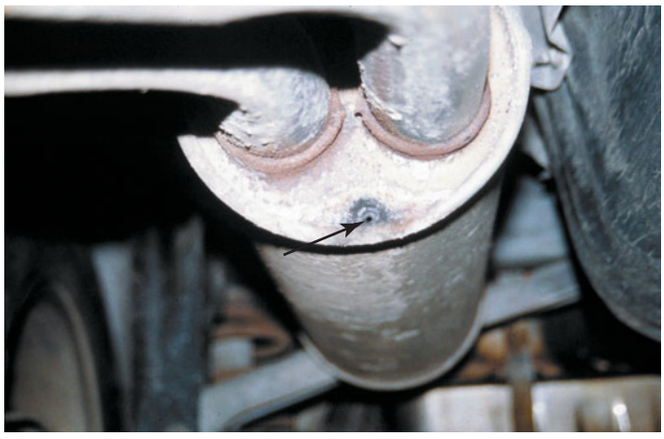


FIGURE 24–21 A hole in the muffler allows condensed water to escape.



FIGURE 24–22 A high-performance aftermarket air filter often can increase airflow into the engine for more power.

HIGH-PERFORMANCE TIP

More Airflow = More Power

One of the most popular high-performance modifications is to replace the factory exhaust system with a low-restriction design and to replace the original air filter and air filter housing with a low-restriction unit, as shown in ● **FIGURE 24–22.**

The installation of an aftermarket air filter not only increases power, but also increases air induction noise, which many drivers prefer. The aftermarket filter housing, however, may not be able to effectively prevent water from being drawn into the engine if the vehicle is traveling through deep water.

Almost every modification that increases performance has a negative effect on some other part of the vehicle, or else the manufacturer would include the change at the factory.

The muffler and tailpipe are supported with brackets, called **hangers,** which help to isolate the exhaust noise from the rest of the vehicle. The types of exhaust system hangers include:

- Rubberized fabric with metal ends that hold the muffler and tailpipe in position so that they do not touch any metal part, to isolate the exhaust noise from the rest of the vehicle
- Rubber material that looks like large rubber bands, which slip over the hooks on the exhaust system and the hooks attached to the body of the vehicle

REVIEW QUESTIONS

1. Why is it necessary to have intake charge velocities of about 50 ft per second?
2. Why can port fuel-injected engines use larger (and longer) intake manifolds and still operate at low engine speed?
3. What is a tuned runner in an intake manifold?
4. How does a muffler quiet exhaust noise?

CHAPTER QUIZ

1. Intake charge velocity has to be _____ to prevent fuel droplet separation.
   a. 25 ft per second **c.** 100 ft per second
   b. 50 ft per second **d.** 300 ft per second
2. The air filter restriction indicator uses what to detect when it signals to replace the filter?
   a. Number of hours of engine operation
   b. Number of miles of vehicle travel
   c. The amount of light that can pass through the filter
   d. The amount of restriction measured in inches of water
3. Why are the EGR gases cooled before entering the engine on some engines?
   a. Cool exhaust gas is more effective at controlling NOx emissions
   b. To help prevent the exhaust from slowing down
   c. To prevent damage to the intake valve
   d. To prevent heating the air-fuel mixture in the cylinder
4. The air-fuel mixture flows through the intake manifold on what type of system?
   a. Port fuel-injection systems
   b. Throttle-body fuel-injection systems
   c. Both a port-injected and throttle-body injected engine
   d. Any fuel-injected engine
5. Air filters can remove particles and dirt as small as _____.
   a. 5 to 10 microns **c.** 30 to 40 microns
   b. 10 to 25 microns **d.** 40 to 50 microns
6. Why do many port fuel-injected engines use long intake manifold runners?
   a. To reduce exhaust emissions
   b. To heat the incoming air
   c. To increase high-RPM power
   d. To increase low-RPM torque
7. Exhaust passages are included in some intake manifolds. Technician A says that the exhaust passages are used for exhaust gas recirculation (EGR) systems. Technician B says that the upper intake is often called the plenum. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
8. The upper portion of a two-part intake manifold is often called the _____.
   a. Housing **c.** Plenum
   b. Lower part **d.** Vacuum chamber
9. Technician A says that a cracked exhaust manifold can affect engine operation. Technician B says that a leaking lower intake manifold gasket could cause a vacuum leak. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
10. Technician A says that some intake manifolds are plastic. Technician B says that some intake manifolds are constructed in two parts or sections: upper and lower. Which technician is correct?
    a. Technician A only **c.** Both Technicians A and B
    b. Technician B only **d.** Neither Technician A nor B

chapter 25

TURBOCHARGING AND SUPERCHARGING

OBJECTIVES: After studying Chapter 25, the reader should be able to: • Prepare for ASE Engine Performance (A8) certification test content area "C" (Fuel, Air Induction, and Exhaust Systems Diagnosis and Repair). • Explain the difference between a turbocharger and a supercharger. • Describe how the boost levels are controlled. • Discuss maintenance procedures for turbochargers and superchargers.

KEY TERMS: Boost 228 • BOV 234 • Bypass valve 230 • CBV 234 • Dry system 236 • Dump valve 234 • Forced induction systems 228 • Intercooler 233 • Naturally (normally) aspirated 228 • Nitrous oxide (N_2O) 235 • Positive displacement 230 • Power adder 235 • Roots supercharger 230 • Supercharger 230 • Turbocharger 230 • Turbo lag 232 • Vent valve 234 • Volumetric efficiency 228 • Wastegate 233 • Wet system 235



FIGURE 25–1 A supercharger on a Ford V-8.

INTRODUCTION

AIRFLOW REQUIREMENTS Naturally aspirated engines with throttle plates use atmospheric pressure to push an air-fuel mixture into the combustion chamber vacuum created by the down stroke of a piston. The mixture is then compressed before ignition to increase the force of the burning, expanding gases. The greater the compression of the air-fuel mixture, the higher the engine power output resulting from combustion.

A four-stroke engine can take in only so much air, and how much fuel it needs for proper combustion depends on how much air it takes in. Engineers calculate engine airflow requirements using three factors.

1. Engine displacement
2. Engine revolutions per minute (RPM)
3. Volumetric efficiency

VOLUMETRIC EFFICIENCY **Volumetric efficiency** is a measure of how well an engine breathes. It is a comparison of the actual volume of air-fuel mixture drawn into an engine to the theoretical maximum volume that could be drawn in. Volumetric efficiency is expressed as a percentage. If the engine takes in the airflow volume slowly, a cylinder might fill to capacity. It takes a definite amount of time for the airflow to pass through all the curves of the intake manifold and valve port. Therefore, volumetric efficiency decreases as engine speed increases due to the shorter amount of time for the cylinders to be filled with air during the intake stroke. At high speed, it may drop to as low as 50%.

The average stock gasoline engine never reaches 100% volumetric efficiency. A new engine is about 85% efficient. A race engine usually has 95% or better volumetric efficiency. These figures apply only to naturally aspirated engines. However, with either turbochargers or superchargers, engines can easily achieve more than 100% volumetric efficiency. Many vehicles are equipped with a supercharger or a turbocharger from the factory to increase power. ● **SEE FIGURES 25–1 AND 25–2**.

FORCED INDUCTION PRINCIPLES

PURPOSE AND FUNCTION The amount of force an air-fuel charge produces when it is ignited is largely a function of the charge density. Charge density is a term used to define

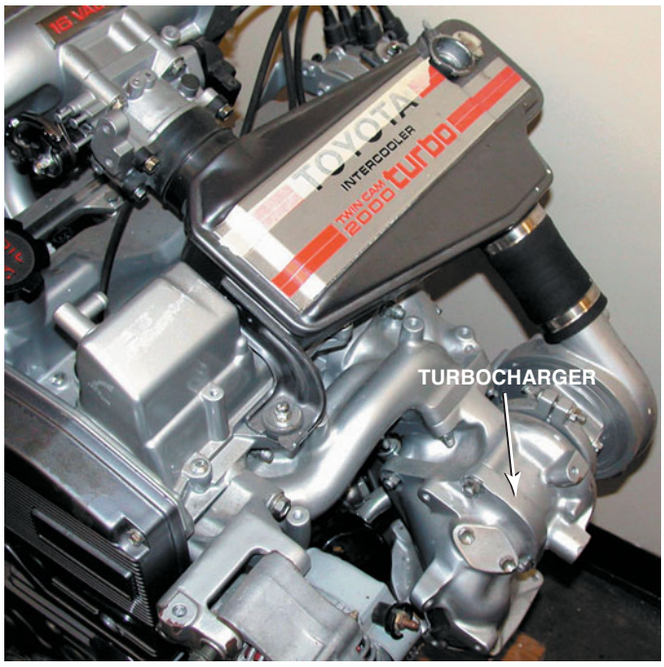


FIGURE 25–2 A turbocharger on a Toyota engine.

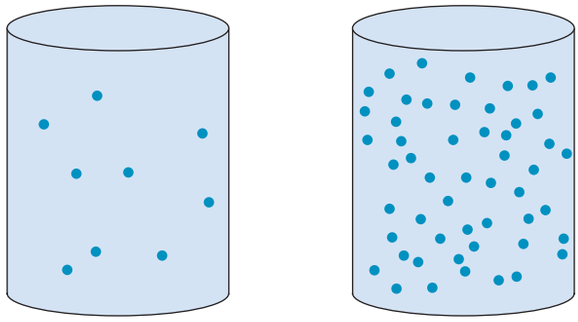


FIGURE 25–3 The more air and fuel that can be packed in a cylinder, the greater the density of the air-fuel charge.

the amount of the air-fuel charge introduced into the cylinders. Density is the mass of a substance in a given amount of space. ● **SEE FIGURE 25–3**.

The greater the density of an air-fuel charge forced into a cylinder, the greater the force it produces when ignited, and the greater the engine power.

An engine that uses atmospheric pressure for its intake charge is called a **naturally (normally) aspirated** engine. A better way to increase air density is to use some type of air pump such as a turbocharger or supercharger.

When air is pumped into the cylinder, the combustion chamber receives an increase of air pressure known as **boost,** and can be measured in:

- Pounds per square inch (PSI)
- Atmospheres (ATM) (1 atmosphere is 14.7 PSI)
- Bars (1 bar is 14.7 PSI)

While boost pressure increases air density, friction heats air in motion and causes an increase in temperature. This increase in temperature works in the opposite direction, decreasing air density. Because of these and other variables, an increase in pressure does not always result in greater air density.

FORCED INDUCTION PRINCIPLES **Forced induction systems** use an air pump to pack a denser air-fuel charge into the

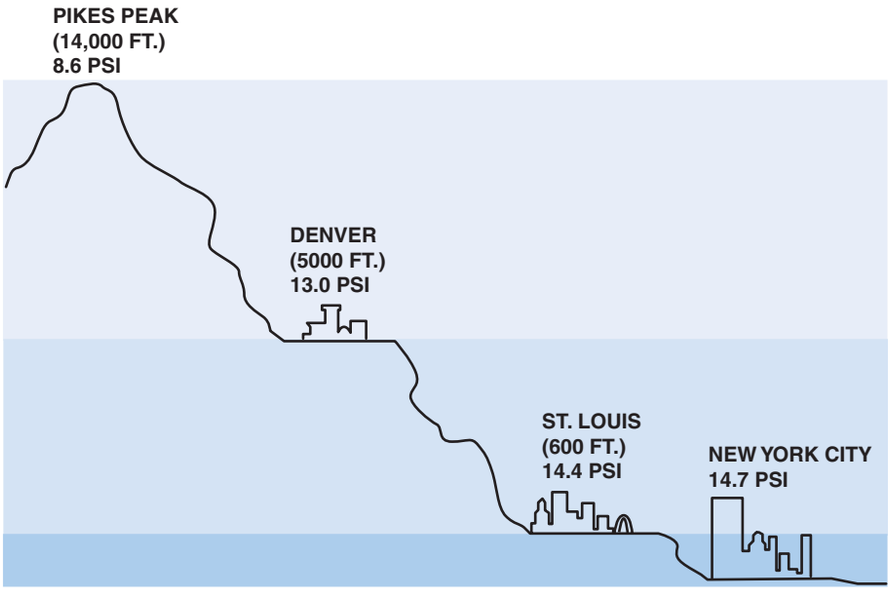


FIGURE 25–4 Atmospheric pressure decreases with increases in altitude.

FINAL COMPRESSION RATIO CHART AT VARIOUS BOOST LEVELS

	BLOWER BOOST (PSI)									
COMP RATIO	**2**	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	*20*
6.5	7.4	8.3	9.2	10	10.9	11.8	12.7	13.6	14.5	*15.3*
7	8	8.9	9.9	10.8	11.8	12.7	13.6	14.5	15.3	*16.2*
7.5	8.5	9.5	10.6	11.6	12.6	13.6	14.6	15.7	16.7	*17.8*
8	9.1	10.2	11.3	12.4	13.4	14.5	15.6	16.7	17.8	*18.9*
8.5	9.7	10.8	12	13.1	14.3	15.4	16.6	17.8	18.9	*19.8*
9	10.2	11.4	12.7	13.9	15.1	16.3	17.6	18.8	20	*21.2*
9.5	10.8	12.1	13.4	14.7	16	17.3	18.5	19.8	21.1	*22.4*
10	*11.4*	*12.7*	*14.1*	*15.4*	*16.8*	*18.2*	*19.5*	*20.9*	*22.2*	*23.6*

CHART 25–1

The effective compression ratio compared to the boost pressure.

cylinders. Because the density of the air-fuel charge is greater, the following occurs.

- The weight of the air-fuel charge is higher.
- Power is increased because it is directly related to the weight of an air-fuel charge consumed within a given time period.

Pumping air into the intake system under pressure forces it through the bends and restrictions of the air intake system at a greater speed than it would travel under normal atmospheric pressure. This added pressure allows more air to enter the intake port before the intake valve closes. By increasing the airflow into the intake, more fuel can be mixed with the air while still maintaining the same air-fuel ratio. The denser the air-fuel charge entering the engine during its intake stroke, the greater the potential energy released during combustion. In addition to the increased power resulting from combustion, there are several other advantages of supercharging an engine, including:

- It increases the air-fuel charge density to provide high-compression pressure when power is required, but allows the engine to run on lower pressures when additional power is not required.
- The pumped air pushes the remaining exhaust from the combustion chamber during intake and exhaust valve overlap. (Overlap is when both the intake and exhaust valves are partially open when the piston is near the top at the end of the exhaust stroke and the beginning of the intake stroke.)
- The forced airflow and removal of hot exhaust gases lowers the temperature of the cylinder head, pistons, and valves, and helps extend the life of the engine.

A supercharger or turbocharger pressurizes air to greater than atmospheric pressure. The pressurization above atmospheric pressure, or boost, can be measured in the same way as atmospheric pressure. Atmospheric pressure drops as altitude increases, but boost pressure remains the same. If a supercharger develops 12 PSI (83 kPa) boost at sea level, it will develop the same amount at a 5,000 ft altitude because boost pressure is measured inside the intake manifold. ● **SEE FIGURE 25–4**.

BOOST AND COMPRESSION RATIOS Boost increases the amount of air drawn into the cylinder during the intake stroke. This extra air causes the effective compression ratio to be greater than the mechanical compression ratio designed into the engine. The higher the boost pressure, the greater the compression ratio. This means that any engine that uses a supercharger or turbocharger must use all of the following engine components.

- Forged pistons, to withstand the increased combustion pressures
- Stronger than normal connecting rods
- Piston oil squirters that direct a stream of oil to the underneath part of the piston, to keep piston temperatures under control
- Lower compression ratio compared to a naturally aspirated engine ● **SEE CHART 25–1**.

SUPERCHARGERS

INTRODUCTION A **supercharger** is an engine-driven air pump that supplies more than the normal amount of air into the intake manifold and boosts engine torque and power. A supercharger provides an instantaneous increase in power without any delay. However, a supercharger, because it is driven by the engine, requires horsepower to operate and is not as efficient as a turbocharger.

A supercharger is an air pump mechanically driven by the engine itself. Gears, shafts, chains, or belts from the crankshaft can all be used to turn the pump. This means that the air pump or supercharger pumps air in direct relation to engine speed.

TYPES OF SUPERCHARGERS There are two general types of superchargers.

- **Roots type.** Named for Philander and Francis Roots, two brothers from Connersville, Indiana, the **roots supercharger** was patented in 1860 as a type of water pump to be used in mines. Later, it was used to move air and is used today on two-stroke-cycle Detroit diesel engines and other supercharged engines. The roots-type supercharger is called a **positive displacement** design, because all of the air that enters is forced through the unit. Examples of a roots-type supercharger include the GMC 6-71 (used originally on GMC diesel engines that had 6 cylinders each with 71 cu. in.). Eaton used the roots design for the supercharger on the 3800 V-6 GM engine. ● **SEE FIGURE 25–5**.
- **Centrifugal supercharger.** A centrifugal supercharger is similar to a turbocharger, but is mechanically driven by the engine instead of being powered by the hot exhaust gases. A centrifugal supercharger is not a positive displacement pump and all of the air that enters is not forced through the unit. Air enters a centrifugal supercharger housing in the center and exits at the outer edges of the compressor wheels at a much higher speed due to centrifugal force. The speed of the blades has to be higher than engine speed so a smaller pulley is used on the supercharger and the crankshaft overdrives the impeller through an internal gear box achieving about seven times the speed of the engine. Examples of centrifugal superchargers include Vortech and Paxton.

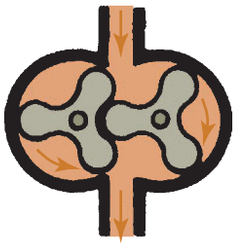


FIGURE 25–5 A roots-type supercharger uses two lobes to force the air around the outside of the housing and into the intake manifold.

SUPERCHARGER BOOST CONTROL Many factory installed superchargers are equipped with a **bypass valve** that allows intake air to flow directly into the intake manifold, bypassing the supercharger. The computer controls the bypass valve actuator. ● **SEE FIGURE 25–6**.

The airflow is directed around the supercharger whenever any of the following conditions occur.

- The boost pressure, as measured by the MAP sensor, indicates that the intake manifold pressure is reaching the predetermined boost level.
- During deceleration, to prevent excessive pressure buildup in the intake.
- Reverse gear is selected.

SUPERCHARGER SERVICE Superchargers are usually lubricated with synthetic engine oil inside the unit. This oil level should be checked and replaced as specified by the vehicle or supercharger manufacturer. The drive belt should also be inspected and replaced as necessary. The air filter should be replaced regularly, and always use the filter specified for a supercharged engine. Many factory supercharger systems use a separate cooling system for the air charge cooler located under the supercharger. Check service information for the exact service procedures to follow. ● **SEE FIGURE 25–7**.

TURBOCHARGERS

INTRODUCTION The major disadvantage of a supercharger is it takes some of the engine power to drive the unit. In some installations, as much as 20% of the engine power is used by a mechanical supercharger. A **turbocharger** uses the heat of the exhaust to power

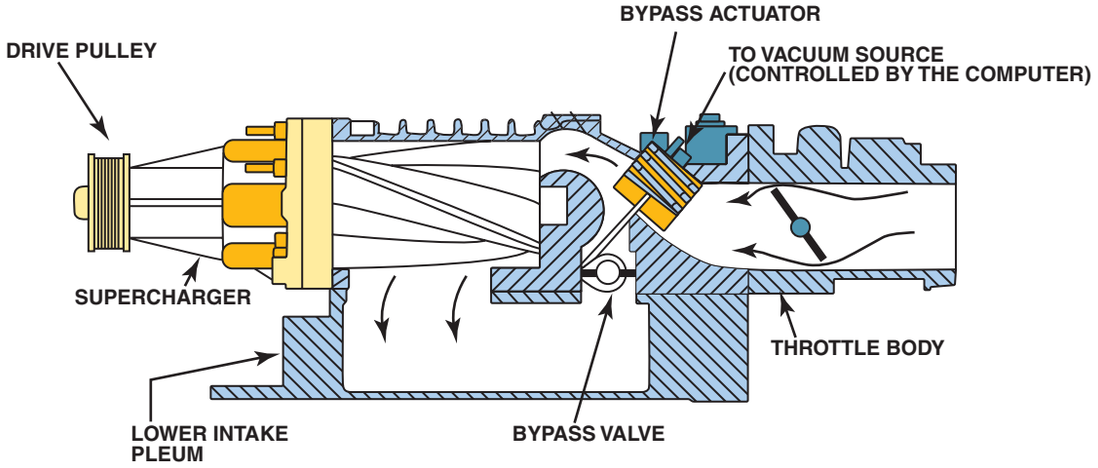


FIGURE 25–6 The bypass actuator opens the bypass valve to control boost pressure.

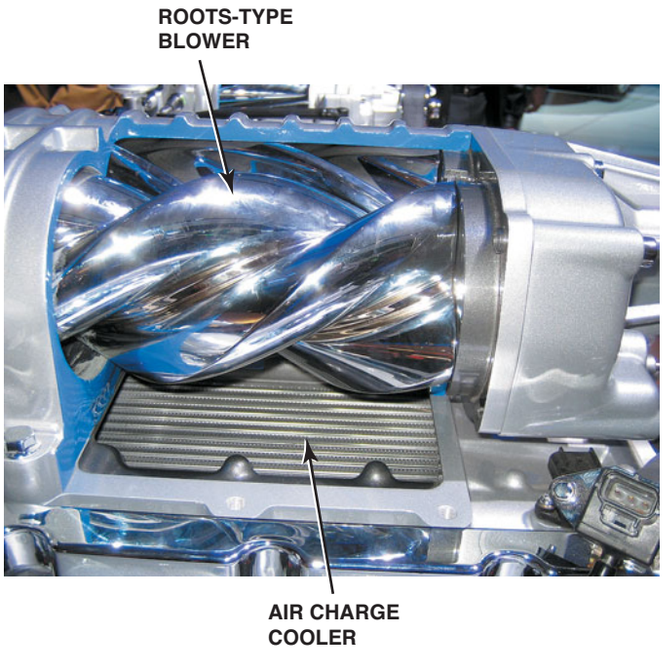


FIGURE 25–7 A Ford supercharger cutaway display showing the roots-type blower and air charge cooler (intercooler). The air charge cooler is used to reduce the temperature of the compressed air before it enters the engine to increase the air charge density.

TECH TIP

Faster Moves More Air

One of the high-performance measures that can be used to increase horsepower on a supercharged engine is to install a smaller diameter pulley. The smaller the pulley diameter, the faster the supercharger will rotate and the higher the potential boost pressure will be. The change will require a shorter belt, and the extra boost could cause serious engine damage.

a turbine wheel and therefore does not directly reduce engine power. In a naturally aspirated engine, about half of the heat energy contained in the fuel goes out the exhaust system. However, some engine power is lost due to the exhaust restriction. This loss in power is regained, though, to perform other work and the combustion heat energy lost in the engine exhaust (as much as 40% to 50%) can be harnessed to do useful work. Another 25% is lost through radiator cooling. Only about 25% is actually converted to mechanical power. A mechanically driven pump uses some of this mechanical output, but a turbocharger gets its energy from the exhaust gases, converting more of the fuel's heat energy into useful mechanical energy. ● **SEE FIGURE 25–8.**

OPERATION

A turbocharger turbine looks much like a typical centrifugal pump used for supercharging.

Hot exhaust gases flow from the combustion chamber to the *turbine wheel.* The gases are heated and expanded as they leave the engine. It is not the speed of force of the exhaust gases that forces the turbine wheel to turn, as is commonly thought, but the expansion of hot gases against the turbine wheel's blades.

A turbocharger consists of two chambers connected with a center housing. The two chambers contain a turbine wheel and an *impeller* (compressor) *wheel* connected by a shaft which passes through the center housing. ● **SEE FIGURE 25–9**

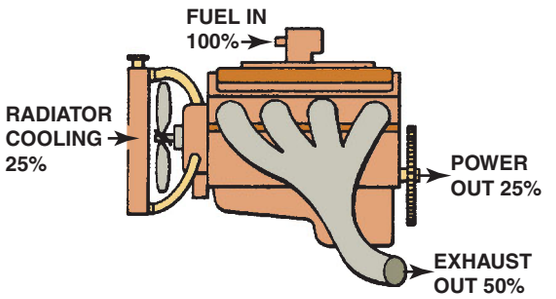


FIGURE 25–8 A turbocharger uses some of the heat energy that would normally be wasted.

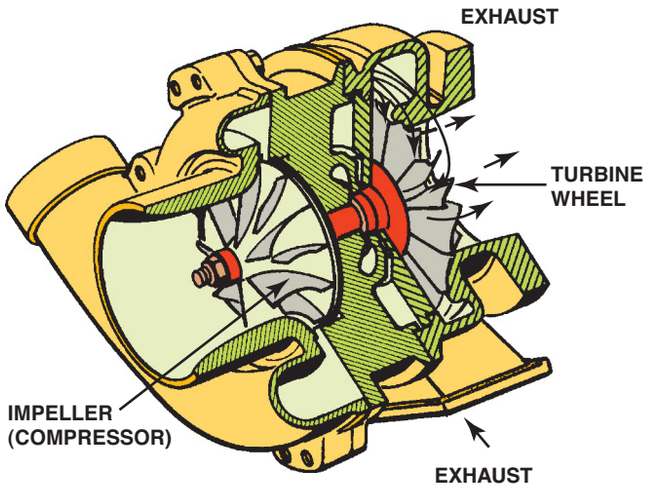


FIGURE 25–9 A turbine wheel is turned by the expanding exhaust gases.

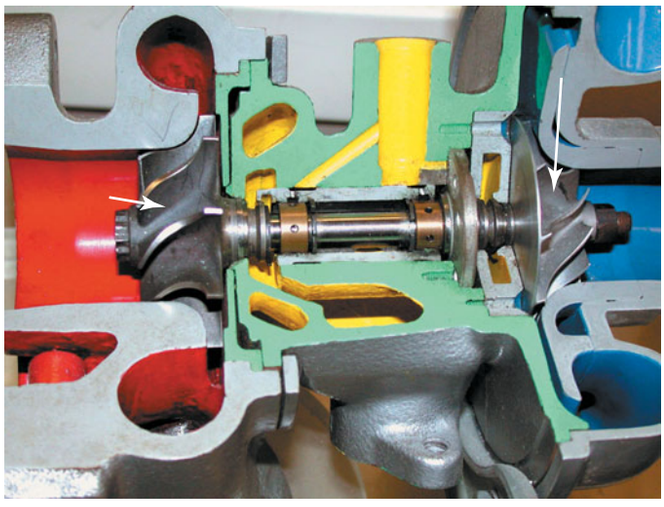


FIGURE 25–10 The exhaust drives the turbine wheel on the left which is connected to the impeller wheel on the right through a shaft. The bushings that support the shaft are lubricated with engine oil under pressure.

To take full advantage of the exhaust heat which provides the rotating force, a turbocharger must be positioned as close as possible to the exhaust manifold. This allows the hot exhaust to pass directly into the unit with minimal heat loss. As exhaust gas enters the turbocharger, it rotates the turbine blades. The turbine wheel and compressor wheel are on the same shaft so that they turn at the same speed. Rotation of the compressor wheel draws air in through a central inlet and centrifugal force pumps it through an outlet at the edge of the housing. A pair of bearings in the center housing supports the turbine and compressor wheel shaft, and is lubricated by engine oil. ● **SEE FIGURE 25–10.**

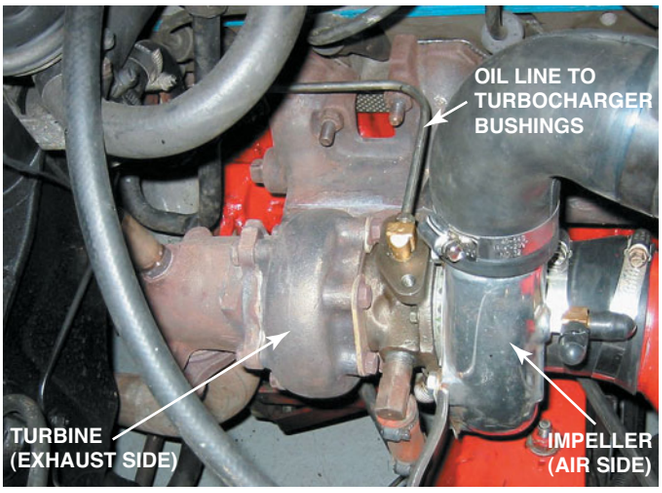


FIGURE 25–11 Engine oil is fed to the center of the turbocharger to lubricate the bushings and returns to the oil pan through a return line.

Both the turbine and compressor wheels must operate with extremely close clearances to minimize possible leakage around their blades. Any leakage around the turbine blades causes a dissipation of the heat energy required for compressor rotation. Leakage around the compressor blades prevents the turbocharger from developing its full boost pressure.

TURBOCHARGER OPERATION

When the engine is started and runs at low speed, both exhaust heat and pressure are low and the turbine runs at a low speed (approximately 1000 RPM). Because the compressor does not turn fast enough to develop boost pressure, air simply passes through it and the engine works like any naturally aspirated engine. As the engine runs faster or load increases, both exhaust heat and flow increase, causing the turbine and compressor wheels to rotate faster. Since there is no brake and very little rotating resistance on the turbocharger shaft, the turbine and compressor wheels accelerate as the exhaust heat energy increases. When an engine is running at full power, the typical turbocharger rotates at speeds between 100,000 and 150,000 RPM. The turbocharger is lubricated by engine oil through an oil line to the center bearing assembly. ● **SEE FIGURE 25–11**.

Engine deceleration from full power to idle requires only a second or two because of its internal friction, pumping resistance, and drivetrain load. The turbocharger, however, has no such load on its shaft, and is already turning many times faster than the engine at top speed. As a result, it can take as much as a minute or more after the engine has returned to idle speed before the turbocharger also has returned to idle. If the engine is decelerated to idle and then shut off immediately, engine lubrication stops flowing to the center housing bearings while the turbocharger is still spinning at thousands of RPM. The oil in the center housing is then subjected to extreme heat and can gradually "coke" or oxidize. The coked oil can clog passages and will reduce the life of the turbocharger.

The high rotating speeds and extremely close clearances of the turbine and compressor wheels in their housings require equally critical bearing clearances. The bearings must keep radial clearances of 0.003 to 0.006 in. (0.08 to 0.15 mm). Axial clearance (endplay) must be maintained at 0.001 to 0.003 in. (0.025 to 0.08 mm). If properly maintained, the turbocharger also is a trouble-free device. However, to prevent problems, the following must be met.

- The turbocharger bearings must be constantly lubricated with clean engine oil. Turbocharged engines usually have specified oil changes at more frequent intervals than nonturbocharged engines. Always use the specified engine oil, which is likely to be vehicle specific and synthetic.
- Dirt particles and other contamination must be kept out of the intake and exhaust housings.
- Whenever a basic engine bearing (crankshaft or camshaft) has been damaged, the turbocharger must be flushed with clean engine oil after the bearing has been replaced.
- If the turbocharger is damaged, the engine oil must be drained and flushed and the oil filter replaced as part of the repair procedure.

Late-model turbochargers all have liquid-cooled center bearings to prevent heat damage. In a liquid-cooled turbocharger, engine coolant is circulated through passages cast in the center housing to draw off the excess heat. This allows the bearings to run cooler and minimize the probability of oil coking when the engine is shut down.

TURBOCHARGER SIZE AND RESPONSE TIME

A time lag occurs between an increase in engine speed and the increase in the speed of the turbocharger. This delay between acceleration and turbo boost is called **turbo lag.** Like any material, moving exhaust gas has inertia. Inertia also is present in the turbine and compressor wheels, as well as the intake airflow. Unlike a supercharger, the turbocharger cannot supply an adequate amount of boost at low speed.

Turbocharger response time is directly related to the size of the turbine and compressor wheels. Small wheels accelerate rapidly; large wheels accelerate slowly. While small wheels would seem to have an advantage over larger ones, they may not have enough airflow capacity for an engine. To minimize turbo lag, the intake and exhaust breathing capacities of an engine must be matched to the exhaust and intake airflow capabilities of the turbocharger.

BOOST CONTROL

PURPOSE AND FUNCTION

Both supercharged and turbocharged systems are designed to provide a pressure greater than atmospheric pressure in the intake manifold. This increased pressure forces additional amounts of air into the combustion chamber over what would normally be forced in by atmospheric pressure. This increased charge increases engine power. The amount of "boost" (or pressure in the intake manifold) is measured in pounds per square inch (PSI), in inches of mercury (in. Hg), in bars, or in atmospheres. The following values will vary due to altitude and weather conditions (barometric pressure).

1 atmosphere = 14.7 PSI

1 atmosphere = 29.50 in. Hg

1 atmosphere = 1 bar

1 bar = 14.7 PSI

BOOST CONTROL FACTORS

The higher the level of boost (pressure), the greater the horsepower output potential. However, other factors must be considered when increasing boost pressure.

1. As boost pressure increases, the temperature of the air also increases.
2. As the temperature of the air increases, combustion temperatures also increase, as well as the possibility of detonation.
3. Power can be increased by cooling the compressed air after it leaves the turbocharger. *The power can be increased about*

1% per 10°F by which the air is cooled. A typical cooling device is called an **intercooler.** It is similar to a radiator, wherein outside air can pass through, cooling the pressurized heated air. An intercooler is located between the turbocharger and the intake manifold. ● **SEE FIGURE 25–12**. Some intercoolers use engine coolant to cool the hot compressed air that flows from the turbocharger to the intake.



FIGURE 25–12 The unit on top of this Subaru that looks like a radiator is the intercooler, which cools the air after it has been compressed by the turbocharger.

4. As boost pressure increases, combustion temperature and pressures increase, which, if not limited, can do severe engine damage. The maximum exhaust gas temperature must be 1,550°F (840°C). Higher temperatures decrease the durability of the turbocharger *and* the engine.

WASTEGATE Turbochargers use exhaust gases to increase boost, which causes the engine to make more exhaust gases, which in turn increases the boost from the turbocharger. To prevent overboost and severe engine damage, most turbocharger systems use a wastegate. A **wastegate** is a valve similar to a door that can open and close. It is a bypass valve at the exhaust inlet to the turbine, which allows all of the exhaust into the turbine, or it can route part of the exhaust past the turbine to the exhaust system. If the valve is closed, all of the exhaust travels to the turbocharger. When a predetermined amount of boost pressure develops in the intake manifold, the wastegate valve is opened. As the valve opens, most of the exhaust flows directly out the exhaust system, bypassing the turbocharger. With less exhaust flowing across the vanes of the turbocharger, the turbocharger decreases in speed, and boost pressure is reduced. When the boost pressure drops, the wastegate valve closes to direct the exhaust over the turbocharger vanes to again allow the boost pressure to rise. Wastegate operation is a continuous process to control boost pressure.

The wastegate is the pressure control valve of a turbocharger system. It is usually controlled by the engine control computer through a boost control solenoid, also called a wastegate control valve. ● **SEE FIGURE 25–13**.

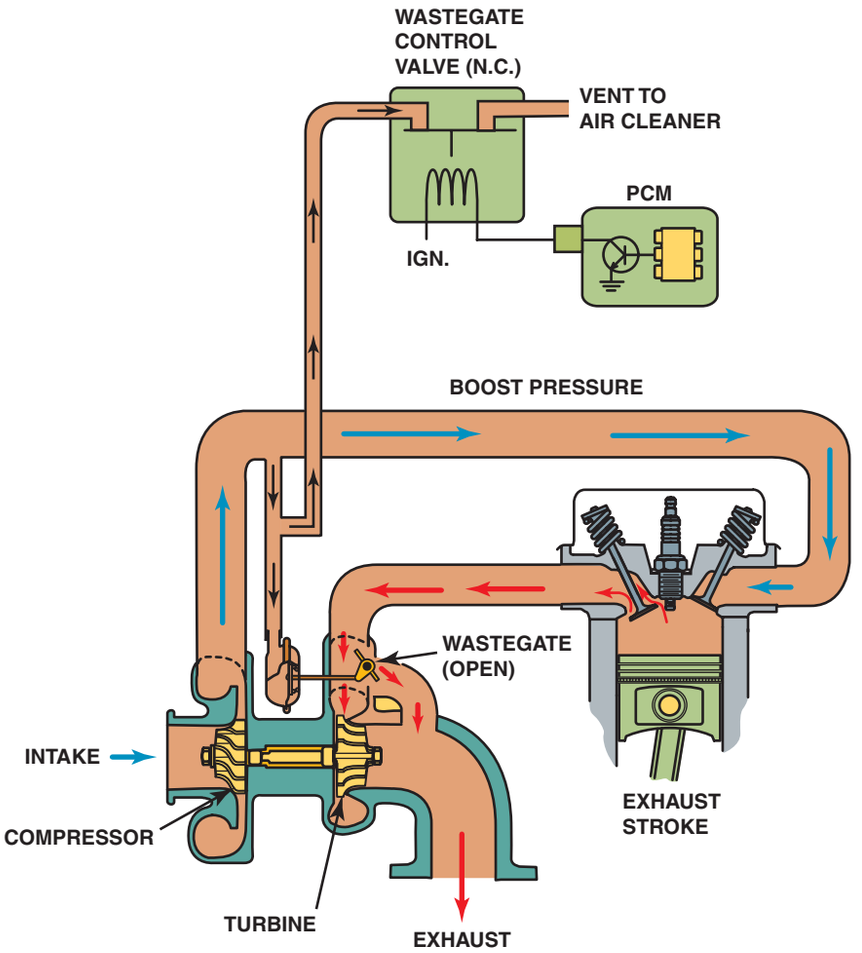


FIGURE 25–13 A wastegate is used on many turbocharged engines to control maximum boost pressure. The wastegate is controlled by a computer-controlled valve.

RELIEF VALVES A wastegate controls the exhaust side of the turbocharger. A relief valve controls the intake side. A relief valve vents pressurized air from the connecting pipe between the outlet of the turbocharger and the throttle whenever the throttle is closed during boost, such as during shifts. If the pressure is not released, the turbocharger turbine wheel will slow down, creating a lag when the throttle is opened again after a shift has been completed. There are two basic types of relief valves.

1. **Compressor bypass valve (CBV).** This type of relief valve routes the pressurized air to the inlet side of the turbocharger for reuse and is quiet during operation.
2. **Blow-off valve (BOV).** Also called a **dump valve** or **vent valve,** the BOV features an adjustable spring design that keeps the valve closed until a sudden release of the throttle. The resulting pressure increase opens the valve and vents the pressurized air directly into the atmosphere. This type of relief valve is noisy in operation and creates a whooshing sound when the valve opens. ● **SEE FIGURE 25–14.**

TECH TIP

Boost Is the Result of Restriction

The boost pressure of a turbocharger (or supercharger) is commonly measured in pounds per square inch. If a cylinder head is restricted because of small valves and ports, the turbocharger will quickly provide boost. Boost results when the air being forced into the cylinder heads cannot flow into the cylinders fast enough and "piles up" in the intake manifold, increasing boost pressure. If an engine had large valves and ports, the turbocharger could provide a much greater *amount* of air into the engine at the same boost pressure as an identical engine with smaller valves and ports. Therefore, by increasing the size of the valves, a turbocharged or supercharged engine will be capable of producing much greater power.

TURBOCHARGER FAILURES

SYMPTOMS OF FAILURE When turbochargers fail to function correctly, a noticeable drop in power occurs. To restore proper operation, the turbocharger must be rebuilt, repaired, or replaced. It is not possible to simply remove the turbocharger, seal any openings, and maintain decent driveability. Bearing failure is a common cause of turbocharger failure, and replacement bearings are usually only available to rebuilders. Another common turbocharger problem is excessive and continuous oil consumption resulting in blue

TECH TIP

If One Is Good, Two Are Better

A turbocharger uses the exhaust from the engine to spin a turbine, which is connected to an impeller inside a turbocharger. This impeller then forces air into the engine under pressure, higher than is normally achieved without a turbocharger. The more air that can be forced into an engine, the greater the power potential. A V-type engine has two exhaust manifolds and so two small turbochargers can be used to help force greater quantities of air into an engine, as shown in ● **FIGURE 25–15.**

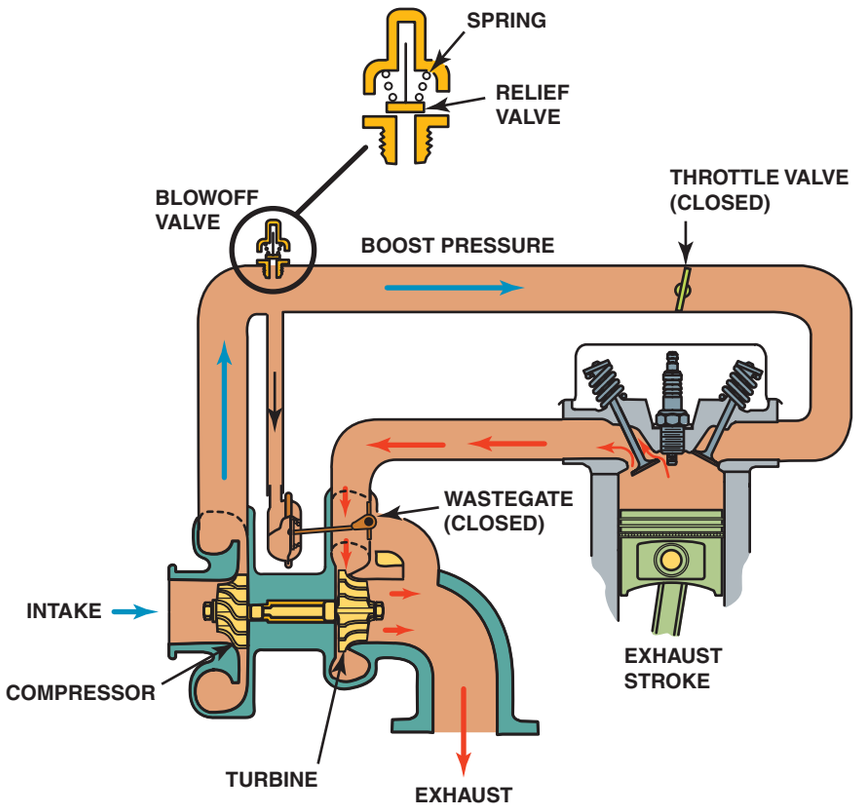


FIGURE 25–14 A blow-off valve is used in some turbocharged systems to relieve boost pressure during deceleration.



FIGURE 25–15 A dual turbocharger system installed on a small block Chevrolet V-8 engine.

exhaust smoke. Turbochargers use small rings similar to piston rings on the shaft to prevent exhaust (combustion gases) from entering the central bearing. Because there are no seals to keep oil in, excessive oil consumption is usually caused by the following:

1. Plugged positive crankcase ventilation (PCV) system, resulting in excessive crankcase pressures forcing oil into the air inlet (This failure is not related to the turbocharger, but the turbocharger is often blamed.)
2. Clogged air filter, which causes a low-pressure area in the inlet, drawing oil past the turbo shaft rings and into the intake manifold.
3. Clogged oil return (drain) line from the turbocharger to the oil pan (sump), which can cause the engine oil pressure to force oil past the turbocharger's shaft rings and into the intake *and* exhaust manifolds (Obviously, oil being forced into both the intake and exhaust would create lots of smoke.)

PREVENTING TURBOCHARGER FAILURES To help prevent turbocharger failures, the wise vehicle owner should follow the vehicle manufacturer's recommended routine service procedures. The most critical of these services include:

- Regular oil changes (synthetic oil would be best)
- Regular air filter replacement intervals
- Performing any other inspections and services recommended such as cleaning the intercooler.

NITROUS OXIDE

INTRODUCTION Nitrous oxide is used for racing or high-performance only, and is not used from the factory on any vehicle. This system is a relatively inexpensive way to get additional power from an engine, but can cause serious engine damage if not used correctly or in excess amounts, or without proper precautions.

PRINCIPLES **Nitrous oxide (N_2O)** is a colorless, nonflammable gas. It was discovered by a British chemist, Joseph Priestly (1733–1804), who also discovered oxygen. Priestly found that if a person breathed in nitrous oxide, it caused light-headedness, and so the gas soon became known as *laughing gas.* Nitrous oxide was used in dentistry during tooth extractions to reduce the pain and cause the patient to forget the experience.

Nitrous oxide has two nitrogen atoms and one oxide atom. About 36% of the molecule weight is oxygen. Nitrous oxide is a manufactured gas because, even though both nitrogen and oxygen are present in our atmosphere, they are not combined into one molecule and require heat and a catalyst to be combined.

TEMPERATURE (°F/°C)	PRESSURE (PSI/KPA)
−30°F/−34°C	67 PSI/468 kPa
−20°F/−29°C	203 PSI/1,400 kPa
−10°F/−23°C	240 PSI/1,655 kPa
0°F/−18°C	283 PSI/1,950 kPa
10°F/−12°C	335 PSI/2,310 kPa
20°F/−7°C	387 PSI/2,668 kPa
30°F/−1°C	460 PSI/3,172 kPa
40°F/4°C	520 PSI/3,585 kPa
50°F/10°C	590 PSI/4,068 kPa
60°F/16°C	675 PSI/4,654 kPa
70°F/21°C	760 PSI/5,240 kPa
80°F/27°C	865 PSI/5,964 kPa
90°F/32°C	985 PSI/6,792 kPa
100°F/38°C	1,120 PSI/7,722 kPa

CHART 25–2

Temperature/pressure relation for nitrous oxide: The higher the temperature, the higher the pressure.

ENGINE POWER ADDER A **power adder** is a device or system added to an engine, such as a supercharger, turbocharger, or nitrous oxide, to increase power. When nitrous oxide is injected into an engine along with gasoline, engine power is increased. The addition of N_2O supplies the needed oxygen for the extra fuel. N_2O by itself does not burn, but provides the oxygen for additional fuel that is supplied along with the N_2O to produce more power.

NOTE: Nitrous oxide was used as a power adder in World War II on some fighter aircraft. Having several hundred more horsepower for a short time saved many lives.

PRESSURE AND TEMPERATURE It requires about 11 lb of pressure per degree Fahrenheit to condense nitrous oxide gas into liquid nitrous oxide. For example, at 70°F, it requires a pressure of about 770 PSI to condense N_2O into a liquid. To change N_2O from a liquid under pressure to a gas, all that is needed is to lower its pressure below the pressure it takes to cause it to become a liquid.

The temperature also affects the pressure of N_2O. ● **SEE CHART 25–2**.

Nitrous oxide is stored in a pressurized storage container and installed at an angle so the pickup tube is in the liquid. The front or discharge end of the storage bottle should be toward the front of the vehicle. ● **SEE FIGURE 25–16**.

WET AND DRY SYSTEM There are two different types of N_2O systems that depend on whether additional fuel (gasoline) is supplied at the same time as when the nitrous oxide is squirted.

- The **wet system** involves additional fuel being injected. It is identified as having both a red and a blue nozzle, with the red flowing gasoline and the blue flowing nitrous oxide.

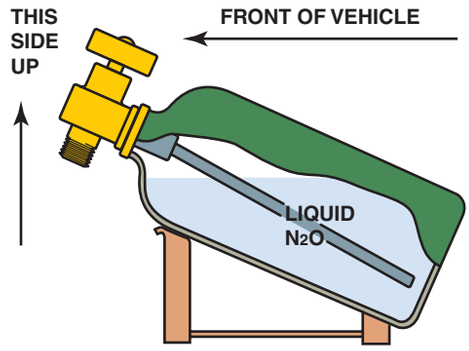


FIGURE 25–16 Nitrous bottles have to be mounted at an angle to ensure that the pickup tube is in the liquid N_2O.

- In a **dry system,** such as an engine using port fuel injection, only nitrous oxide needs to be injected because the PCM can be commanded to provide more fuel when the N_2O is being sprayed. As a result, the intake manifold contains only air and the injected gaseous N_2O.

ENGINE CHANGES NEEDED FOR N_2O If nitrous oxide is going to be used to increase horsepower more than 50 hp, the engine must be designed and built to withstand the greater heat and pressure that will occur in the combustion chambers. For example, the following items should be considered if adding a turbocharger, supercharger, or nitrous oxide system.

- Forged pistons are best able to withstand the pressure and temperature when using nitrous oxide or other power adder.
- Cylinder-to-wall clearance should be increased. Due to the greater amount of heat created by the extra fuel and N_2O injection, the piston temperature will be increased. Although using forged pistons will help, most experts recommend using increased cylinder-to-wall clearance.
- Using forged crankshaft and connecting rods.

Check the instructions from the nitrous oxide supplier for details and other suggested changes.

CAUTION: The use of a nitrous oxide injection system can cause catastrophic engine damage. Always follow the instructions that come with the kit and be sure that all of the internal engine parts meet the standard specified to help avoid severe engine damage.



FIGURE 25–17 An electrical heating mat is installed on the bottle of nitrous oxide to increase the pressure of the gas inside.

TECH TIP

Increase Bottle Pressure

To increase the pressure of the nitrous oxide in a bottle, an electrical warming blanket can be used, as seen in **FIGURE 25–17**. The higher the temperature, the higher the pressure and the greater the amount of N_2O flow when energized.

SYSTEM INSTALLATION AND CALIBRATION Nitrous oxide systems are usually purchased as a kit with all of the needed components included. The kit also includes one or more sizes of nozzle(s), which are calibrated to control the flow of nitrous oxide into the intake manifold.

The sizes of the nozzles are often calibrated in horsepower that can be gained by their use. Commonly sized nozzles include:

- 50 hp
- 100 hp
- 150 hp

Installation of a nitrous oxide kit also includes the installation of an on-off switch and a switch on or near the throttle, which is used to activate the system only when the throttle is fully opened (WOT).

REVIEW QUESTIONS

1. What are the reasons why supercharging increases engine power?
2. How does the bypass valve work on a supercharged engine?
3. What are the advantages and disadvantages of supercharging?
4. What are the advantages and disadvantages of turbocharging?
5. What turbocharger control valves are needed for proper engine operation?

CHAPTER QUIZ

1. Boost pressure is generally measured in _____.
   a. in. Hg **c.** in. H_2O
   b. PSI **d.** in. lb
2. Two types of superchargers include _____.
   a. Rotary and reciprocating **c.** Double and single acting
   b. Roots-type and centrifugal **d.** Turbine and piston

3. Which valve is used on a factory supercharger to limit boost?
   a. Bypass valve **c.** Blow-off valve
   b. Wastegate **d.** Air valve
4. How are most superchargers lubricated?
   a. By engine oil under pressure through lines from the engine
   b. By an internal oil reservoir
   c. By greased bearings
   d. No lubrication is needed because the incoming air cools the supercharger
5. How are most turbochargers lubricated?
   a. By engine oil under pressure through lines from the engine
   b. By an internal oil reservoir
   c. By greased bearings
   d. No lubrication is needed because the incoming air cools the supercharger
6. Two technicians are discussing the term *turbo lag.* Technician A says that it refers to the delay between when the exhaust leaves the cylinder and when it contacts the turbine blades of the turbocharger. Technician B says that it refers to the delay in boost pressure that occurs when the throttle is first opened. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
7. What is the purpose of an intercooler?
   a. To reduce the temperature of the air entering the engine
   b. To cool the turbocharger
   c. To cool the engine oil on a turbocharged engine
   d. To cool the exhaust before it enters the turbocharger
8. Which type of relief valve used on a turbocharged engine is noisy?
   a. Bypass valve **c.** Dump valve
   b. BOV **d.** Both b and c
9. Technician A says that a stuck open wastegate can cause the engine to burn oil. Technician B says that a clogged PCV system can cause the engine to burn oil. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
10. What service operation is *most* important on engines equipped with a turbocharger?
    a. Replacing the air filter regularly
    b. Replacing the fuel filter regularly
    c. Regular oil changes
    d. Regular exhaust system maintenance

chapter 26

ENGINE CONDITION DIAGNOSIS

OBJECTIVES: **After studying Chapter 26, the reader should be able to:** • Prepare for ASE Engine Performance (A8) certification test content area "A" (General Engine Diagnosis). • List the visual checks to determine engine condition. • Discuss engine noise and its relation to engine condition. • Describe how to perform a dry and a wet compression test. • Explain how to perform a cylinder leakage test.

KEY TERMS: Back pressure 248 • Compression test 242 • Cranking vacuum test 246 • Cylinder leakage test 244 • Dynamic compression test 244 • Idle vacuum test 246 • Inches of mercury (in. Hg) 245 • Paper test 242 • Power balance test 245 • Restricted exhaust 247 • Running compression test 244 • Vacuum test 246 • Wet compression test 243

If there is an engine operation problem, then the cause could be any one of many items, including the engine itself. The condition of the engine should be tested anytime the operation of the engine is not satisfactory.

TYPICAL ENGINE-RELATED COMPLAINTS

Many driveability problems are *not* caused by engine mechanical problems. A thorough inspection and testing of the ignition and fuel systems should be performed before testing for mechanical engine problems.

Typical engine mechanical-related complaints include the following:

- Excessive oil consumption
- Engine misfiring
- Loss of power
- Smoke from the engine or exhaust
- Engine noise

ENGINE SMOKE DIAGNOSIS

The color of engine exhaust smoke can indicate what engine problem might exist.

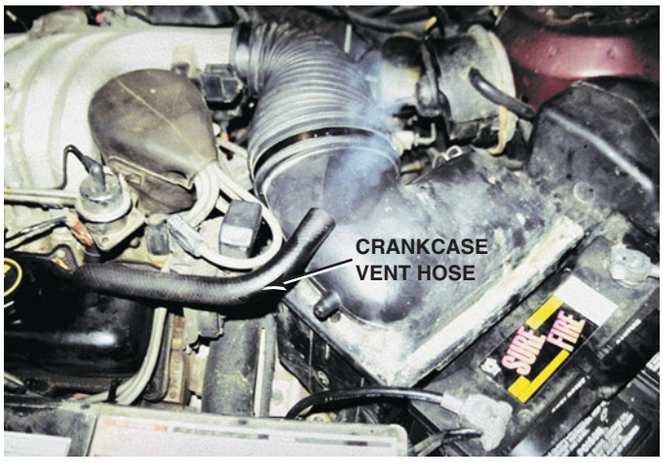


FIGURE 26–1 Blowby gases coming out of the crankcase vent hose. Excessive amounts of combustion gases flow past the piston rings and into the crankcase.



FIGURE 26–2 White steam is usually an indication of a blown (defective) cylinder head gasket that allows engine coolant to flow into the combustion chamber where it is turned to steam.

Typical Exhaust Smoke Color	Possible Causes
Blue	Blue exhaust indicates that the engine is burning oil. Oil is getting into the combustion chamber either past the piston rings or past the valve stem seals. Blue smoke only after start-up is usually due to defective valve stem seals. ● **SEE FIGURE 26–1**.
Black	Black exhaust smoke is due to excessive fuel being burned in the combustion chamber. Typical causes include a defective or misadjusted throttle body, leaking fuel injector, or excessive fuel-pump pressure.
White (steam)	White smoke or steam from the exhaust is normal during cold weather and represents condensed steam. Every engine creates about 1 gallon of water for each gallon of gasoline burned. If the steam from the exhaust is excessive, then water (coolant) is getting into the combustion chamber. Typical causes include a defective cylinder head gasket, a cracked cylinder head, or in severe cases a cracked block. ● **SEE FIGURE 26–2**.

Note: White smoke can also be created when automatic transmission fluid (ATF) is burned. A common source of ATF getting into the engine is through a defective vacuum modulator valve on older automatic transmissions.

THE DRIVER IS YOUR BEST RESOURCE

The driver of the vehicle knows a lot about the vehicle and how it is driven. *Before* diagnosis is started, always ask the following questions.

- When did the problem first occur?
- Under what conditions does it occur?
  1. Cold or hot?
  2. Acceleration, cruise, or deceleration?
  3. How far was it driven?
  4. What recent repairs have been performed?

After the nature and scope of the problem are determined, the complaint should be verified before further diagnostic tests are performed.

VISUAL CHECKS

The first and most important "test" that can be performed is a careful visual inspection.

OIL LEVEL AND CONDITION

The first area for visual inspection is oil level and condition.

1. Oil level—oil should be to the proper level
2. Oil condition
   - **a.** Using a match or lighter, try to light the oil on the dipstick; if the oil flames up, gasoline is present in the engine oil.
   - **b.** Drip some of the engine oil from the dipstick onto the hot exhaust manifold. If the oil bubbles or boils, there is coolant (water) in the oil.
   - **c.** Check for grittiness by rubbing the oil between your fingers.

COOLANT LEVEL AND CONDITION

Most mechanical engine problems are caused by overheating. The proper operation of the cooling system is critical to the life of any engine.

NOTE: Check the coolant level in the radiator only if the radiator is cool. If the radiator is hot and the radiator cap is removed, the drop in pressure above the coolant will cause the coolant to boil immediately and can cause severe burns when the coolant explosively expands upward and outward from the radiator opening.

1. The coolant level in the coolant recovery container should be within the limits indicated on the overflow bottle. If this level is too low or the coolant recovery container is empty, then check the level of coolant in the radiator (only when cool) and also check the operation of the pressure cap.

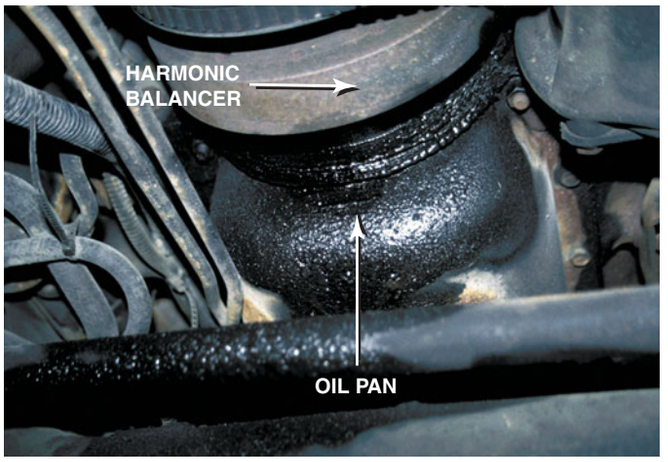


FIGURE 26–3 What looks like an oil pan gasket leak can be a rocker cover gasket leak. Always look up and look for the highest place you see oil leaking; that should be repaired first.

TECH TIP

Your Nose Knows

Whenever diagnosing any vehicle try to use all senses including smell. Some smells and their cause include:

- **Gasoline.** If the exhaust smells like gasoline or unburned fuel, then a fault with the ignition system is a likely cause. Unburned fuel due to lean air-fuel mixture causing a lean misfire is also possible.
- **Sweet smell.** A coolant leak often gives off a sweet smell especially if the leaking coolant flows onto the hot exhaust.
- **Exhaust smell.** Check for an exhaust leak including a possible cracked exhaust manifold which can be difficult to find because it often does not make noise.

2. The coolant should be checked with a hydrometer for boiling and freezing temperature. This test indicates if the concentration of the antifreeze is sufficient for proper protection.
3. Pressure test the cooling system and look for leakage. Coolant leakage can often be seen around hoses or cooling system components because it will often cause:
   a. A grayish white stain
   b. A rusty color stain
   c. Dye stains from antifreeze (greenish or yellowish depending on the type of coolant)
4. Check for cool areas of the radiator indicating clogged sections.
5. Check operation and condition of the fan clutch, fan, and coolant pump drive belt.

OIL LEAKS Oil leaks can lead to severe engine damage if the resulting low oil level is not corrected. Besides causing an oily mess where the vehicle is parked, the oil leak can cause blue smoke to occur under the hood as leaking oil drips on the exhaust system. *Finding* the location of the oil leak can often be difficult. ● **SEE FIGURES 26–3 AND 26–4**. To help find the source of oil leaks follow these steps:

STEP 1 Clean the engine or area around the suspected oil leak. Use a high-powered hot-water spray to wash the engine. While the engine is running, spray the entire engine and the engine compartment. Avoid letting the water come into direct contact with the air inlet and ignition distributor or ignition coil(s).

NOTE: If the engine starts to run rough or stalls when the engine gets wet, then the secondary ignition wires (spark plug wires) or distributor cap may be defective or have weak insulation. Be certain to wipe all wires and the distributor cap dry with a soft, dry cloth if the engine stalls.

An alternative method is to spray a degreaser on the engine, then start and run the engine until warm. Engine heat helps



FIGURE 26–4 The transmission and flexplate (flywheel) were removed to check the exact location of this oil leak. The rear main seal and/or the oil pan gasket could be the cause of this leak.

TECH TIP

What's Leaking?

The color of the leaks observed under a vehicle can help the technician determine and correct the cause. Some leaks, such as condensate (water) from the air-conditioning system, are normal, whereas a brake fluid leak is very dangerous. The following are colors of common leaks.

Sooty Black	Engine Oil
Yellow, green, blue, or orange	Antifreeze (coolant)
Red	Automatic transmission fluid
Murky brown	Brake or power steering fluid or very neglected antifreeze (coolant)
Clear	Air-conditioning condensate (water) (normal)



FIGURE 26–5 Using a black light to spot leaks after adding dye to the oil.

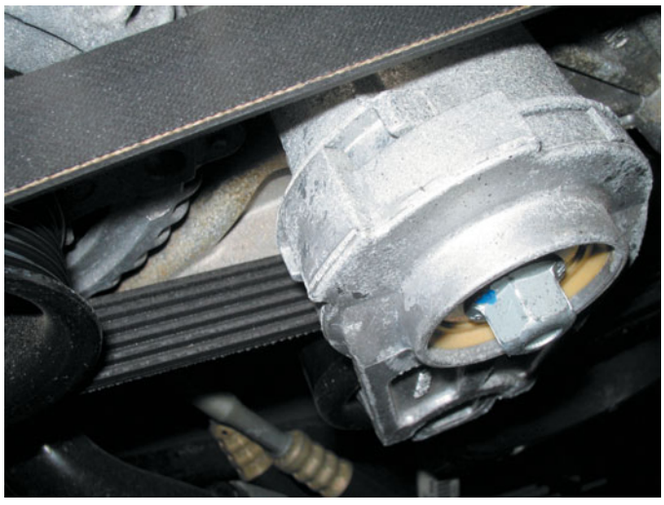


FIGURE 26–6 An accessory belt tensioner. Most tensioners have a mark that indicates normal operating location. If the belt has stretched, this indicator mark will be outside of the normal range. Anything wrong with the belt or tensioner can cause noise.

the degreaser penetrate the grease and dirt. Use a water hose to rinse off the engine and engine compartment.

STEP 2 If the oil leak is not visible or oil seems to be coming from "everywhere," use a white talcum powder. The leaking oil will show as a dark area on the white powder. See the Tech Tip, "The Foot Powder Spray Trick."

STEP 3 Fluorescent dye can be added to the engine oil. Add about 1/2 oz (15 cc) of dye per 5 quarts of engine oil. Start the engine and allow it to run about 10 minutes to thoroughly mix the dye throughout the engine. A black light can then be shown around every suspected oil leak location. The black light will easily show all oil leak locations because the dye will show as a bright yellow/green area. ● **SEE FIGURE 26–5**.

NOTE: Fluorescent dye works best with clean oil.

TECH TIP

The Foot Powder Spray Trick

The source of an oil or other fluid leak is often difficult to determine. A quick and easy method that works is the following. First, clean the entire area. This can best be done by using a commercially available degreaser to spray the entire area. Let it soak to loosen all accumulated oil and greasy dirt. Clean off the degreaser with a water hose. Let the area dry. Start the engine, and using spray foot powder or other aerosol powder product, spray the entire area. The leak will turn the white powder dark. The exact location of any leak can be quickly located.

NOTE: Most oil leaks appear at the bottom of the engine due to gravity. Look for the highest, most forward location for the source of the leak.

ENGINE NOISE DIAGNOSIS

An engine knocking noise is often difficult to diagnose. Several items that can cause a deep engine knock include:

- **Valves clicking.** This can happen because of lack of oil to the lifters. This noise is most noticeable at idle when the oil pressure is the lowest.
- **Torque converter.** The attaching bolts or nuts may be loose on the flex plate. This noise is most noticeable at idle or when there is no load on the engine.
- **Cracked flex plate.** The noise of a cracked flex plate is often mistaken for a rod- or main-bearing noise.
- **Loose or defective drive belts or tensioners.** If an accessory drive belt is loose or defective, the flopping noise often sounds similar to a bearing knock. ● **SEE FIGURE 26–6**.
- **Piston pin knock.** This knocking noise is usually not affected by load on the cylinder. If the clearance is too great, a double knock noise is heard when the engine idles. If all cylinders are grounded out one at a time and the noise does not change, a defective piston pin could be the cause.
- **Piston slap.** A piston slap is usually caused by an undersized or improperly shaped piston or oversized cylinder bore. A piston slap is most noticeable when the engine is cold and tends to decrease or stop making noise as the piston expands during engine operation.
- **Timing chain noise.** An excessively loose timing chain can cause a severe knocking noise when the chain hits the timing chain cover. This noise can often sound like a rod-bearing knock.
- **Rod-bearing noise.** The noise from a defective rod bearing is usually load sensitive and changes in intensity as the load on the engine increases and decreases. A rod-bearing failure can often be detected by grounding out the spark plugs one cylinder at a time. If the knocking noise decreases or is eliminated when a particular cylinder is grounded (disabled), then the grounded cylinder is the one from which the noise is originating.
- **Main-bearing knock.** A main-bearing knock often cannot be isolated to a particular cylinder. The sound can vary in intensity and may disappear at times depending on engine load.

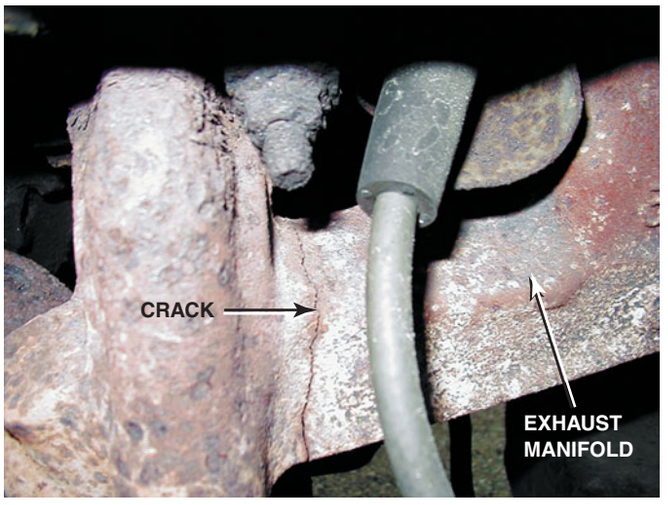


FIGURE 26–7 A cracked exhaust manifold on a Ford V-8.

Typical Noises	Possible Causes
Clicking noise—like the clicking of a ballpoint pen	1. Loose spark plug 2. Loose accessory mount (for air-conditioning compressor, alternator, power steering pump, etc.) 3. Loose rocker arm 4. Worn rocker arm pedestal 5. Fuel pump (broken mechanical fuel pump return spring) 6. Worn camshaft 7. Exhaust leak ● **SEE FIGURE 26–7.**
Clacking noise—like tapping on metal	1. Worn piston pin 2. Broken piston 3. Excessive valve clearance 4. Timing chain hitting cover
Knock—like knocking on a door	1. Rod bearing(s) 2. Main bearing(s) 3. Thrust bearing(s) 4. Loose torque converter 5. Cracked flex plate (drive plate)
Rattle—like a baby rattle	1. Manifold heat control valve 2. Broken harmonic balancer 3. Loose accessory mounts 4. Loose accessory drive belt or tensioner
Clatter—like rolling marbles	1. Rod bearings 2. Piston pin 3. Loose timing chain
Whine—like an electric motor running	1. Alternator bearing 2. Drive belt 3. Power steering 4. Belt noise (accessory or timing)
Clunk—like a door closing	1. Engine mount 2. Drive axle shaft U-joint or constant velocity (CV) joint

Regardless of the type of loud knocking noise, after the external causes of the knocking noise have been eliminated, the engine should be disassembled and carefully inspected to determine the exact cause.

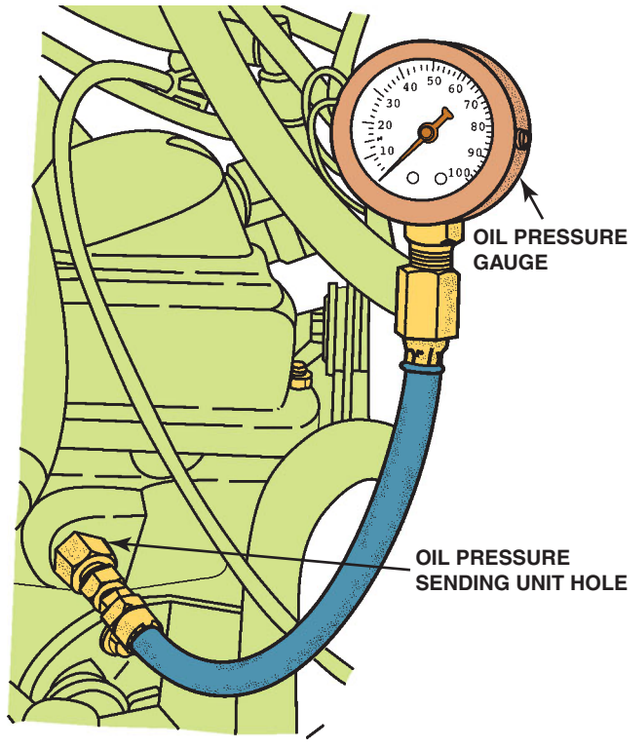


FIGURE 26–8 To measure engine oil pressure, remove the oil pressure sending (sender) unit usually located near the oil filter. Screw the pressure gauge into the oil pressure sending unit hole.

TECH TIP

Engine Noise and Cost

A light ticking noise often heard at one-half engine speed and associated with valve train noise is a less serious problem than many deep-sounding knocking noises. Generally, the deeper the sound of the engine noise, the more the owner will have to pay for repairs. A light "tick tick tick," though often not cheap, is usually far less expensive than a deep "knock knock knock" from the engine.

OIL PRESSURE TESTING

Proper oil pressure is very important for the operation of any engine. *Low oil pressure can cause engine wear, and engine wear can cause low oil pressure.*

If main thrust or rod bearings are worn, oil pressure is reduced because of leakage of the oil around the bearings. Oil pressure testing is usually performed with the following steps.

STEP 1 Operate the engine until normal operating temperature is achieved.

STEP 2 With the engine off, remove the oil pressure sending unit or sender, usually located near the oil filter. Thread an oil pressure gauge into the threaded hole. ● **SEE FIGURE 26–8.**

NOTE: An oil pressure gauge can be made from another gauge, such as an old air-conditioning gauge and a flexible brake hose. The threads are often the same as those used for the oil pressure sending unit.

TECH TIP

Use the KISS Test Method

Engine testing is done to find the cause of an engine problem. All the simple things should be tested first. Just remember KISS—"keep it simple, stupid." A loose alternator belt or loose bolts on a torque converter can sound just like a lifter or rod bearing. A loose spark plug can make the engine perform as if it had a burned valve. Some simple items that can cause serious problems include the following:

Oil Burning

- Low oil level
- Clogged PCV valve or system, causing blowby and oil to be blown into the air cleaner
- Clogged drainback passages in the cylinder head
- Dirty oil that has not been changed for a long time (Change the oil and drive for about 1,000 miles, or 1,600 km, and change the oil and filter again.)

Noises

- Carbon on top of the piston(s) can sound like a bad rod bearing (often called a carbon knock)
- Loose torque-to-flex plate bolts (or nuts), causing a loud knocking noise

NOTE: Often this problem will cause noise only at idle; the noise tends to disappear during driving or when the engine is under load.

- A loose and/or defective drive belt, which may cause a rod- or main-bearing knocking noise (A loose or broken mount for the generator [alternator], power steering pump, or air-conditioning compressor can also cause a knocking noise.)

STEP 3 Start the engine and observe the gauge. Record the oil pressure at idle and at 2500 RPM. Most vehicle manufacturers recommend a minimum oil pressure of 10 PSI per 1000 RPM. Therefore, at 2500 RPM, the oil pressure should be at least 25 PSI. Always compare your test results with the manufacturer's recommended oil pressure.

Besides engine bearing wear, other possible causes for low oil pressure include:

- Low oil level
- Diluted oil
- Stuck oil pressure relief valve

OIL PRESSURE WARNING LAMP

The red oil pressure warning lamp in the dash usually lights when the oil pressure is less than 4 to 7 PSI, depending on vehicle and engine. The oil light should not be on during driving. If the oil warning lamp is on, stop the engine immediately. Always confirm oil pressure with a reliable mechanical gauge before performing engine repairs. The sending unit or circuit may be defective.

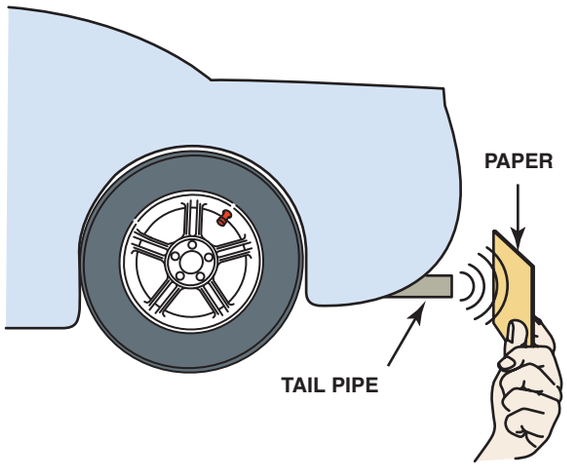


FIGURE 26–9 The paper test involves holding a piece of paper near the tailpipe of an idling engine. A good engine should produce even, outward puffs of exhaust. If the paper is sucked in toward the tailpipe, a burned valve is a possibility.

TECH TIP

The Paper Test

A soundly running engine should produce even and steady exhaust at the tailpipe. You can test this with the **paper test.** Hold a piece of paper or a 3″ × 5″ index card (even a dollar bill works) within 1 in. (25 mm) of the tailpipe with the engine running at idle. ● **SEE FIGURE 26–9.**

The paper should blow out evenly without "puffing." If the paper is drawn *toward* the tailpipe at times, the exhaust valves in one or more cylinders could be burned. Other reasons why the paper might be sucked toward the tailpipe include the following:

1. The engine could be misfiring because of a lean condition that could occur normally when the engine is cold.
2. Pulsing of the paper toward the tailpipe could also be caused by a hole in the exhaust system. If exhaust escapes through a hole in the exhaust system, air could be drawn in during the intervals between the exhaust puffs from the tailpipe to the hole in the exhaust, causing the paper to be drawn toward the tailpipe.
3. Ignition fault causing misfire.

COMPRESSION TEST

An engine **compression test** is one of the fundamental engine diagnostic tests that can be performed. For smooth engine operation, all cylinders must have equal compression. An engine can lose compression by leakage of air through one or more of only three routes.

- Intake or exhaust valve
- Piston rings (or piston, if there is a hole)
- Cylinder head gasket

For best results, the engine should be warmed to normal operating temperature before testing. An accurate compression test should be performed as follows:

STEP 1 Remove all spark plugs. This allows the engine to be cranked to an even speed. Be sure to label all spark plug wires.



FIGURE 26–10 A two-piece compression gauge set. The threaded hose is screwed into the spark plug hole after removing the spark plug. The gauge part is then snapped onto the end of the hose.

CAUTION: Disable the ignition system by disconnecting the primary leads from the ignition coil or module or by grounding the coil wire after removing it from the center of the distributor cap. Also disable the fuel-injection system to prevent the squirting of fuel into the cylinder.

STEP 2 Block open the throttle. This permits the maximum amount of air to be drawn into the engine. This step also ensures consistent compression test results.

STEP 3 Thread a compression gauge into one spark plug hole and crank the engine. ● **SEE FIGURE 26–10.**

Continue cranking the engine through *four* compression strokes. Each compression stroke makes a puffing sound.

NOTE: Note the reading on the compression gauge after the first puff. This reading should be at least one-half the final reading. For example, if the final, highest reading is 150 PSI, then the reading after the first puff should be higher than 75 PSI. A low first-puff reading indicates possible weak piston rings. Release the pressure on the gauge and repeat for the other cylinders.

STEP 4 Record the highest readings and compare the results. Most vehicle manufacturers specify the minimum compression reading and the maximum allowable variation among cylinders. Most manufacturers specify a maximum difference of 20% between the highest reading and the lowest reading. For example:

If the high reading is	**150 PSI**
Subtract 20%	**−30 PSI**
Lowest allowable compression is	**120 PSI**

NOTE: To make the math quick and easy, think of 10% of 150, which is 15 (move the decimal point to the left one place). Now double it: 15 × 2 = 30. This represents 20%.

NOTE: During cranking, the oil pump cannot maintain normal oil pressure. Extended engine cranking, such as that which occurs during a compression test, can cause hydraulic lifters to collapse. When the engine starts, loud valve clicking noises may be heard. This should be considered normal after performing a compression test, and the noise should stop after the vehicle has been driven a short distance.

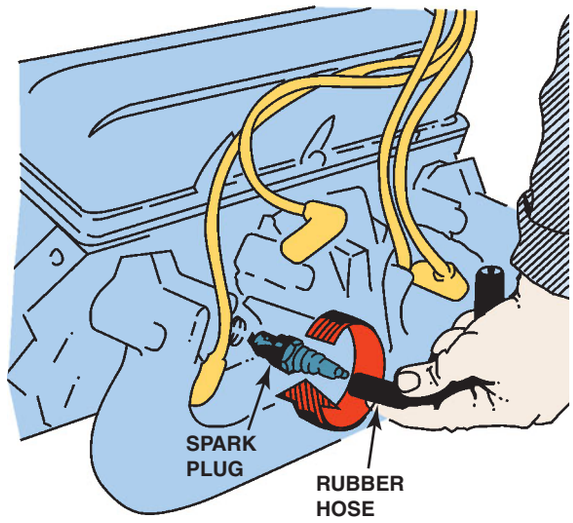


FIGURE 26–11 Use a vacuum or fuel line hose over the spark plug to install it without danger of cross-threading the cylinder head.

TECH TIP

The Hose Trick

Installing spark plugs can be made easier by using a rubber hose on the end of the spark plug. The hose can be a vacuum hose, fuel line, or even an old spark plug wire end. ● **SEE FIGURE 26–11.**

The hose makes it easy to start the threads of the spark plug into the cylinder head. After starting the threads, continue to thread the spark plug for several turns. Using the hose eliminates the chance of cross-threading the plug. This is especially important when installing spark plugs in aluminum cylinder heads.

WET COMPRESSION TEST

If the compression test reading indicates low compression on one or more cylinders, add three squirts of oil to the cylinder and retest. This is called a **wet compression test,** when oil is used to help seal around the piston rings.

CAUTION: Do not use more oil than three squirts from a hand-operated oil squirt can. Too much oil can cause a hydrostatic lock, which can damage or break pistons or connecting rods or even crack a cylinder head.

Perform the compression test again and observe the results. If the first-puff readings greatly improve and the readings are much higher than without the oil, the cause of the low compression is worn or defective piston rings. If the compression readings increase only slightly (or not at all), then the cause of the low compression is usually defective valves. ● **SEE FIGURE 26–12.**

NOTE: During both the dry and wet compression tests, be sure that the battery and starting system are capable of cranking the engine at normal cranking speed.

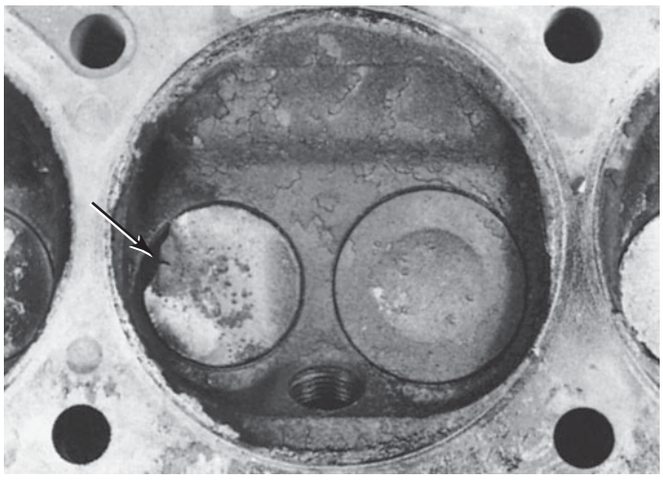


FIGURE 26–12 Badly burned exhaust valve. A compression test could have detected a problem, and a cylinder leakage test (leak-down test) could have been used to determine the exact problem.

RUNNING (DYNAMIC) COMPRESSION TEST

A compression test is commonly used to help determine engine condition and is usually performed with the engine cranking.

What is the RPM of a cranking engine? An engine idles at about 600 to 900 RPM, and the starter motor obviously cannot crank the engine as fast as the engine idles. Most manufacturers' specifications require the engine to crank at 80 to 250 cranking RPM. Therefore, a check of the engine's compression at cranking speed determines the condition of an engine that does not run at such low speeds.

But what should be the compression of a running engine? Some would think that the compression would be substantially higher, because the valve overlap of the cam is more effective at higher engine speeds, which would tend to increase the compression.

A **running compression test,** also called a **dynamic compression test,** is done with the engine running rather than during engine cranking as is done in a regular compression test.

Actually, the compression pressure of a running engine is much *lower* than cranking compression pressure. This results from the volumetric efficiency. The engine is revolving faster, and therefore, there is less *time* for air to enter the combustion chamber. With less air to compress, the compression pressure is lower. Typically, the higher the engine RPM, the lower the running compression. For most engines, the value ranges are as follows:

- Compression during cranking: 125 to 160 PSI
- Compression at idle: 60 to 90 PSI
- Compression at 2,000 RPM: 30 to 60 PSI

As with cranking compression, the running compression of all cylinders should be equal. Therefore, a problem is not likely to be detected by single compression values, but by *variations* in running compression values among the cylinders. Broken valve springs, worn valve guides, bent pushrods, and worn cam lobes are some items that would be indicated by a low running compression test reading on one or more cylinders.



FIGURE 26–13 A typical handheld cylinder leakage tester.



FIGURE 26–14 A whistle stop used to find top dead center. Remove the spark plug and install the whistle stop, then rotate the engine by hand. When the whistle stops making a sound, the piston is at the top.

PERFORMING A RUNNING COMPRESSION TEST

To perform a running compression test, remove just one spark plug at a time. With one spark plug removed from the engine, use a jumper wire to *ground* the spark plug wire to a good engine ground. This prevents possible ignition coil damage. Start the engine, push the pressure release on the gauge, and read the compression. Increase the engine speed to about 2,000 RPM and push the pressure release on the gauge again. Read the gauge. Stop the engine, reinstall the spark plug, reattach the spark plug wire, and repeat the test for each of the remaining cylinders. Just like the cranking compression test, the running compression test can inform a technician of the *relative* compression of all the cylinders.

CYLINDER LEAKAGE TEST

One of the best tests that can be used to determine engine condition is the **cylinder leakage test.** This test involves injecting air under pressure into the cylinders one at a time. The amount and location of any escaping air helps the technician determine the condition of the engine. The air is injected into the cylinder through a cylinder leakage gauge into the spark plug hole. ● **SEE FIGURE 26–13**. To perform the cylinder leakage test, take the following steps:

STEP 1 For best results, the engine should be at normal operating temperature (upper radiator hose hot and pressurized).

STEP 2 The cylinder being tested must be at top dead center (TDC) of the compression stroke. ● **SEE FIGURE 26–14**.

NOTE: The greatest amount of wear occurs at the top of the cylinder because of the heat generated near the top of the cylinders. The piston ring flex also adds to the wear at the top of the cylinder.

STEP 3 Calibrate the cylinder leakage unit as per manufacturer's instructions.

STEP 4 Inject air into the cylinders one at a time, rotating the engine as necessitated by firing order to test each cylinder at TDC on the compression stroke.

STEP 5 Evaluate the results:
Less than 10% leakage: good
Less than 20% leakage: acceptable
Less than 30% leakage: poor
More than 30% leakage: definite problem

NOTE: If leakage seems unacceptably high, repeat the test, being certain that it is being performed correctly and that the cylinder being tested is at TDC on the compression stroke.

STEP 6 Check the source of air leakage.

a. If air is heard escaping from the oil filler cap, the *piston rings* are worn or broken.
b. If air is observed bubbling out of the radiator, there is a possible blown *head gasket* or cracked *cylinder head.*
c. If air is heard coming from the throttle body or air inlet on fuel-injection-equipped engines, there is a defective *intake valve(s).*
d. If air is heard coming from the tailpipe, there is a defective *exhaust valve(s).*

CYLINDER POWER BALANCE TEST

Most large engine analyzers and scan tools have a cylinder power balance feature. The purpose of a cylinder **power balance test** is to determine if all cylinders are contributing power equally. It determines this by shorting out one cylinder at a time. If the engine speed (RPM) does not drop as much for one cylinder as for other cylinders of the same engine, then the shorted cylinder must be weaker than the other cylinders. For example:

Cylinder Number	RPM Drop When Ignition Is Shorted
1	75
2	70
3	15
4	65
5	75
6	70

Cylinder 3 is the weak cylinder.

NOTE: Most automotive test equipment uses automatic means for testing cylinder balance. Be certain to correctly identify the offending cylinder. Cylinder 3 as identified by the equipment may be the third cylinder in the firing order instead of the actual cylinder 3.

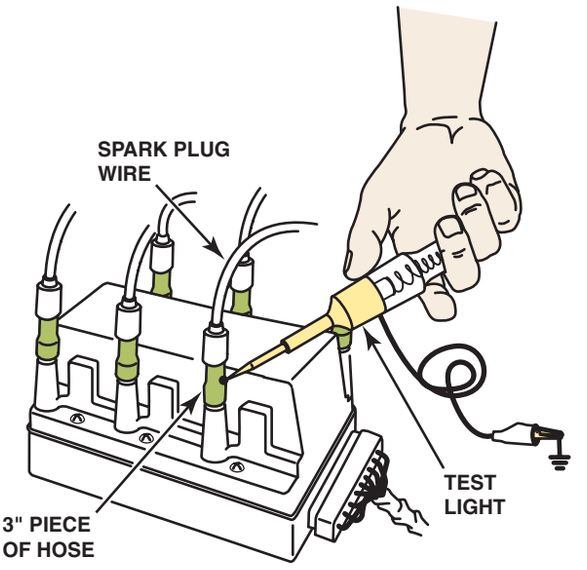


FIGURE 26–15 Using a vacuum hose and a test light to ground one cylinder at a time on a distributorless ignition system. This works on all types of ignition systems and provides a method for grounding out one cylinder at a time without fear of damaging any component. To avoid possible damage to the catalytic converter, do not short out a cylinder for longer than five seconds.

POWER BALANCE TEST PROCEDURE

When point-type ignition was used on all vehicles, the common method for determining which, if any, cylinder was weak was to remove a spark plug wire from one spark plug at a time while watching a tachometer and a vacuum gauge. This method is not recommended on any vehicle with any type of electronic ignition. If any of the spark plug wires are removed from a spark plug with the engine running, the ignition coil tries to supply increasing levels of voltage attempting to jump the increasing gap as the plug wires are removed. This high voltage could easily track the ignition coil, damage the ignition module, or both.

The acceptable method of canceling cylinders, which will work on all types of ignition systems, including distributorless, is to *ground* the secondary current for each cylinder. ● **SEE FIGURE 26–15**. The cylinder with the least RPM drop is the cylinder not producing its share of power.

VACUUM TESTS

Vacuum is pressure below atmospheric pressure and is measured in **inches** (or millimeters) **of mercury** (Hg). An engine in good mechanical condition will run with high manifold vacuum. Manifold vacuum is developed by the pistons as they move down on the intake stroke to draw the charge from the throttle body and intake manifold. Air to refill the manifold comes past the throttle plate into the manifold. Vacuum will increase anytime the engine turns faster or has better cylinder sealing while the throttle plate remains in a fixed position. Manifold vacuum will decrease when the engine turns more slowly or when the cylinders no longer do an efficient job of pumping.

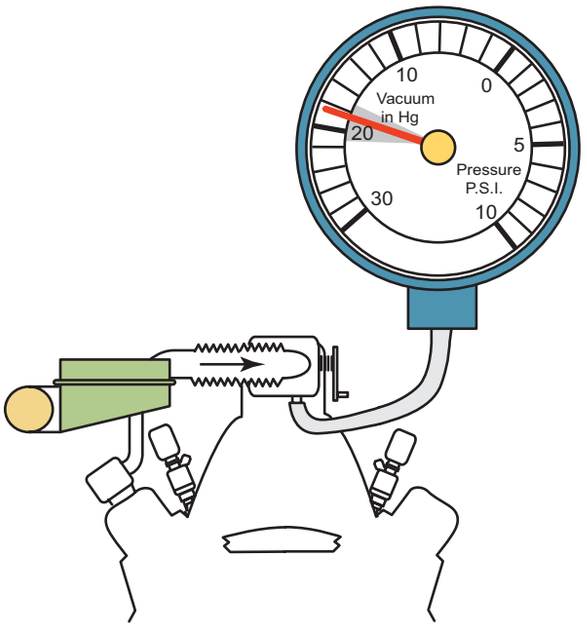


FIGURE 26–16 An engine in good mechanical condition should produce 17 to 21 in. Hg of vacuum at idle at sea level.

Vacuum tests include testing the engine for **cranking vacuum, idle vacuum,** and vacuum at 2,500 RPM.

CRANKING VACUUM TEST

Measuring the amount of manifold vacuum during cranking is a quick and easy test to determine if the piston rings and valves are properly sealing. (For accurate results, the engine should be warm and the throttle closed.) To perform the cranking vacuum test, take the following steps.

STEP 1 Disable the ignition or fuel injection.

STEP 2 Connect the vacuum gauge to a manifold vacuum source.

STEP 3 Crank the engine while observing the vacuum gauge.

Cranking vacuum should be higher than 2.5 in. Hg. (Normal cranking vacuum is 3 to 6 in. Hg.) If it is lower than 2.5 in. Hg, then the following could be the cause.

- Too slow a cranking speed
- Worn piston rings
- Leaking valves
- Excessive amounts of air bypassing the throttle plate (This could give a false low vacuum reading. Common sources include a throttle plate partially open or a high-performance camshaft with excessive overlap.)

IDLE VACUUM TEST

An engine in proper condition should idle with a steady vacuum between 17 and 21 in. Hg. ● **SEE FIGURE 26–16**.

NOTE: Engine vacuum readings vary with altitude. A reduction of 1 in. Hg per 1,000 ft (300 m) of altitude should be subtracted from the expected values if testing a vehicle above 1,000 ft (300 m).

LOW AND STEADY VACUUM

If the vacuum is lower than normal, yet the gauge reading is steady, the most common causes include:

- Retarded ignition timing
- Retarded cam timing (check timing chain for excessive slack or timing belt for proper installation) ● **SEE FIGURE 26–17**.

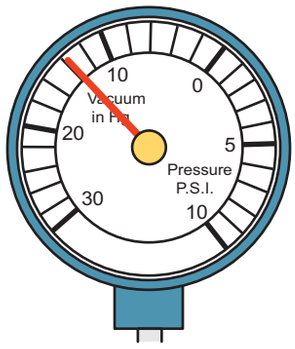


FIGURE 26–17 A steady but low reading could indicate retarded valve or ignition timing.

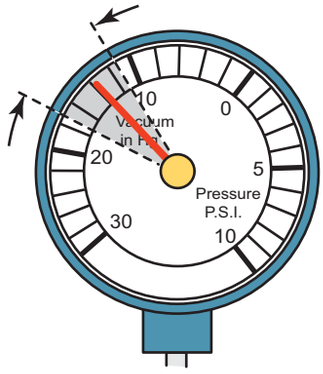


FIGURE 26–18 A gauge reading with the needle fluctuating 3 to 9 in. Hg below normal often indicates a vacuum leak in the intake system.

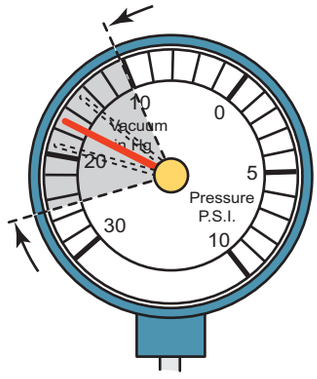


FIGURE 26–19 A leaking head gasket can cause the needle to vibrate as it moves through a range from below to above normal.

FLUCTUATING VACUUM

If the needle drops, then returns to a normal reading, then drops again, and again returns, this indicates a sticking valve. A common cause of sticking valves is lack of lubrication of the valve stems. ● **SEE FIGURES 26–18 THROUGH 26–26**. If the vacuum gauge fluctuates above and below a center point, burned valves or weak valve springs may be indicated. If the fluctuation is slow and steady, unequal fuel mixture could be the cause.

NOTE: A common trick that some technicians use is to squirt some automatic transmission fluid (ATF) down the throttle body or into the air inlet of a warm engine. Often the idle quality improves and normal vacuum gauge readings are restored. The use of ATF does create excessive exhaust smoke for a short time, but it should not harm oxygen sensors or catalytic converters.

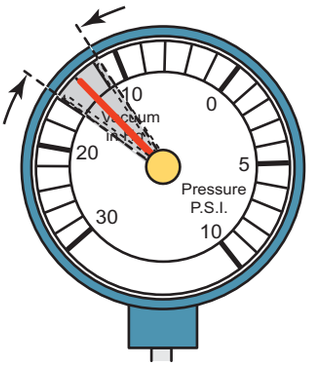


FIGURE 26–20 An oscillating needle 1 or 2 in. Hg below normal could indicate an incorrect air-fuel mixture (either too rich or too lean).

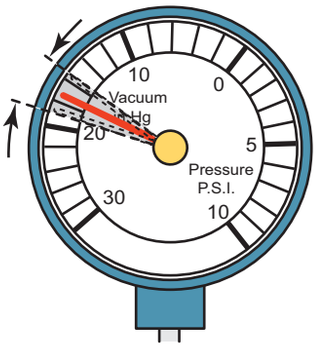


FIGURE 26–21 A rapidly vibrating needle at idle that becomes steady as engine speed is increased indicates worn valve guides.

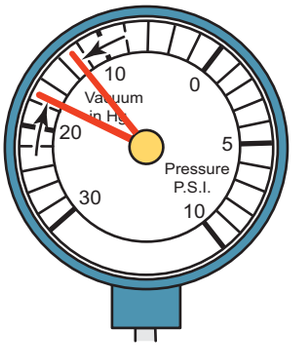


FIGURE 26–22 If the needle drops 1 or 2 in. Hg from the normal reading, one of the engine valves is burned or not seating properly.

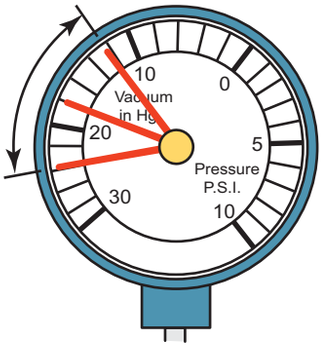


FIGURE 26–23 Weak valve springs will produce a normal reading at idle, but as engine speed increases, the needle will fluctuate rapidly between 12 and 24 in. Hg.

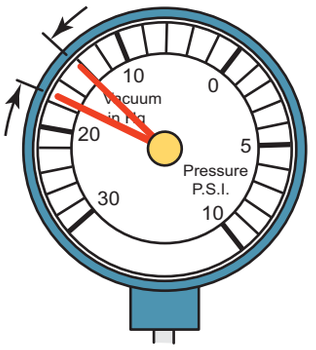


FIGURE 26–24 A steady needle reading that drops 2 or 3 in. Hg when the engine speed is increased slightly above idle indicates that the ignition timing is retarded.

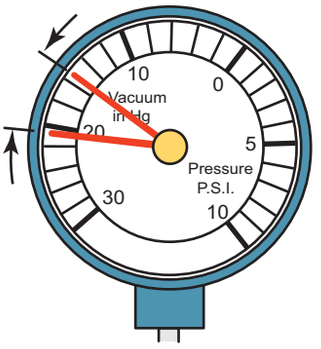


FIGURE 26–25 A steady needle reading that rises 2 or 3 in. Hg when the engine speed is increased slightly above idle indicates that the ignition timing is advanced.

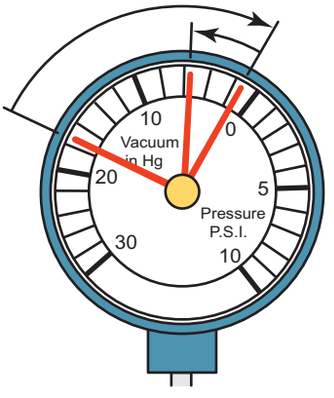


FIGURE 26–26 A needle that drops to near zero when the engine is accelerated rapidly and then rises slightly to a reading below normal indicates an exhaust restriction.

EXHAUST RESTRICTION TEST

If the exhaust system is restricted, the engine will be low on power, yet smooth. Common causes of **restricted exhaust** include the following:

- **Clogged catalytic converter.** Always check the ignition and fuel-injection systems for faults that could cause excessive amounts of unburned fuel to be exhausted. Excessive unburned fuel can overheat the catalytic converter and cause the beads or structure of the converter to fuse together, creating the restriction. A defective fuel delivery system could also cause excessive unburned fuel to be dumped into the converter.

- **Clogged or restricted muffler.** This can cause low power. Often a defective catalytic converter will shed particles that can clog a muffler. Broken internal baffles can also restrict exhaust flow.
- **Damaged or defective piping.** This can reduce the power of any engine. Some exhaust pipe is constructed with double walls, and the inside pipe can collapse and form a restriction that is not visible on the outside of the exhaust pipe.

TESTING BACK PRESSURE WITH A VACUUM GAUGE

A vacuum gauge can be used to measure manifold vacuum at a high idle (2000 to 2500 RPM). If the exhaust system is restricted, pressure increases in the exhaust system. This pressure is called **back pressure.** Manifold vacuum will drop gradually if the engine is kept at a constant speed if the exhaust is restricted.

The reason the vacuum will drop is that all exhaust leaving the engine at the higher engine speed cannot get through the restriction. After a short time (within one minute), the exhaust tends to "pile up" above the restriction and eventually remains in the cylinder of the engine at the end of the exhaust stroke. Therefore, at the beginning of the intake stroke, when the piston traveling downward should be lowering the pressure (raising the vacuum) in the intake manifold, the extra exhaust in the cylinder *lowers* the normal vacuum. If the exhaust restriction is severe enough, the vehicle can become undriveable because cylinder filling cannot occur except at idle.

TESTING BACK PRESSURE WITH A PRESSURE GAUGE

- **With an oxygen sensor.** Use a back pressure gauge and adapter or remove the inside of an old, discarded oxygen sensor and thread in an adapter to convert to a vacuum or pressure gauge.
- **With the exhaust gas recirculation (EGR) valve.** Remove the EGR valve and fabricate a plate to connect to a pressure gauge.

  NOTE: An adapter can be easily made by inserting a metal tube or pipe. A short section of brake line works great. The pipe can be brazed to the oxygen sensor housing or it can be glued in with epoxy. An 18 mm compression gauge adapter can also be adapted to fit into the oxygen sensor opening. ● **SEE FIGURE 26–27.**

- **With the air-injection reaction (AIR) check valve.** Remove the check valve from the exhaust tubes leading down to the exhaust manifold. Use a rubber cone with a tube inside to seal against the exhaust tube. Connect the tube to a pressure gauge. Exhaust system back pressure can be measured directly by installing a pressure gauge into an exhaust opening. This can be accomplished in one of the following ways.

At idle, the maximum back pressure should be less than 1.5 PSI (10 kPa), and it should be less than 2.5 PSI (15 kPa) at 2500 RPM.

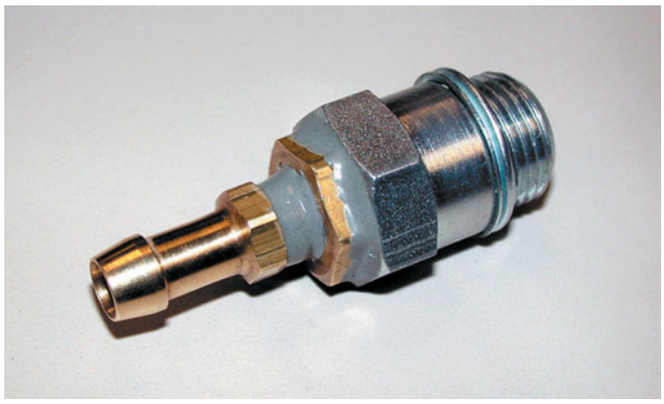


FIGURE 26–27 A technician-made adapter used to test exhaust system back pressure.



FIGURE 26–28 A tester that uses a blue liquid to check for exhaust gases in the exhaust, which would indicate a head gasket leak problem.

DIAGNOSING HEAD GASKET FAILURE

Several items can be used to help diagnose a head gasket failure.

- **Exhaust gas analyzer.** With the radiator cap removed, place the probe from the exhaust analyzer above the radiator filler neck. If the HC reading increases, the exhaust (unburned hydrocarbons) is getting into the coolant from the combustion chamber.
- **Chemical test.** A chemical tester using blue liquid is also available. The liquid turns yellow if combustion gases are present in the coolant. ● **SEE FIGURE 26–28.**
- **Bubbles in the coolant.** Remove the coolant pump belt to prevent pump operation. Remove the radiator cap and start the engine. If bubbles appear in the coolant before it begins to boil, a defective head gasket or cracked cylinder head is indicated.
- **Excessive exhaust steam.** If excessive water or steam is observed coming from the tailpipe, this means that coolant is getting into the combustion chamber from a defective head gasket or a cracked head. If there is leakage between cylinders, the engine usually misfires and a power balancer test and/or compression test can be used to confirm the problem.

If any of the preceding indicators of head gasket failure occur, remove the cylinder head(s) and check all of the following:

1. Head gasket
2. Sealing surfaces—for warpage
3. Castings—for cracks

NOTE: A leaking thermal vacuum valve can cause symptoms similar to those of a defective head gasket. Most thermal vacuum valves thread into a coolant passage, and they often leak only after they get hot.

DASH WARNING LIGHTS

Most vehicles are equipped with several dash warning lights often called "telltale" or "idiot" lights. These lights are often the only warning a driver receives that there may be engine problems. A summary of typical dash warning lights and their meanings follows.

OIL (ENGINE) LIGHT The red oil light indicates that the engine oil pressure is too low (usually lights when oil pressure is 4 to 7 PSI [20 to 50 kPa]). Normal oil pressure should be 10 to 60 PSI (70 to 400 kPa) or 10 PSI per 1000 engine RPM.

When this light comes on, the driver should shut off the engine immediately and check the oil level and condition for possible dilution with gasoline caused by a fuel system fault. If the oil level is okay, then there is a possible serious engine problem or a possible defective oil pressure sending (sender) unit. The automotive technician should always check the oil pressure using a reliable mechanical oil pressure gauge if low oil pressure is suspected.

NOTE: Some automobile manufacturers combine the dash warning lights for oil pressure and coolant temperature into one light, usually labeled "engine." Therefore, when the engine light comes on, the technician should check for possible coolant temperature and/or oil pressure problems.

COOLANT TEMPERATURE LIGHT Most vehicles are equipped with a coolant temperature gauge or dash warning light. The warning light may be labeled "coolant," "hot," or "temperature." If the coolant temperature warning light comes on during driving, this usually indicates that the coolant temperature is above a safe level, or above about 250°F (120°C). Normal coolant temperature should be about 200°F to 220°F (90°C to 105°C).

If the coolant temperature light comes on during driving, the following steps should be followed to prevent possible engine damage.

1. Turn off the air conditioning and turn on the heater. The heater will help get rid of some of the heat in the cooling system.
2. Raise the engine speed in neutral or park to increase the circulation of coolant through the radiator.
3. If possible, turn the engine off and allow it to cool (this may take over an hour).
4. Do not continue driving with the coolant temperature light on (or the gauge reading in the red warning section or above 260°F) or serious engine damage may result.

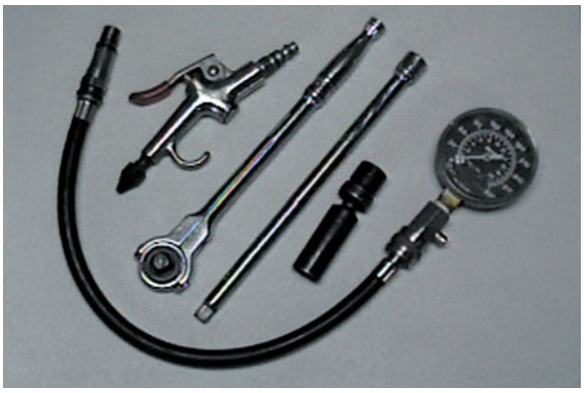
NOTE: If the engine does not feel or smell hot, it is possible that the problem is a faulty coolant temperature sensor or gauge.

TECH TIP

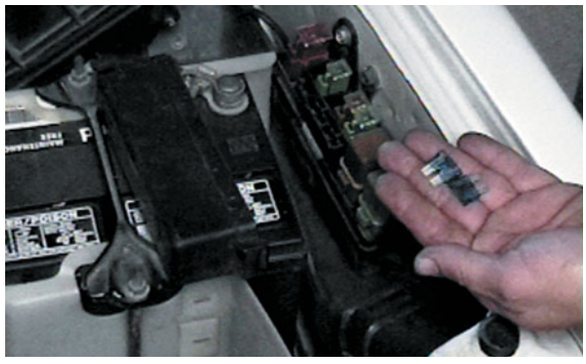
Misfire Diagnosis

If a misfire goes away with propane added to the air inlet, suspect a lean injector.

COMPRESSION TEST



1 The tools and equipment needed to perform a compression test include a compression gauge, an air nozzle, and the socket ratchets and extensions that may be necessary to remove the spark plugs from the engine.



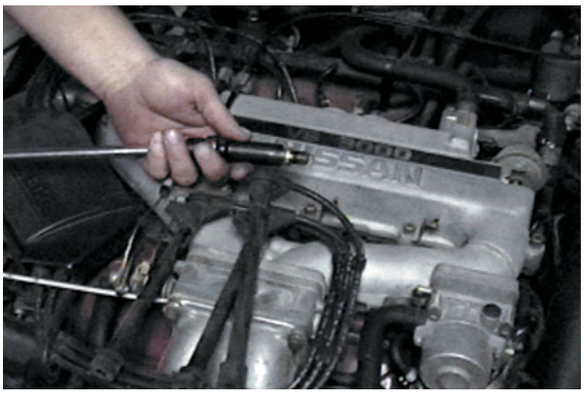
2 To prevent ignition and fuel-injection operation while the engine is being cranked, remove both the fuel-injection fuse and the ignition fuse. If the fuses cannot be removed, disconnect the wiring connectors for the injectors and the ignition system.



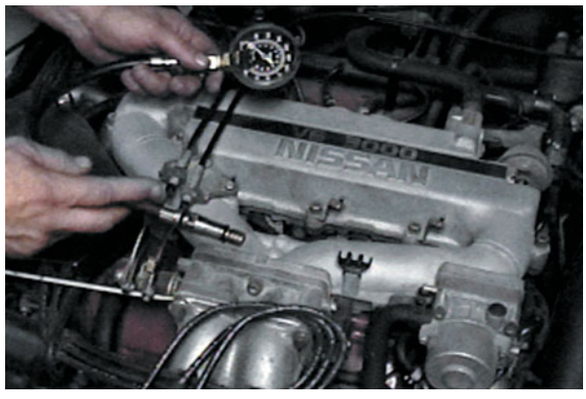
3 Block open the throttle (and choke, if the engine is equipped with a carburetor). Here a screwdriver is being used to wedge the throttle linkage open. Keeping the throttle open ensures that enough air will be drawn into the engine so that the compression test results will be accurate.



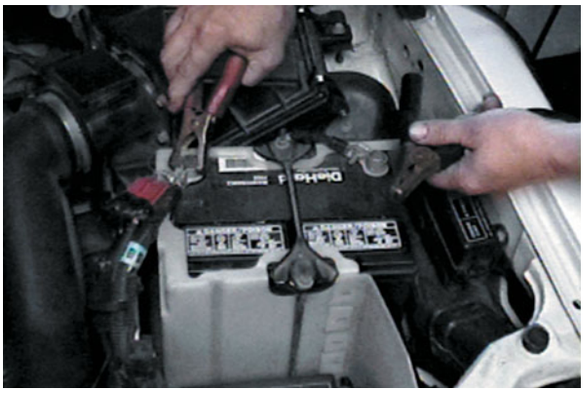
4 Before removing the spark plugs, use an air nozzle to blow away any dirt that may be around the spark plug. This step helps prevent debris from getting into the engine when the spark plugs are removed.



5 Remove all of the spark plugs. Be sure to mark the spark plug wires so that they can be reinstalled onto the correct spark plugs after the compression test has been performed.



6 Select the proper adapter for the compression gauge. The threads on the adapter should match those on the spark plug.



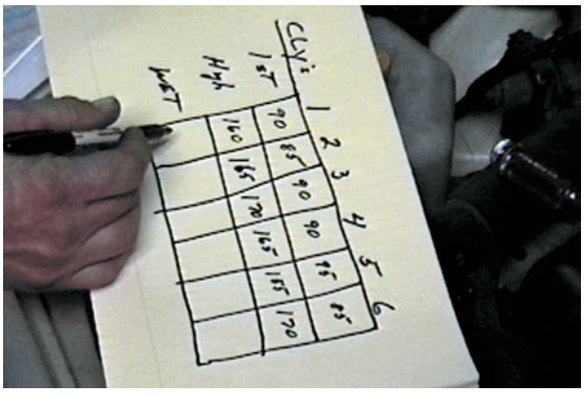
7 If necessary, connect a battery charger to the battery before starting the compression test. It is important that consistent cranking speed be available for each cylinder being tested.



8 Make a note of the reading on the gauge after the first "puff," which indicates the first compression stroke that occurred on that cylinder as the engine was being rotated. If the first puff reading is low and the reading gradually increases with each puff, weak or worn piston rings may be indicated.



9 After the engine has been cranked for four "puffs," stop cranking the engine and observe the compression gauge.



10 Record the first puff and this final reading for each cylinder. The final readings should all be within 20% of each other.



11 If a cylinder(s) is lower than most of the others, use an oil can and squirt two squirts of engine oil into the cylinder and repeat the compression test. This is called performing a wet compression test.



12 If the gauge reading is now much higher than the first test results, then the cause of the low compression is due to worn or defective piston rings. The oil in the cylinder temporarily seals the rings which causes the higher reading.

REVIEW QUESTIONS

1. Describe the visual checks that should be performed on an engine if a mechanical malfunction is suspected.
2. List three simple items that could cause excessive oil consumption.
3. List three simple items that could cause engine noises.
4. Describe how to perform a compression test and how to determine what is wrong with an engine based on a compression test result.
5. Describe the cylinder leakage test.
6. Describe how a vacuum gauge would indicate if the valves were sticking in their guides.
7. Describe the test procedure for determining if the exhaust system is restricted (clogged) using a vacuum gauge.

CHAPTER QUIZ

1. Technician A says that the paper test could detect a burned valve. Technician B says that a grayish white stain on the engine could be a coolant leak. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
2. Two technicians are discussing oil leaks. Technician A says that an oil leak can be found using a fluorescent dye in the oil with a black light to check for leaks. Technician B says that a white spray powder can be used to locate oil leaks. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
3. Which of the following is the *least likely* to cause an engine noise?
   a. Carbon on the pistons
   b. Cracked exhaust manifold
   c. Loose accessory drive belt
   d. Vacuum leak
4. A good engine should produce how much compression during a running (dynamic) compression test at idle?
   a. 150 to 200 PSI **c.** 60 to 90 PSI
   b. 100 to 150 PSI **d.** 30 to 60 PSI
5. A smoothly operating engine depends on _____.
   a. High compression on most cylinders
   b. Equal compression between cylinders
   c. Cylinder compression levels above 100 PSI (700 kPa) and within 70 PSI (500 kPa) of each other
   d. Compression levels below 100 PSI (700 kPa) on most cylinders
6. A good reading for a cylinder leakage test would be _____.
   a. Within 20% between cylinders
   b. All cylinders below 20% leakage
   c. All cylinders above 20% leakage
   d. All cylinders above 70% leakage and within 7% of each other
7. Technician A says that during a power balance test, the cylinder that causes the biggest RPM drop is the weak cylinder. Technician B says that if one spark plug wire is grounded out and the engine speed does not drop, a weak or dead cylinder is indicated. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
8. *Cranking* vacuum should be _____.
   a. 2.5 in. Hg or higher **c.** 17 to 21 in. Hg
   b. Over 25 in. Hg **d.** 6 to 16 in. Hg
9. Technician A says that a leaking head gasket can be tested for using a chemical tester. Technician B says that leaking head gasket can be found using an exhaust gas analyzer.
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
10. The low oil pressure warning light usually comes on _____.
    a. Whenever an oil change is required
    b. Whenever oil pressure drops dangerously low (4 to 7 PSI)
    c. Whenever the oil filter bypass valve opens
    d. Whenever the oil filter antidrainback valve opens

chapter 27

IN-VEHICLE ENGINE SERVICE

OBJECTIVES: **After studying Chapter 27, the reader should be able to:** • Prepare for ASE certification test content area “A” (General Engine Diagnosis). • Diagnose and replace the thermostat. • Diagnose and replace the water pump. • Diagnose and replace an intake manifold gasket. • Determine and verify correct cam timing. • Replace a timing a belt. • Describe how to adjust valves. • Explain hybrid engine precautions.

KEY TERMS: EREV 255 • Fretting 254 • HEV 255 • Idle stop 255 • Skewed 253

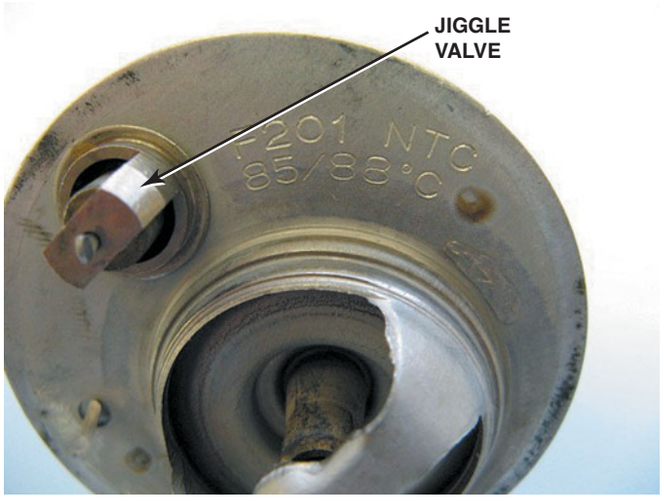


FIGURE 27–1 If the thermostat has a jiggle valve, it should be placed toward the top to allow air to escape. If a thermostat were to become stuck open or open too soon, this can set a diagnostic trouble code P0128 (coolant temperature below thermostat regulating temperature).

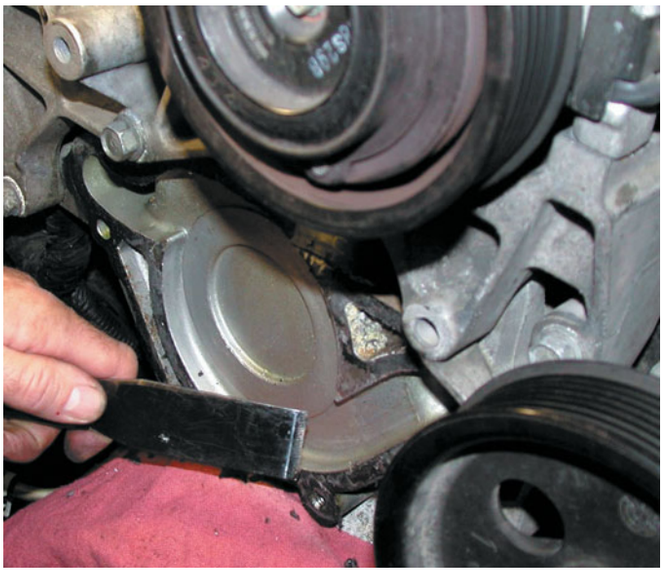


FIGURE 27–2 Use caution if using a steel scraper to remove a gasket from aluminum parts. It is best to use a wood or plastic scraper.

THERMOSTAT REPLACEMENT

FAILURE PATTERNS

All thermostat valves move during operation to maintain the desired coolant temperature. Thermostats can fail in the following ways.

- **Stuck open.** If a thermostat fails open or partially open, the operating temperature of the engine will be less than normal. ● **SEE FIGURE 27–1**.
- **Stuck closed.** If the thermostat fails closed or almost closed, the engine will likely overheat.
- **Stuck partially open.** This will cause the engine to warm up slowly if at all. This condition can cause the powertrain control module (PCM) to set a P0128 diagnostic trouble code (DTC) which means that the engine coolant temperature does not reach the specified temperature.
- **Skewed.** A **skewed** thermostat works, but not within the correct temperature range. Therefore, the engine could overheat or operate cooler than normal or even do both.

REPLACEMENT PROCEDURE

Before replacing the thermostat, double-check that the cooling system problem is not due to another fault, such as being low on coolant or an inoperative cooling fan. Check service information for the specified procedure to follow to replace the thermostat. Most recommended procedures include the following steps.

STEP 1 Allow the engine to cool for several hours so the engine and the coolant should be at room temperature.

STEP 2 Drain the coolant into a suitable container. Most vehicle manufacturers recommend that new coolant be used and the old coolant disposed of properly or recycled.

STEP 3 Remove any necessary components to get access to the thermostat.

STEP 4 Remove the thermostat housing and thermostat.

STEP 5 Replace the thermostat housing gasket and thermostat. Torque all fasteners to specifications.

STEP 6 Refill the cooling system with the specified coolant and bleed any trapped air from the system.

STEP 7 Pressurize the cooling system to verify that there are no leaks around the thermostat housing.

STEP 8 Run the engine until it reaches normal operating temperature and check for leaks.

STEP 9 Verify that the engine is reaching correct operating temperature.

WATER PUMP REPLACEMENT

NEED FOR REPLACEMENT

A water pump will require replacement if any of the following conditions are present.

- Leaking coolant from the weep hole
- Bearing noisy or loose
- Lack of proper coolant flow caused by worn or slipping impeller blades

REPLACEMENT GUIDELINES

After diagnosis has been confirmed that the water pump requires replacement, check service information for the exact procedure to follow. The steps usually include the following:

STEP 1 Allow the engine to cool to room temperature.

STEP 2 Drain the coolant and dispose of properly or recycle.

STEP 3 Remove engine components to gain access to the water pump as specified in service information.

STEP 4 Remove the water pump assembly.

STEP 5 Clean the gasket surfaces and install the new water pump using a new gasket or seal as needed. ● **SEE FIGURE 27–2**. Torque all fasteners to factory specifications.

STEP 6 Install removed engine components.

STEP 7 Fill the cooling system with the specified coolant.

STEP 8 Run the engine, check for leaks, and verify proper operation.



FIGURE 27–3 An intake manifold gasket that failed and allowed coolant to be drawn into the cylinder(s).

INTAKE MANIFOLD GASKET INSPECTION

CAUSES OF FAILURE

Many V-type engines leak oil, coolant, or experience an air (vacuum) leak caused by a leaking intake manifold gasket. This failure can be contributed to one or more of the following:

1. Expansion/contraction rate difference between the cast-iron head and the aluminum intake manifold can cause the intake manifold gasket to be damaged by the relative motion of the head and intake manifold. This type of failure is called **fretting.**
2. Plastic (Nylon 6.6) gasket deterioration caused by the coolant. ● **SEE FIGURE 27–3**.

DIAGNOSIS OF LEAKING INTAKE MANIFOLD GASKET

Because intake manifold gaskets are used to seal oil, air, and coolant in most causes, determining that the intake manifold gasket is the root cause can be a challenge. To diagnose a possible leaking intake manifold gasket, perform the following tests.

Visual inspection. Check for evidence of oil or coolant between the intake manifold and the cylinder heads.

Coolant level. Check the coolant level and determine if the level has been dropping. A leaking intake manifold gasket can cause coolant to leak and then evaporate, leaving no evidence of the leak.

Air (vacuum) leak. If there is a stored diagnostic trouble code (DTC) for a lean exhaust (P0171, P0172, or P0174), a leaking intake manifold gasket could be the cause. Use propane to check if the engine changes when dispensed around the intake manifold gasket. If the engine changes in speed or sound, then this test verifies that an air leak is present.

INTAKE MANIFOLD GASKET REPLACEMENT

When replacing the intake manifold gasket, always check service information for the exact procedure to follow. The steps usually include the following:

STEP 1 Be sure the engine has been off for about an hour and then drain the coolant into a suitable container.



FIGURE 27–4 The lower intake manifold attaches to the cylinder heads.



FIGURE 27–5 The upper intake manifold, often called a plenum, attaches to the lower intake manifold.

STEP 2 Remove covers and other specified parts needed to get access to the retaining bolts.

STEP 3 To help ensure that the manifold does not warp when removed, loosen all fasteners in the reverse order of the tightening sequence. This means that the bolts should be loosened starting at the ends and working toward the center.

STEP 4 Remove the upper intake manifold (plenum), if equipped, and inspect for faults. ● **SEE FIGURES 27–4 AND 27–5**.

STEP 5 Remove the lower intake manifold, using the same bolt removal procedure of starting at the ends and working toward the center.

STEP 6 Thoroughly clean the area and replace the intake manifold if needed. Check that the correct replacement manifold is being used, and even the current part could look different from the original. ● **SEE FIGURE 27–6**.

STEP 7 Install the intake manifold using new gaskets as specified. Some designs use gaskets that are reusable. Replace as needed.

STEP 8 Torque all fasteners to factory specifications and in the proper sequences. The tightening sequences usually start at the center and work outward to the ends.

CAUTION: Double-check the torque specifications and be sure to use the correct values. Many intake manifolds use fasteners that are torqued to values expressed in pound-inches and not pound-feet.



FIGURE 27–6 Many aftermarket replacement intake manifolds have a different appearance from the original manifold.

STEP 9 Reinstall all parts needed to allow the engine to start and run, including refilling the coolant if needed.

STEP 10 Start the engine and check for leaks and proper engine operation.

STEP 11 Reset or relearn the idle if specified, using a scan tool.

STEP 12 Install all of the remaining parts and perform a test drive to verify proper operation and no leaks.

STEP 13 Check and replace the air filter if needed.

STEP 14 Change the engine oil if the intake manifold leak could have caused coolant to leak into the engine, which would contaminate the oil.

TIMING BELT REPLACEMENT

NEED FOR REPLACEMENT

Timing belts have a limited service and a specified replacement interval ranging from 60,000 miles (97,000 km) to about 100,000 miles (161,000 km). Timing belts are required to be replaced if any of the following conditions occur.

- Meets or exceeds the vehicle manufacturer's recommended timing belt replacement interval.
- The timing belt has been contaminated with coolant or engine oil.
- The timing belt has failed (missing belt teeth or broken).

TIMING BELT REPLACEMENT GUIDELINES

Before replacing the timing belt, check service information for the recommended procedure to follow. Most timing belt replacement procedures include the following steps.

STEP 1 Allow the engine to cool before starting to remove components to help eliminate the possibility of personal injury or warpage of the parts.

STEP 2 Remove all necessary components to gain access to the timing belt and timing marks.

STEP 3 If the timing belt is not broken, rotate the engine until the camshaft and crankshaft timing marks are aligned according to the specified marks. ● **SEE FIGURE 27–7**.

STEP 4 Loosen or remove the tensioner as needed to remove the timing belt.

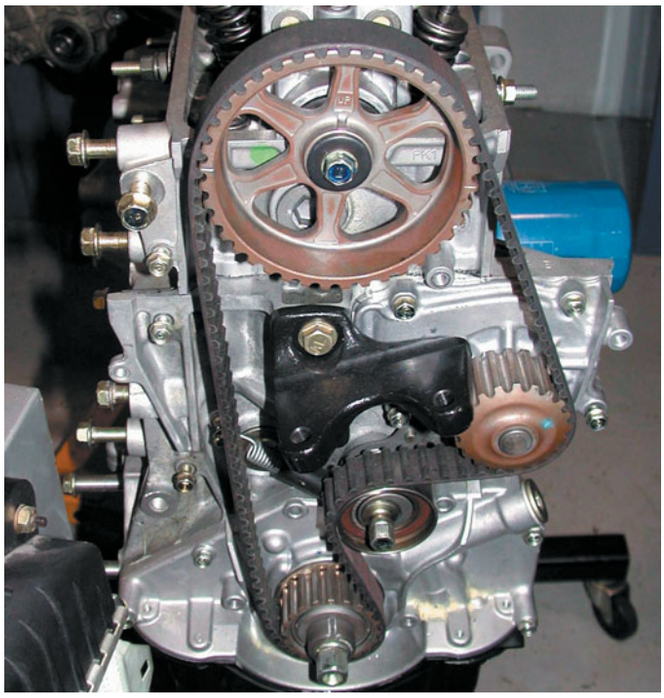


FIGURE 27–7 A single overhead camshaft engine with a timing belt that also rotates the water pump.

STEP 5 Replace the timing belt and any other recommended items. Components that some vehicle manufacturers recommend replacing in addition to the timing belt include:

- Tensioner assembly
- Water pump
- Camshaft oil seal(s)
- Front crankshaft seal

STEP 6 Check (verify) that the camshaft timing is correct by rotating the engine several revolutions.

STEP 7 Install enough components to allow the engine to start to verify proper operation. Check for any leaks, especially if seals have been replaced.

STEP 8 Complete the reassembly of the engine and perform a test drive before returning the vehicle to the customer.

HYBRID ENGINE PRECAUTIONS

HYBRID VEHICLE ENGINE OPERATION

Gasoline engines used in **hybrid electric vehicles (HEVs)** and in **extended range electric vehicles (EREVs)** can be a hazard to be around under some conditions. These vehicles are designed to stop the gasoline engines unless needed. This feature is called **idle stop.** This means that the engine is not running, but could start at any time if the computer detects the need to charge the hybrid batteries or other issue that requires the gasoline engine to start and run.

PRECAUTIONS

Always check service information for the exact procedures to follow when working around or under the hood of a hybrid electric vehicle. These precautions could include:

- Before working under the hood or around the engine, be sure that the ignition is off and the key is out of the ignition.
- Check that the "Ready" light is off. ● **SEE FIGURE 27–8**.

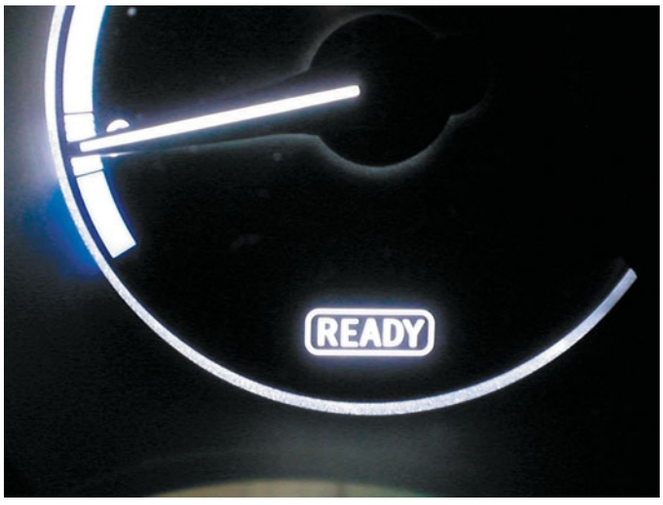


FIGURE 27–8 A Toyota/Lexus hybrid electric vehicle has a ready light. If the ready light is on, the engine can start at anytime without warning.

- Do not touch any circuits that have orange electrical wires or conduit. The orange color indicates dangerous high-voltage wires, which could cause serious injury or death if touched.
- Always use high-voltage linesman's gloves whenever depowering the high-voltage system.

HYBRID ENGINE SERVICE The gasoline engine in most hybrid electric vehicles specifies low viscosity engine oil as a way to achieve maximum fuel economy. ● **SEE FIGURE 27–9**. The viscosity required is often:



FIGURE 27–9 Always use the viscosity of oil as specified on the oil fill cap.

- SAE 0W-20
- SAE 5W-20

Many shops do not keep this viscosity in stock so preparations need to be made to get and use the specified engine oil.

In addition to engine oil, some hybrid electric vehicles such as the Honda Insight (1999–2004) require special spark plugs. Check service information for the specified service procedures and parts needed if a hybrid electric vehicle is being serviced.



1 Before starting the process of adjusting the valves, look up the specifications and exact procedures. The technician is checking this information from a computer CD-ROM-based information system.



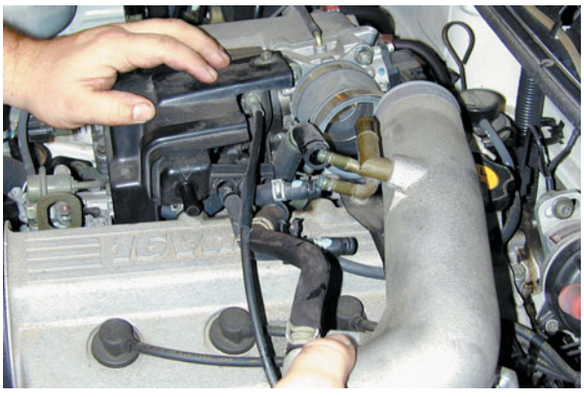
2 The tools necessary to adjust the valves on an engine with adjustable rocker arms include basic hand tools, feeler gauge, and a torque wrench.



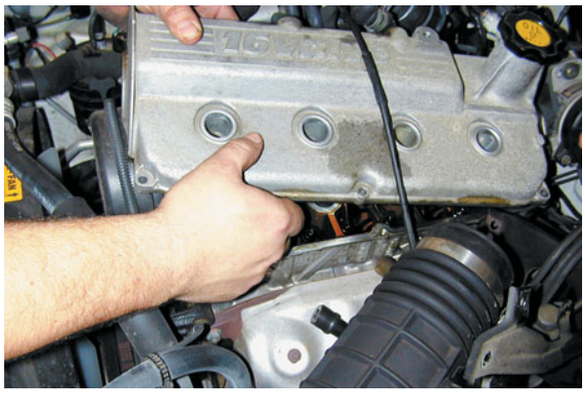
3 An overall view of the 4-cylinder engine that is due for a scheduled valve adjustment according to the vehicle manufacturer's recommendations.



4 Start the valve adjustment procedure by first disconnecting and labeling, if necessary, all vacuum lines that need to be removed to gain access to the valve cover.



5 The air intake tube is being removed from the throttle body.

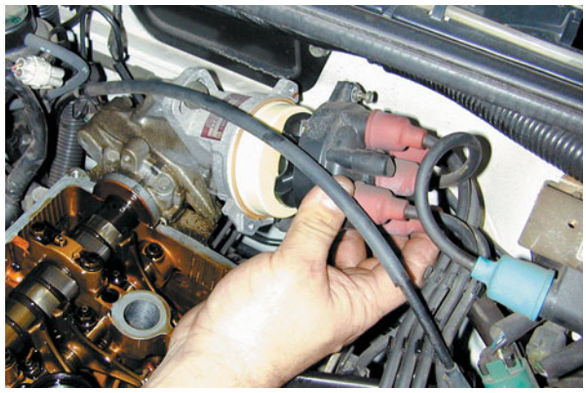


6 With all vacuum lines and the intake tube removed, the valve cover can be removed after removing all retaining bolts.

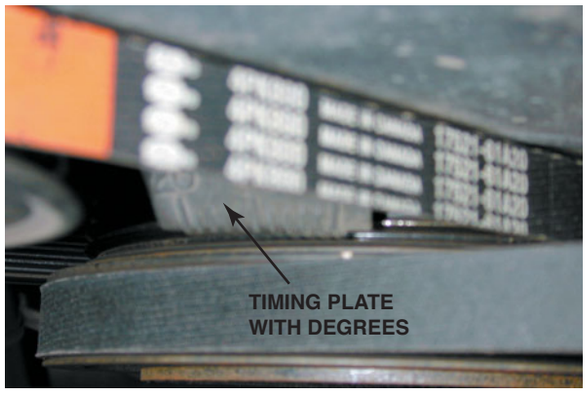
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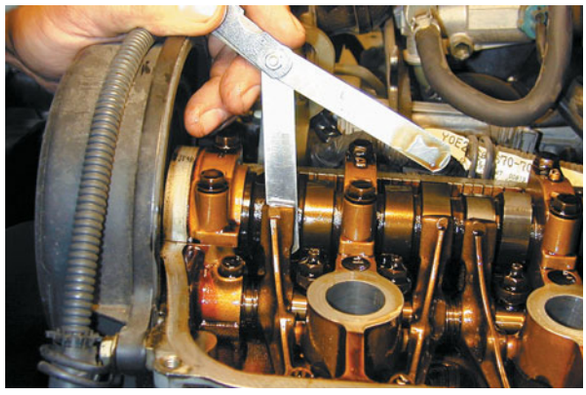
7 Notice how clean the engine appears. This is a testament of proper maintenance and regular oil changes by the owner.



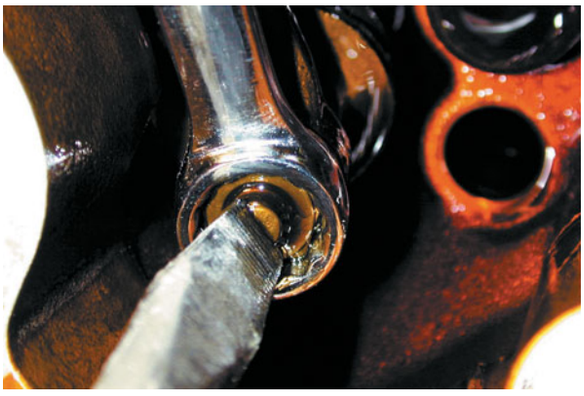
8 To help locate how far the engine is being rotated, the technician is removing the distributor cap to be able to observe the position of the rotor.



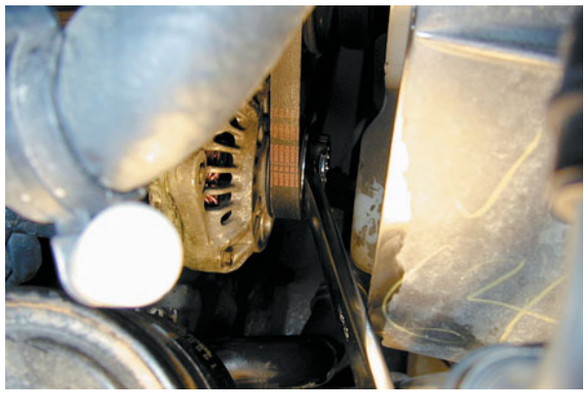
9 The engine is rotated until the timing marks on the front of the crankshaft line up with zero degrees—top dead center (TDC)—with both valves closed on #1 cylinder.



10 With the rocker arms contacting the base circle of the cam, insert a feeler gauge of the specified thickness between the camshaft and the rocker arm. There should be a slight drag on the feeler gauge.



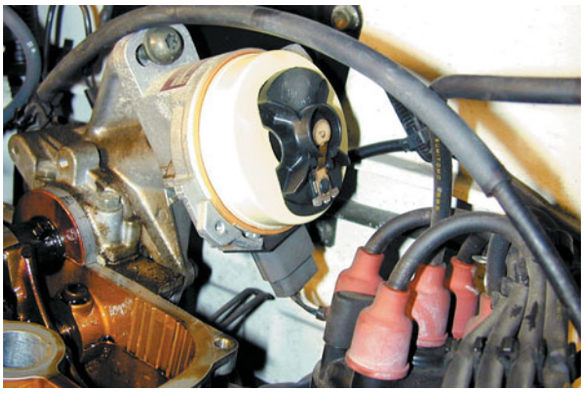
11 If the valve clearance (lash) is not correct, loosen the retaining nut and turn the valve adjusting screw with a screwdriver to achieve the proper clearance.



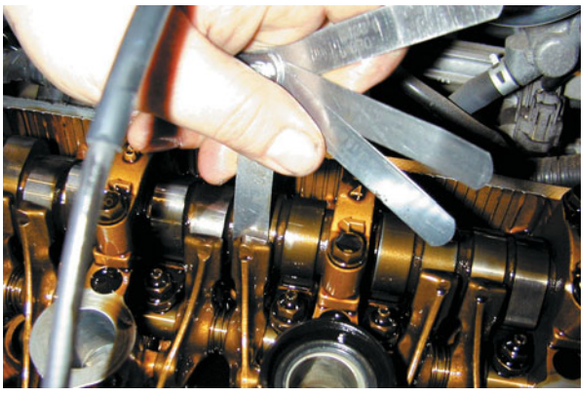
12 After adjusting the valves that are closed, rotate the engine one full rotation until the engine timing marks again align.



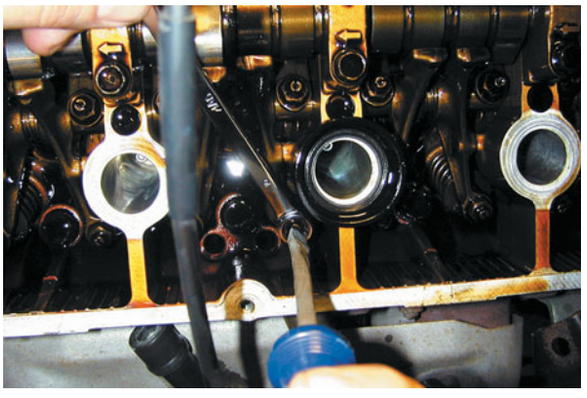
13 The engine is rotated until the timing marks again align indicating that the companion cylinder will now be in position for valve clearance measurement.



14 On some engines, it is necessary to watch the direction the rotor is pointing to help determine how far to rotate the engine. Always follow the vehicle manufacturer's recommended procedure.



15 The technician is using a feeler gauge that is one-thousandth of an inch thinner and another one-thousandth of an inch thicker than the specified clearance as a double-check that the clearance is correct.



16 Adjusting a valve takes both hands—one to hold the wrench to loosen and tighten the lock nut and one to turn the adjusting screw. Always double check the clearance after an adjustment is made.



17 After all valves have been properly measured and adjusted as necessary, start the reassembly process by replacing all gaskets and seals as specified by the vehicle manufacturer.



18 Reinstall the valve cover being careful to not pinch a wire or vacuum hose between the cover and the cylinder head.

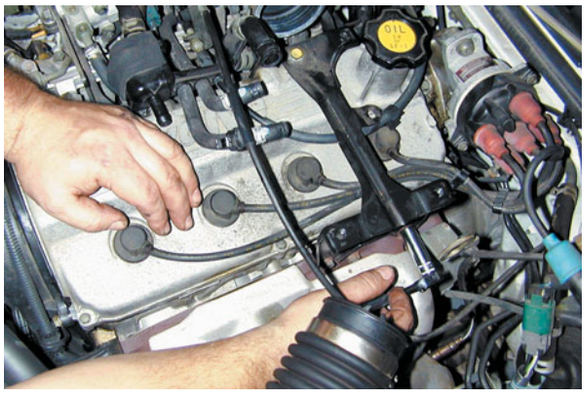
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19 Use a torque wrench and torque the valve cover retaining bolts to factory specifications.



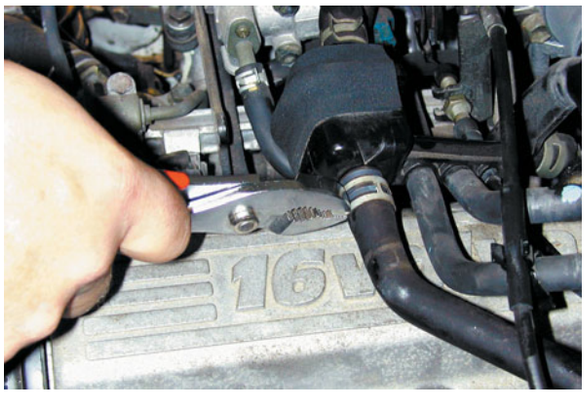
20 Reinstall the distributor cap.



21 Reinstall the spark plug wires and all brackets that were removed to gain access to the valve cover.



22 Reconnect all vacuum and air hoses and tubes. Replace any vacuum hoses that are brittle or swollen with new ones.



23 Be sure that the clips are properly installed. Start the engine and check for proper operation.



24 Double-check for any oil or vacuum leaks after starting the engine.

REVIEW QUESTIONS

1. How can a thermostat fail?
2. How can a water pump fail requiring replacement?
3. What will happen to the engine if the intake manifold gasket fails?
4. Why must timing belts be replaced?
5. Why is it important that the READY light be out on the dash before working under the hood of a hybrid electric vehicle?

CHAPTER QUIZ

1. A thermostat can fail in which way?
   a. Stuck open
   b. Stuck closed
   c. Stuck partially open
   d. Any of the above
2. A skewed thermostat means it is _____.
   a. Working, but not at the correct temperature
   b. Not working
   c. Missing the thermo wax in the heat sensor
   d. Contaminated with coolant
3. Coolant drained from the cooling system when replacing a thermostat or water pump should be _____.
   a. Reused
   b. Disposed of properly or recycled
   c. Filtered and reinstalled after the repair
   d. Poured down a toilet
4. A water pump can fail to provide the proper amount of flow of coolant through the cooling system if what has happened?
   a. The coolant is leaking from the weep hole.
   b. The bearing is noisy.
   c. The impeller blades are worn or slipping on the shaft.
   d. A bearing failure has caused the shaft to become loose.
5. Intake manifold gaskets on a V-type engine can fail due to what factor?
   a. Fretting
   b. Coolant damage
   c. Relative movement between the intake manifold and the cylinder head
   d. All of the above
6. A defective thermostat can cause the powertrain control module to set what diagnostic trouble code (DTC)?
   a. P0171
   b. P0172
   c. P0128
   d. P0300
7. A replacement plastic intake manifold may have a different design or appearance from the original factory-installed part.
   a. True
   b. False
8. The torque specifications for many plastic intake manifolds are in what unit?
   a. Pound-inches
   b. Pound-feet
   c. Ft-lb per minute
   d. Lb-ft per second
9. When replacing a timing belt, many experts and vehicle manufacturers recommend that what other part(s) should be replaced?
   a. Tensioner assembly
   b. Water pump
   c. Camshaft oil seal(s)
   d. All of the above
10. Hybrid electric vehicles usually require special engine oil of what viscosity?
    a. SAE 5W-30
    b. SAE 10W-30
    c. SAE 0W-20
    d. SAE 5W-40

chapter 28

ENGINE REMOVAL AND DISASSEMBLY

OBJECTIVES: **After studying Chapter 28, the reader should be able to:** • Prepare for ASE Engine Repair (A1) certification test content areas “B” (Cylinder Head and Valve Train Diagnosis and Repair) and “C” (Engine Block Diagnosis and Repair). • Explain the differences between a long block and a short block assembly. • Describe how to remove an engine from a vehicle. • Explain how to remove engine accessory components, such as the covers and valve train components. • Discuss how to remove cylinder heads without causing warpage. • List the steps necessary to remove a piston from a cylinder. • Explain how to remove a valve from a cylinder head.

KEY TERMS: Freshening 262 • Long block 262 • Rebuilding 262 • Short block 262 • Vibration damper 267

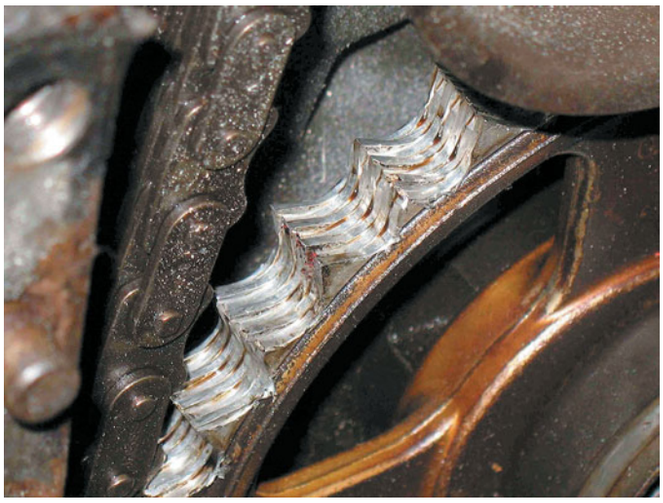


FIGURE 28–1 A worn timing sprocket that resulted in a retarded valve timing and reduced engine performance.



FIGURE 28–2 A crate engine from Chrysler to be used in a restored muscle car. Using a complete new engine costs more than rebuilding an existing engine, but it has a warranty and uses all new parts.

ENGINE REPAIR OPTIONS

TECHNICIAN AND OWNER DECISION The decision to repair an engine should be based on all the information about the engine that is available to the service technician and the vehicle owner.

- In some cases, the engine might not be worth repairing. It is the responsibility of the technician to discuss the advantages and disadvantages of the different repair options with the customer.
- The customer, who is paying for the repair, must make the final decision on the reconditioning procedure to be used. The repair might involve replacing a worn component instead of reconditioning. The decision will be based on the recommendation of the service technician.

REPAIR OPTIONS Most customers want to spend the least amount of money possible, so they have only the faulty component repaired. This is the correct procedure in many cases. Examples of component repairs include:

- **Component replacement.** Timing chain replacement is an example of a component repair due to wear that can cause a loss of engine performance. If testing indicates that the timing chain has excessive slack, the front of the engine can be disassembled and the actual slack measured. Usually a slack of 0.5 in. (13 mm) or more indicates that the timing chain and gears need to be replaced. ● **SEE FIGURE 28–1**.
- **Valve job.** Valve leakage is corrected by doing a valve job. This does not necessarily correct the customer's concerns, however. Stopping valve leakage improves manifold vacuum. After completing a valve job, the greater manifold vacuum may draw the oil past worn piston rings and into the combustion chamber during the intake stroke, causing oil consumption to increase.
- **Minor overhaul.** A minor overhaul can usually be done without removing the engine from the chassis. It requires removal of both the head and the oil pan. The overhaul is usually done when the engine lacks power, has poor fuel economy, uses an excessive amount of oil, produces visible tailpipe emissions, runs rough, or is hard to start. It is still only a repair procedure. Parts normally replaced include the piston rings, rod bearings and gaskets, as well as a valve job. Other engine problems may be noticed after the oil pan is removed and the piston and rod assemblies are taken out. The customer should be informed about any other engine problem, in order to authorize the service that the engine requires. In the high-performance industry, this procedure is called **freshening** the engine.
- **Major overhaul.** A complete engine reconditioning job is called **rebuilding.** Sometimes, this type of reconditioning is called a major overhaul. To rebuild the engine, the engine must be removed from the chassis and be completely disassembled. All serviceable parts are reconditioned to either new or service standards. All bearings, gaskets, and seals are replaced. When the reconditioning is done properly, a rebuilt engine should operate like a new engine.
- **Short block.** The quickest way to get a vehicle back in service is to exchange the faulty engine for a different one. In an older vehicle, the engine may be replaced with a used engine from a salvage yard. In some cases, only a reconditioned block, including the crankshaft, rods, and pistons, is used. This replacement assembly is called a **short block.** The original heads, valve train, oil pump, and all external components are reconditioned and used on the short block.
- **Long block.** The replacement assembly is called a **long block** when the reconditioned assembly includes the heads and valve train. Many automotive machine shops maintain a stock of short and long blocks of popular engines. Usually, the original engine parts, called the core, are exchanged for the reconditioned assembly. The core parts are reconditioned by the automotive machine shop and put back in stock for the next customer.
- **Crate engines.** Crate engines are new engines built by the engine manufacturer and sold through vehicle dealers. ● **SEE FIGURE 28–2**.
- **Remanufactured engines.** Some engines are remanufactured and can be replaced in a day or two, greatly reducing the amount of time the customer is without a vehicle. The engine cores are completely disassembled, and each serviceable part is reconditioned with specialized machinery. Engines are then assembled on an engine assembly line similar to the original manufacturer's assembly line. The parts that are assembled together as an engine have not come out of the same engine. The remanufactured engine usually has new pistons, valves, and lifters, together with other parts that are normally replaced in a rebuilt engine. All clearances and fits in the remanufactured

engine are the same as in a new engine. A remanufactured engine should give service as good as that of a new engine, and it will cost about half as much. Remanufactured engines usually carry a warranty. This means that they will be replaced if they fail during the period of the warranty. They may even cost less than a rebuilt engine, because much of the reconditioning is done by specialized machines rather than by expensive skilled labor.

ENGINE REMOVAL

CHECK SERVICE INFORMATION Whenever any engine-related work is being performed, always print out the specified procedure as published in service information to avoid doing any harm to the vehicle or the engine.

USUAL ENGINE REMOVAL PROCEDURES The procedures that are usually specified include:

- **Remove the hood.** Removing the hood allows easier access to all of the components around the engine. Store the hood in a place where it will not be damaged. Some technicians place a fender cover on the roof of the vehicle and then place the hood upside down on top of the fender cover.
- **Clean the engine area.** The engine exterior and the engine compartment should be cleaned before work is begun. Using a power washer is the most commonly used way to clean the engine compartment area. A clean engine is easier to work on, and the cleaning not only helps to keep dirt out of the engine, but also minimizes accidental damage from slipping tools.
- **Disconnect the negative (−) battery cable,** and remove the battery from the vehicle if it could interfere with the removal of the engine.
- **Remove the air cleaner assembly.** Remove the hoses and other components of the air intake system. Mark or bag and tag all fasteners.
- **Remove all accessories.** Those that usually need to be removed include the alternator, engine driven fan, and AIR pump, if equipped.
- **Drain the coolant.** Draining coolant from the radiator and the engine block help reduce the chance of coolant getting into the cylinders when the cylinder head is removed. Dispose of the used coolant properly.
- **Remove the radiator.** Disconnect the transmission oil cooler lines and radiator hoses from the radiator. Removing the radiator helps provide room for moving the engine during removal and helps prevent the possibility of damage.
- **Disconnect the exhaust system.** On some engines, it may be easier to remove the exhaust manifold(s) from the cylinder head(s), whereas on others, it may be easier to disconnect the exhaust pipe from the manifold(s).
- **Recover the air-conditioning refrigerant.** Set the air-conditioning compressor aside and do not open the system unless absolutely necessary. If the air-conditioning system has to be opened to remove components, then the system must be evacuated. Tape or cover all open refrigerant fittings and hoses to prevent contaminants from entering the A/C system. Check service information for the exact procedures to follow.
- **Remove the power steering pump.** Remove the fasteners to the power steering pump and set aside the pump and hoses.

TECH TIP

A Picture Is Worth a Thousand Words

Take pictures with a cell phone camera, digital camera, or a video camcorder of the engine being serviced. These pictures will be worth their weight in gold when it comes time to reassemble or reinstall the engine. It is very difficult for anyone to remember the *exact* location of every bracket, wire, and hose. Referring back to the photos of the engine before work was started will help you restore the vehicle to like-new condition.

- **Drain the engine oil.** Draining the engine oil and removing the oil filter also helps prevent fluid loss during the removal process.
- **Disconnect fuel lines.** Disconnect and plug all fuel supply and return lines.
- **Disconnect wiring and vacuum hoses.** Mark and remove all vacuum hoses and electrical wiring attached to the engine.

PROCEDURE FOR ENGINE REMOVAL There are two ways to remove the engine.

1. The engine can be lifted out of the chassis with the transmission/transaxle attached.
2. The transmission/transaxle can be separated from the engine and left in the chassis.

The method to be used must be determined before the engine is removed from the vehicle.

- **Rear-wheel-drive vehicle.** The removal procedure for most rear-wheel-drive vehicles includes the following steps.

STEP 1 Under the vehicle, remove the driveshaft (propeller shaft) and disconnect the exhaust pipes. Also remove the engine (motor) mounts. In some installations, it may be necessary to loosen the steering linkage idler arm to give clearance. The transmission controls and wiring need to be disconnected at the connectors, and clutch linkages disconnected and labeled.

STEP 2 Attach a sling, either a chain or lift cable, to one of the following:

- Factory-installed lifting hooks
- Intake manifold
- Cylinder head bolts, on top of the engine

An engine lift hoist chain or cable is attached and snugged to take most of the weight. This leaves the engine resting on the mounts.

NOTE: For the best results, use the factory-installed lifting hooks that are attached to the engine. These hooks are used in the assembly plant to install the engine and are usually in the best location to remove the engine.

STEP 3 Remove the rear cross-member, and lower the transmission. Cover the extension housing with a plug or a plastic bag to help prevent the automatic transmission fluid from leaking during the removal process. If the engine alone is being removed, the transmission retaining bolts and torque converter fasteners will need to be removed. Check service information for exact procedures to follow when removing an automatic transmission.

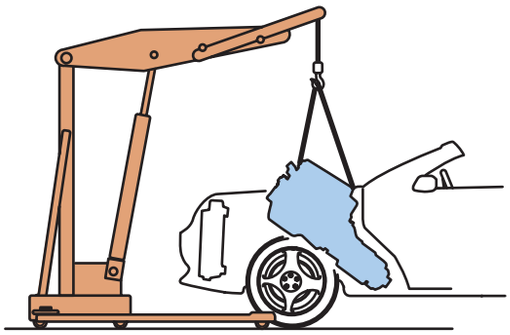


FIGURE 28–3 An engine must be tipped as it is pulled from the chassis.



FIGURE 28–4 When removing just the engine from a front-wheel-drive vehicle, the transaxle must be supported. Shown here is a typical fixture that can be used to hold the engine if the transaxle is removed or to hold the transaxle if the engine is removed.

STEP 4 The front of the engine must come almost straight up as the transmission slides from under the floor pan. The engine and transmission are hoisted free of the automobile, swung clear, and lowered on an open floor area. ● **SEE FIGURE 28–3.**

- **Front-wheel-drive vehicle.** Check service information for the exact procedure to follow to remove the engine from a front-wheel-drive vehicle. Depending on the vehicle, the engine could be removed from the top or lowered and removed from underneath on many front-wheel-drive vehicles. Typical steps include:

STEP 1 Disconnect units that might interfere with engine removal, including the steering unit, engine electrical harness, and radiator.

STEP 2 If removing the engine from underneath, the upper strut and lower engine cradle fasteners will have to be removed.

STEP 3 Disconnect the torque converter and bell housing bolts and clutch linkage if required.

STEP 4 Often special holding fixtures are required to help hold the transaxle in place while removing the engine. ● **SEE FIGURES 28–4 AND 28–5.**

ENGINE DISASSEMBLY

MOUNTING THE ENGINE ON A STAND

Engines should be installed to a sturdy engine stand. For safety, always check the following:



FIGURE 28–5 The entire cradle, which included the engine, transaxle, and steering gear, was removed and placed onto a stand. The rear cylinder head has been removed to check for the root cause of a coolant leak.

TECH TIP

Tag and Bag

All components and fasteners should be marked for future reference. Large components should be marked or a tag installed that identifies the part. Smaller parts and fasteners should be placed in plastic bags and labeled as to what they are used for, such as the water pump bolts.

- Always use at least four grade 8 bolts when mounting an engine to an engine stand. Using low-quality nongraded bolts or fewer than four bolts can cause the engine to fall. Also check to ensure that the proper threads of bolts are being used. Some engines use fractional threads, whereas others use metric threads.
- Install the bolts so that at least 1/2 in. (13 mm) of thread is engaged in the back of the engine to ensure that the fasteners are securely attached the engine block.
- Check that the engine is properly balanced on the engine stand before work is started on the engine. ● **SEE FIGURE 28–6.**

DISASSEMBLING A CAM-IN-BLOCK (OHV) ENGINE

Check service information for the specified engine disassembly procedure. Read, understand, and follow all safety instructions. Following are the usual steps involved.

STEP 1 Engines should be cold before disassembly to minimize the chance of warpage of the components that are being removed.

STEP 2 Removal of the rocker arm covers gives the first opportunity to see inside a part of the engine. Examine the rocker arms, valve springs, and valve tips for obvious defects. Remove the rocker arms and pushrods and, if they are to be reused, place them in a location so that the rockers and the pushrods can be installed back to their original location. ● **SEE FIGURE 28–7.**

STEP 3 Remove the intake manifold bolts and lift off the manifold. Use care to avoid damaging the parting surface as the gasket is loosened. When the intake manifold and lifter valley cover

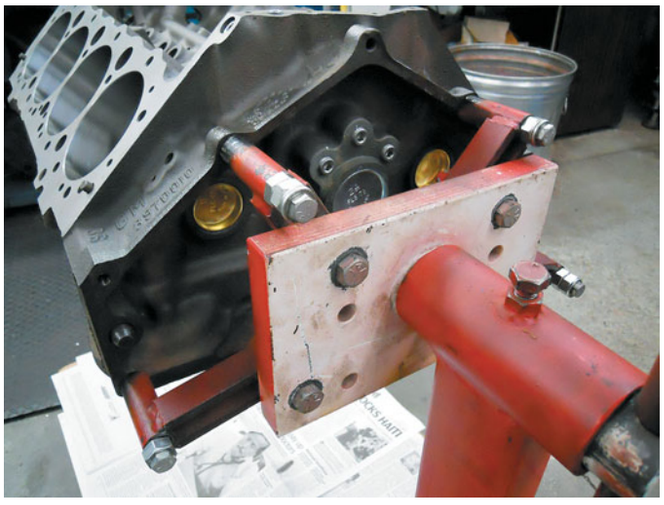


FIGURE 28–6 Always use graded bolts—either grade 5 or 8 bolts—whenever mounting an engine to a stand.



FIGURE 28–7 Keeping the pushrods and the lifters sorted by cylinder, including the spark plugs, is a wise way to proceed when disassembling the cylinder heads.

(if equipped) are off of V-type engines, the technician has another opportunity to examine the interior of the engine. On some V-type engines, it is possible to see the condition of the cam at the bottom of the lifter valley.

STEP 4 The lifters can be removed at this time if they are causing the problem or if the engine valve train is to be serviced.

STEP 5 Remove the cylinder head bolts (also called cap screws) following the reverse of the installation procedure. Loosening the fasteners at the ends of the cylinder head first, then working toward the center, helps reduce the chance of warpage to the cylinder head. Be sure to notice and mark the head bolt locations as they are often different lengths depending on their location in the head. Carefully lift the head from the block deck. If the head gasket is stuck, carefully pry the head to loosen the gasket. Use care not to scratch the block or head machined surfaces. The combustion chamber in the head and the top of the piston should be given a thorough visual examination. ● **SEE FIGURE 28–8**.

- Check the cylinder head and head gasket for signs of leakage.

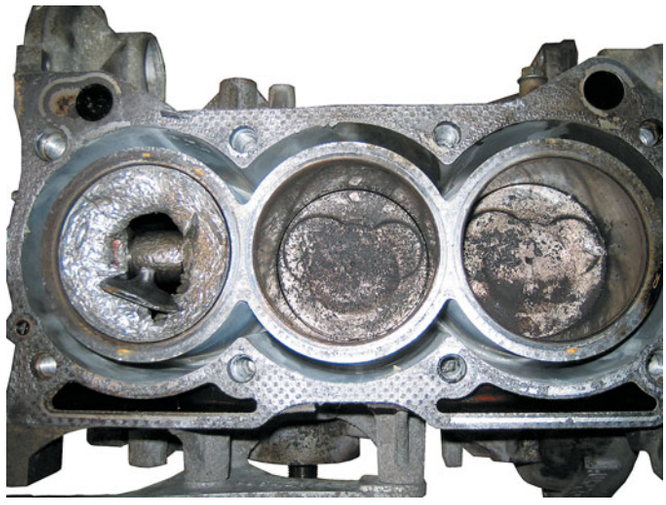


FIGURE 28–8 Sometimes after the cylinder head has been removed, the engine condition is discovered to be so major that the entire engine may need to be replaced rather than overhauled.

TECH TIP

Disassembly Is the Reverse Order of Assembly

Cylinder heads often warp upward in the center. Loosening the center head bolts first will tend to increase the warpage, especially if the head is being removed to replace a head gasket because of overheating. Always follow the torque table backwards, starting with the highest-number bolt and working toward the lowest number. In other words, always loosen fasteners starting at the end or outside of the component and work toward the inside or center of the component.

- A normal combustion chamber is coated with a layer of hard, light-colored deposits.
- If the combustion chamber has been running too hot, the deposits will be very thin and white.

OVERHEAD CAMSHAFT (OHC) ENGINE DISASSEMBLY

Disassembling an overhead camshaft engine differs from a cam-in-block (OHV) engine. Check service information for the specified disassembly procedure for the engine being serviced. Read, understand, and follow all safety notices and warnings included in the instructions to help avoid causing damage to parts or components during the disassembly process. The usual steps include:

STEP 1 Remove the intake and exhaust manifolds if they have not already been removed and bag and tag all fasteners.

STEP 2 Remove the crankshaft harmonic balancer pulley that will allow access to the timing chain or belt cover.

STEP 3 Remove the timing belt/chain cover(s) and then the timing belt(s) or chain(s).

STEP 4 With most overhead camshaft engines, the camshaft(s) must be removed before removing the cylinder head due to location of the head bolts.

STEP 5 Remove the cylinder head by removing the cylinder head bolts in the opposite order of assembly. This means to loosen the outermost fasteners first, then work toward the center of the cylinder head.

STEP 6 Carefully lift the cylinder head from the block.

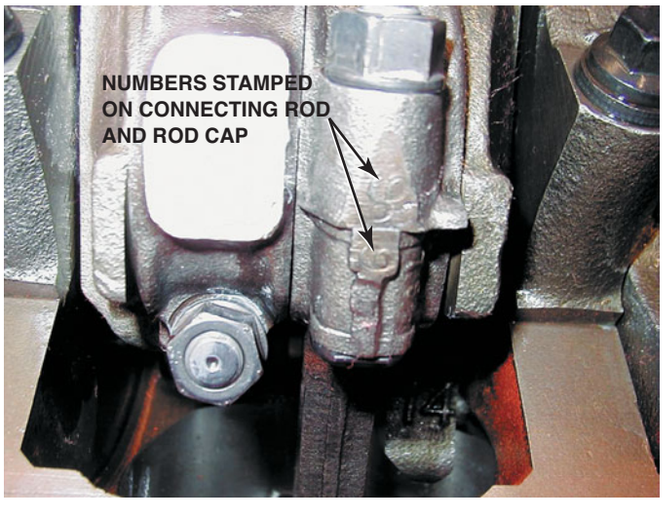


FIGURE 28–9 These connecting rods were numbered from the factory. If they are not, then they should be marked.

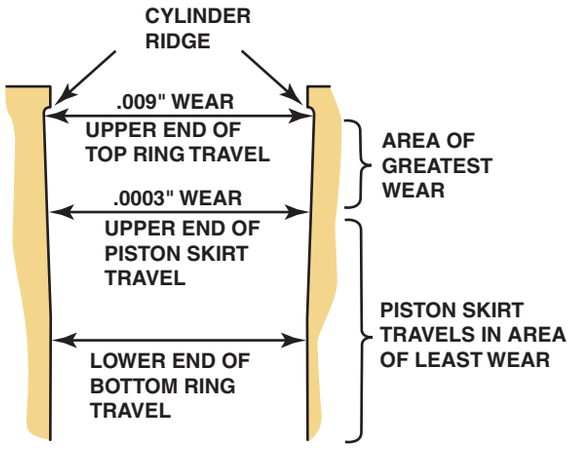


FIGURE 28–10 Most of the cylinder wear is on the top inch just below the cylinder ridge. This wear is due to the heat and combustion pressures that occur when the piston is near the top of the cylinder.

DISASSEMBLY OF THE SHORT BLOCK

REMOVING THE OIL PAN To remove the oil pan, turn the engine upside down.

NOTE: Some engine builders prefer to remove the oil pan before turning it upside down so the technician can see the oil pan deposits first.

Deposits are a good indication of the condition and care taken of the engine. Heavy sludge indicates infrequent oil changes; hard carbon indicates overheating. The oil pump pickup screen should be checked to see how much plugging exists.

MARKING CONNECTING RODS AND CAPS The connecting rod caps should be marked (numbered) so that they can be reassembled in exactly the same position. If the connecting rods are not marked from the factory, then they should be marked using a number stamp, electric pencil, or permanent marker. ● **SEE FIGURE 28–9**.

CAUTION: Some vehicle manufacturers warn *not* to use a punch or an electric pencil on powdered metal connection rods. Use only a permanent marker to label powdered metal rods. If in doubt as to the type of rod that is in the engine, use a marker to be safe.

REMOVING THE CYLINDER RIDGE Before the pistons can be removed from the block, the ridge must be removed. Piston wear against the cylinder wall leaves an upper ridge, because the top ring does not travel all the way to the top of the cylinder. Ridge removal is necessary to avoid catching a ring on the ridge and breaking the piston. ● **SEE FIGURE 28–10**.

The ridge is removed with a cutting tool that has a guide to help prevent accidental cutting below the ridge. ● **SEE FIGURE 28–11**.

PISTON REMOVAL Removing the piston and rod assembly includes the following steps.

STEP 1 Rotate the engine until the piston that is to be removed is at bottom dead center (BDC).



FIGURE 28–11 This ridge is being removed with one type of ridge reamer before the piston assemblies are removed from the engine.

TECH TIP

Measure the Cylinder Bore Before Further Disassembly

As soon as the cylinder head has been removed from the engine, take a measurement of the cylinder bore. This is done for the following reasons.

- To verify that the engine size is the same as specified by the vehicle identification number (VIN)
- To measure the bore and compare it to factory specifications, to help the technician determine if the cylinder(s) are too worn to use or cannot be restored

STEP 2 Remove connecting rod nuts from the rod so that the rod cap with its bearing half can be removed.

STEP 3 Fit the rod bolts with protectors to keep the bolt threads from damaging the crankshaft journals, and then carefully remove the piston and rod assemblies.

STEP 4 After removal of each piston, replace the rod cap and nuts to avoid losing or mismatching them.

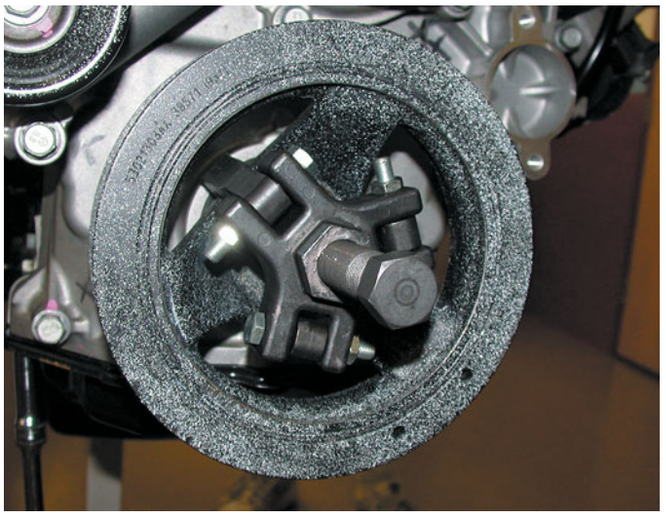


FIGURE 28–12 Puller being used to pull the vibration damper from the crankshaft.

ROTATING ENGINE ASSEMBLIES REMOVAL

HARMONIC BALANCER REMOVAL The next step after the water pump has been removed is to remove the crankshaft **vibration damper** (also called a *harmonic balancer*). The bolt and washer that hold the damper are removed. The damper should be removed only with a threaded puller. ● **SEE FIGURE 28–12**.

If a hook-type puller is used around the edge of the damper, it may pull the damper ring from the hub. If this happens, the damper assembly will have to be replaced with a new assembly. With the damper assembly off, the timing cover can be removed, exposing the timing gear or timing chain. Examine these parts for excessive wear and looseness. ● **SEE FIGURE 28–13**.

Bolted cam sprockets can be removed to free the timing chain. On some engines this will require removal of the crankshaft gear at the same time. Pressed-on gears and sprockets are removed from the shaft *only* if they are faulty. They are removed after the camshaft is removed from the block. It is necessary to remove the camshaft thrust plate retaining screws when they are used.

CAMSHAFT REMOVAL The camshaft and balance shafts, if equipped, can be removed at this time, or they can be removed after the crankshaft is out. For best results, insert a long bolt into one of the camshaft threaded holes to serve as handles for removing (or installing) a camshaft. It must be carefully eased from the engine to avoid damaging the cam bearings or cam lobes. This is done most easily with the front of the engine pointing up. Bearing surfaces are soft and scratch easily, and the cam lobes are hard and can chip easily.

CRANKSHAFT AND MAIN BEARING REMOVAL The main bearing caps should be checked for position markings before they are removed. If they are not marked, use steel number stamps to mark them and also be sure to indicate which side of each main cap faces to the front of the engine. ● **SEE FIGURE 28–14**.

They have been machined in place and will not fit perfectly in any other location. After marking, they can be removed to free the crankshaft. When the crankshaft is removed, the main bearing caps and bearings are reinstalled on the block to reduce the chance of damage to the caps.

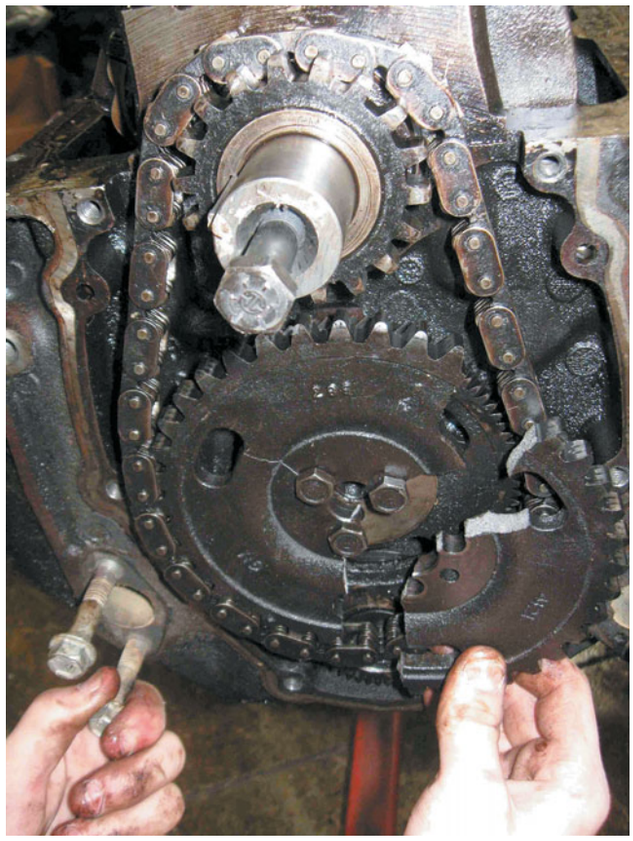


FIGURE 28–13 When the timing chain cover was removed, the broken timing gear explained why this GM 4.3 liter V-6 engine stopped running.

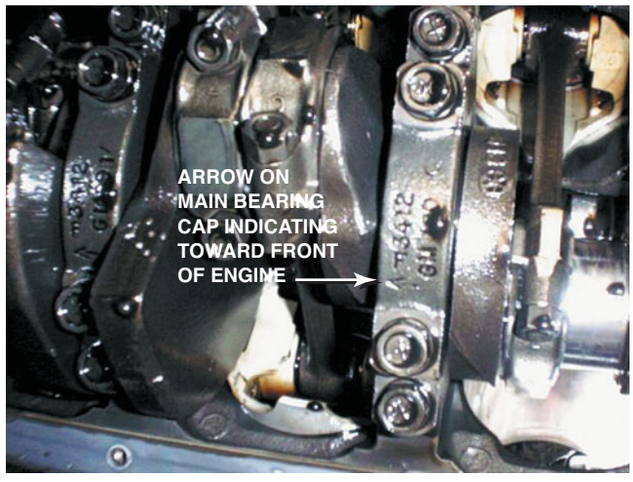


FIGURE 28–14 Most engines such as this Chevrolet V-8 with four-bolt main bearing caps have arrows marked on the bearing caps which should point to the front of the engine.

BLOCK INSPECTION After the pistons and crankshaft have been removed, then remove all cups and plugs and carefully inspect the block for faults that could affect whether the engine can be rebuilt. ● **SEE FIGURE 28–15**.

Further detailed inspection should be completed after the components have been cleaned.

CYLINDER HEAD DISASSEMBLY

OHV ENGINE CYLINDER HEADS After the heads are removed and placed on the bench, the valves can be removed.

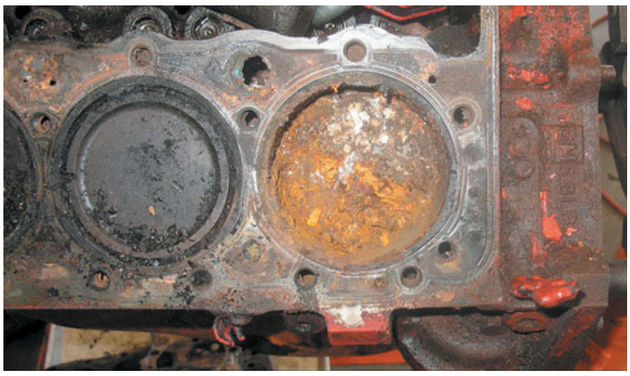


FIGURE 28–15 This small block Chevrolet V-8 had water standing in the cylinders, causing a lot of rust, which was discovered as soon as the head was removed.

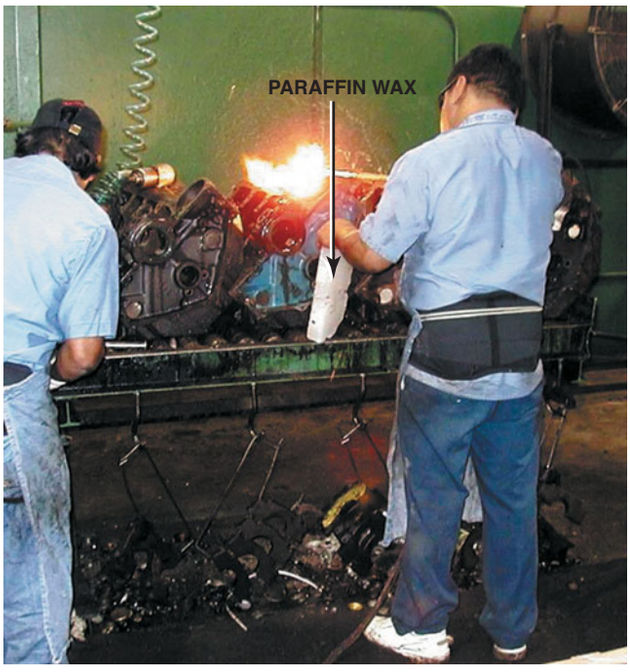


FIGURE 28–16 A torch is used to heat gallery plugs. Paraffin wax is then applied and allowed to flow around the threads. This procedure results in easier removal of the plugs and other threaded fasteners that cannot otherwise be loosened.

TECH TIP

The Wax Trick

Before the engine block can be thoroughly cleaned, all oil gallery plugs must be removed. A popular trick of the trade for plug removal involves heating the plug (not the surrounding metal) with an oxyacetylene torch. The heat tends to expand the plug and make it tighter in the block. Do not overheat.

As the plug is cooling, touch the plug with paraffin wax (beeswax or candle wax may be used). ● **SEE FIGURE 28–16**.

The wax will be drawn down around the threads of the plug by capillary attraction as the plug cools and contracts. After being allowed to cool, the plug is easily removed.

CAUTION: Always wear safety glasses when working on a cylinder head. Valve springs can release quickly, causing valve parts to fly.

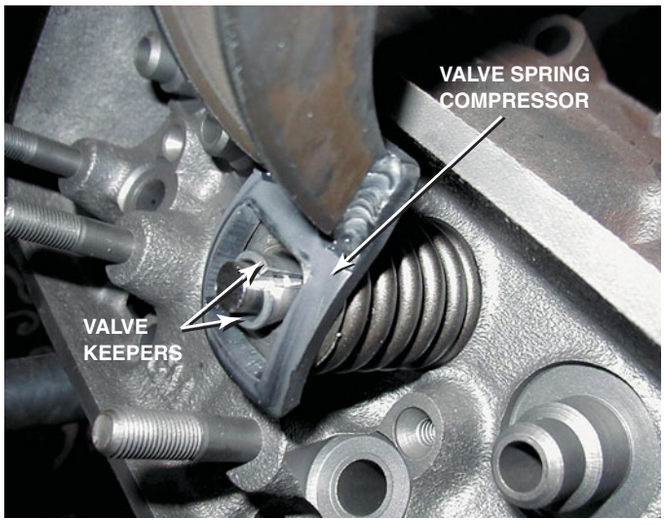


FIGURE 28–17 A valve spring compressor is used to compress the valve spring before removing the keepers (locks).

TECH TIP

Mark It to Be Safe

Whenever you disassemble anything, it is always wise to mark the location of parts, bolts, hoses, and other items that could be incorrectly assembled. Remember, the first part removed will be the last part that is assembled. If you think you will remember where everything goes—forget it! It just does not happen in the real world.

One popular trick is to use correction fluid to mark the location of parts before they are removed. Most of these products are alcohol or water based, dry quickly, and usually contain a brush in the cap for easy use.

To disassemble a cylinder head, perform the following steps.

STEP 1 Tap the valve spring retainer with a brass hammer, hitting the retainer on an angle to "break the taper" of the valve keepers (locks).

STEP 2 Using a valve spring compressor, compress the valve spring far enough to expose the keepers. ● **SEE FIGURE 28–17**.

STEP 3 Remove the two keepers using a magnet.

STEP 4 After the valve keepers have been removed, slowly release the compressor to remove and to free the valve retainer and spring.

STEP 5 The valve tip edge and keeper (lock) area should be lightly filed or stoned to remove any burrs *before* sliding the valve from the head. Burrs will scratch the valve guide.

STEP 6 Remove all valve stem seals and the metal spring seats that are used on aluminum heads.

STEP 7 When all valves are removed following the same procedure, carefully inspect the valve springs, retainers, keepers (locks), guides, and seats.

OHC ENGINE CYLINDER HEADS After the heads are removed and placed on the bench, the valves can be removed after the camshaft is removed. Often a special valve spring compressor is required to reach the valve retainers. Always read, understand, and follow all vehicle manufacturer's instructions.



1 Before beginning work on removing the engine, mark and remove the hood and place it in a safe location.



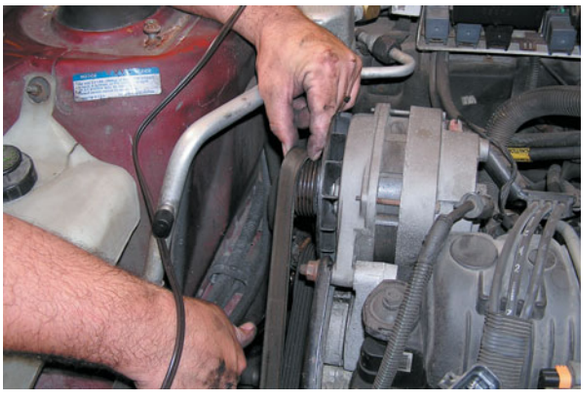
2 For safety, remove the negative battery cable to avoid any possible electrical problems from occurring.



3 Drain the coolant and dispose of properly.



4 Disconnect all cooling system and heater hoses and remove the radiator.



5 Remove the accessory drive belt(s) and set the alternator, power steering pump, and air-conditioning compressor aside.

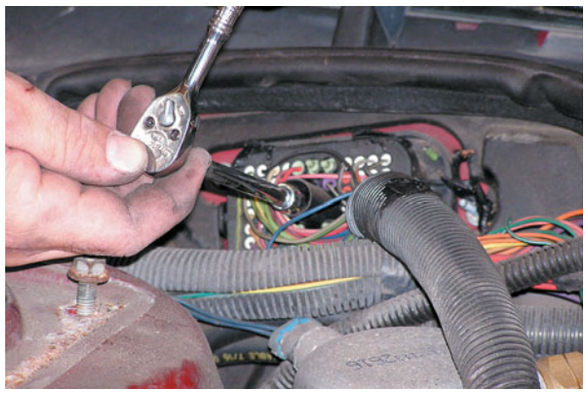


6 Remove the air intake system including the air filter housing as needed.

CONTINUED ▶



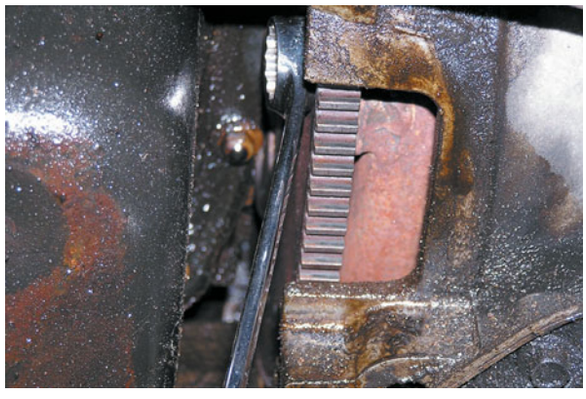
7 Remove the electrical connector from all sensors and label.



8 Disconnect the engine wiring harness connector at the bulkhead.



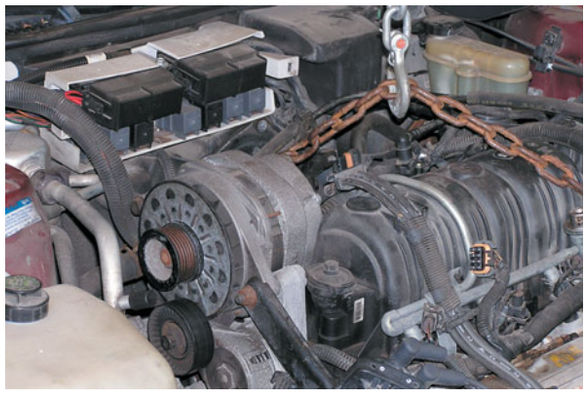
9 Safely hoist the vehicle and disconnect the exhaust system from the exhaust manifolds.



10 Mark and then remove the fasteners connecting the flex plate to the torque converter.



11 Lower the vehicle and remove the engine mount bolts and transaxle bell housing fasteners.



12 Secure the lifting chain to the engine hooks and carefully remove the engine from the vehicle.

REVIEW QUESTIONS

1. What are the differences between a minor and a major overhaul?
2. When should the factory-installed lifting hooks be used?
3. Why should the cylinder bore be measured before continuing with an engine disassembly?
4. State two reasons for the removal of the ridge at the top of the cylinder.
5. Explain why the burrs must be removed from valves before removing the valves from the cylinder head.

CHAPTER QUIZ

1. A short block includes the _____.
   - **a.** Block
   - **b.** Crankshaft and main bearings
   - **c.** Pistons, rods, and rod bearings
   - **d.** All of the above
2. When removing cylinder heads, the fasteners should be removed in which order?
   - **a.** The reverse order of tightening
   - **b.** The same order as the specified tightening sequence
   - **c.** Any order
   - **d.** Loosened slightly in the same order as the tightening sequence and then removed in any order
3. A long block can be made from a short block with the addition of _____.
   - **a.** Cylinder heads and valve train
   - **b.** Intake and exhaust manifolds
   - **c.** Oil pump, oil pan, and timing chain cover
   - **d.** Fuel pump, carburetor, and air cleaner assembly
4. What needs to be removed before the valves can be removed from the cylinder head?
   - **a.** The valve keepers
   - **b.** The camshaft if OHV engine
   - **c.** The cylinder head from the block
   - **d.** Both a and c
5. With the rocker cover (valve cover) removed, the technician can inspect all items *except* _____.
   - **a.** Combustion chamber deposits
   - **b.** Rocker arms and valve spring
   - **c.** Camshaft (overhead camshaft engine only)
   - **d.** Valve stems and pushrods (overhead valve engines only)
6. After the oil pan (sump) is removed, the technician should inspect _____.
   - **a.** The oil pump and pickup screen
   - **b.** To make certain that all rod and main bearings are numbered or marked
   - **c.** The valve lifters (tappets) for wear
   - **d.** Both a and b
7. The ridge at the top of the cylinder _____.
   - **a.** Is caused by the rings that do not travel all the way to top of the cylinder
   - **b.** Represents a failure of the top piston ring to correctly seal against the cylinder wall
   - **c.** Should not be removed before removing pistons except when reboring the cylinders
   - **d.** Means that a crankshaft with an incorrect stroke was installed in the engine
8. Before the timing chain can be inspected and removed, the _____ must be removed.
   - **a.** Valve cover
   - **b.** Vibration damper
   - **c.** Cylinder head(s)
   - **d.** Intake manifold (V-type engines only)
9. Before the valves are removed from the cylinder head, what operations need to be completed?
   - **a.** Remove valve keepers (locks)
   - **b.** Remove cylinder head(s) from the engine
   - **c.** Remove burrs from the stem of the valve(s)
   - **d.** All of the above
10. Technician A says that a minor overhaul can often be done with the engine remaining in the vehicle. Technician B says that a core is required for most remanufactured engines. Which technician is correct?
    - **a.** Technician A only
    - **b.** Technician B only
    - **c.** Both Technicians A and B
    - **d.** Neither Technician A nor B

chapter 29

ENGINE CLEANING AND CRACK DETECTION

OBJECTIVES: After studying Chapter 29, the reader should be able to: • Prepare for ASE Engine Repair (A1) certification test content area "A" (General Engine Diagnosis). • List the types of engine cleaning methods. • List the various methods that can be used to check engine parts for cracks. • Describe crack repair procedures.

KEY TERMS: Acid materials 273 • Agitation 275 • Aqueous-based solutions 274 • Caustic materials 273 • Fusible link 275 • Hydroseal 275 • pH 273 • Putty knife 272 • Pyrolytic 274 • Ultrasonic cleaning 275 • Zyglo 276

INTRODUCTION

After an engine has been disassembled and before it can be overhauled or repaired, the engine and engine parts should go through two important operations.

1. All parts, including fasteners, must be thoroughly cleaned.
2. All components and parts must be inspected to ensure that they are serviceable and free from faults such as cracks.

MECHANICAL CLEANING

PRINCIPLES Heavy deposits should be removed by mechanical cleaning before using other cleaning methods. Mechanical cleaning involves:

- Scraping
- Abrasive brushing
- Abrasive blasting

SCRAPING The scraper most frequently used is a **putty knife,** or a plastic card. The broad blade of the putty knife helps avoid scratching the surface as it is used to clean the parts. A plastic card such as an old gift, credit, or other similar card can be used to clean aluminum parts such as cylinder head gasket surfaces without causing any damage.

ABRASIVE PADS OR DISCS An abrasive pad or disc can be used on *disassembled* parts only. After an abrasive pad or disc has been used, the part *must* be thoroughly cleaned to remove the particles from the plastic bristles or pad. The abrasive aluminum oxide particles from the bristles can get into the engine and cause major damage.

There are three colors of rotary discs, and each is made from a different grit size of abrasive. The three colors of bristle discs and their applications include:

- **White.** Has the finest grit size, and is used for cleaning aluminum parts
- **Yellow.** Has a coarse grit, and can be used on aluminum
- **Green.** For use on cast-iron components only

● **SEE FIGURES 29–1 AND 29–2.**

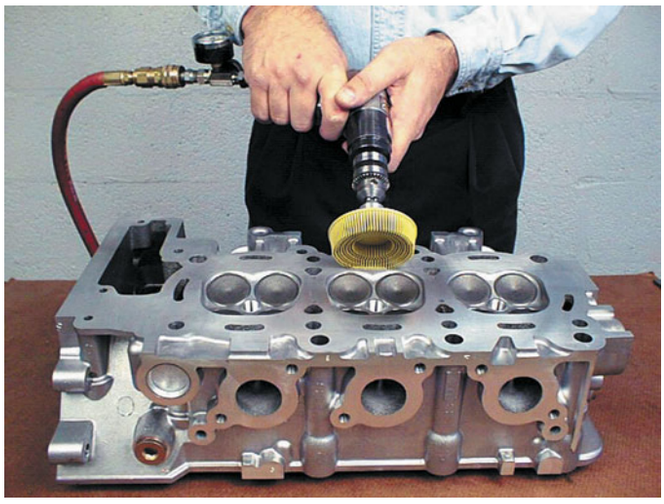


FIGURE 29–1 An air-powered grinder attached to a bristle pad being used to clean the gasket surface of a cylinder head. This type of cleaning pad should not be used on the engine block where the grit could get into the engine oil and cause harm when the engine is started and run after the repair.

TECH TIP

The Ice Scraper Trick

Using a steel scraper can damage aluminum heads or block deck surfaces. To prevent damage, try using a file to sharpen a plastic ice scraper and then use this to scrape gaskets from aluminum engine parts. This method works very well.

CAUTION: Do not use steel wire brushes on aluminum parts! Steel is harder than aluminum and will remove some of the aluminum from the surface during cleaning.

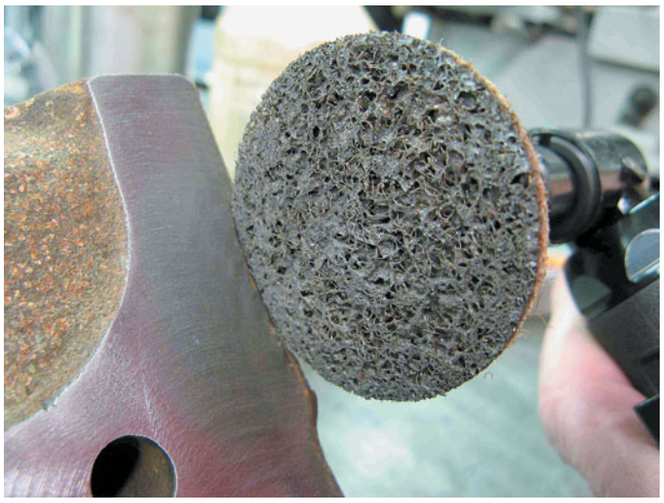


FIGURE 29–2 An abrasive disc commonly called by its trade name, Scotch Brite™ pad.



FIGURE 29–3 Using baking soda is the recommended way to clean engine parts because any soda that is left on or in the part is dissolved in oil or water, unlike either sand or glass beads, which can be engine damaging.

MEDIA BLASTING Media blasting with baking soda is the cleaning method of choice for most shops. Baking soda (bicarbonate of soda) works well because it is:

- Nontoxic
- Nonflammable
- Nonhazardous
- Environmentally safe

A soda blasting machine uses compressed air to deliver the baking soda media onto the part being cleaned. ● **SEE FIGURE 29–3**.

Cleaning cast-iron or aluminum engine parts with solvents or heat usually requires another operation to achieve a uniform surface finish. Blasting the parts with steel, cast-iron, aluminum, or stainless steel shot, baking soda, or glass beads is a simple way to achieve a matte or satin surface finish on the engine parts. To keep the shot or beads from sticking to the parts, they must be dry, without a trace of oil or grease, prior to blasting. This means that blasting is the second cleaning method after the part has been precleaned in a tank, spray washer, or oven. Some blasting is done automatically in an airless shot-blasting machine. Another method is to hard-blast parts in a sealed cabinet. ● **SEE FIGURE 29–4**.

CAUTION: Glass beads often remain in internal passages of engine parts, where they can come loose and travel through the cylinders when the engine is started. Among other places, these small but destructive beads can easily be trapped under the oil baffles of rocker covers and in oil pans and piston ring grooves. To help prevent the glass beads from sticking, be sure the parts being cleaned are free of grease and dirt, and completely *dry*.



FIGURE 29–4 Small engine parts can be blasted clean in a sealed cabinet.

CHEMICAL CLEANERS

pH Most chemical cleaners used for cleaning carbon-type deposits are strong soaps called **caustic materials. pH** value, measured on a scale from 1 to 14, indicates the amount of chemical activity in the soap. The term *pH* is from the French *pouvoir hydrogine,* meaning "hydrogen power." Pure water is neutral; on the pH scale, water is pH 7. Caustic materials have pH numbers from 8 through 14. The higher the number, the stronger the caustic action will be. **Acid materials** have pH numbers from 1 through 6. The lower the number, the stronger the acid action will be. Caustic materials and acid materials neutralize each other. This is what happens when baking soda (a caustic) is used to clean the outside of the battery (an acid surface). The caustic baking soda neutralizes any sulfuric acid that has been spilled or splashed on the outside of the battery.

CAUTION: Whenever working with chemicals, you must use eye protection.

SOLVENT-BASED CLEANING Cleaning chemicals applied to engine parts will mix with and dissolve deposits. The chemicals loosen the deposits so that they can be brushed or rinsed from the surface. A deposit is said to be *soluble* when it can be dissolved with a chemical or solvent. Chemical cleaning can involve a spray washer or a soak in a cold or hot tank. The cleaning solution is usually solvent based, with a medium pH rating of between 10 and 12. Most chemical solutions also contain silicates to protect the metal (aluminum) against corrosion.

Strong caustics do an excellent job on cast-iron items but are often too corrosive for aluminum parts. Aluminum cleaners include mineral spirit solvents as well as alkaline detergents.



FIGURE 29–5 A pressure jet washer is similar to a large industrial-sized dishwasher. Each part is then rinsed with water to remove chemicals or debris that may remain there while it is still in the tank.

CAUTION: When cleaning aluminum cylinder heads, blocks, or other engine components, make sure that the chemicals used are "aluminum safe." Many chemicals that are not aluminum safe may turn the aluminum metal black. Try to explain that to a customer!

WATER-BASED CHEMICAL CLEANING Because of environmental concerns, most chemical cleaning is now performed using water-based solutions (also called **aqueous-based solutions**). Most aqueous-type chemicals are silicate based and are mixed with water. Aqueous-based solutions can be used in one of two ways.

- Sprayed on
- Used in a tank for soaking parts

Aluminum heads and blocks usually require overnight soaking in a solution kept at about 190°F (90°C). For best results, the cleaning solution should be agitated.

SPRAY AND STEAM WASHING

SPRAY WASHING A spray washer directs streams of liquid through numerous high-pressure nozzles to dislodge dirt and grime on an engine surface. The force of the liquid hitting the surface, combined with the chemical action of the cleaning solution, produces a clean surface. Spray washing is typically performed in an enclosed washer (like a dishwasher), where parts are rotated on a washer turntable. ● **SEE FIGURE 29–5**.

Spray washing is faster than soaking. A typical washer cycle is less than 30 minutes per load, compared to eight or more hours for soaking. Most spray washers use an aqueous-based cleaning solution heated to 160°F to 180°F (70°C to 80°C) with foam suppressants. High-volume remanufacturers use industrial dishwashing machines to clean the disassembled engine component parts.

STEAM CLEANING Steam vapor is mixed with high-pressure water and sprayed on the parts. The heat of the steam plus the force of the high-pressure water perform the actual cleaning. Steam cleaning must be used with extreme care. Usually, a caustic cleaner is added to the steam and water to aid in the cleaning. This mixture is so active that it will damage and even remove paint, so painted surfaces must be protected from the spray. Engines are often steam cleaned before they are removed from the vehicle.



FIGURE 29–6 A microbial cleaning tank uses microbes to clean grease and oil from parts.

THERMAL CLEANING

TEMPERATURES INVOLVED Thermal cleaning uses heat to vaporize and change dirt, oil, and grease into a dry, powdery ash. Thermal cleaning is best suited for cleaning cast iron, where temperatures as high as 800°F (425°C) are used, whereas aluminum should not be heated to over 600°F (315°C).

ADVANTAGES The major advantages of thermal cleaning include the following:

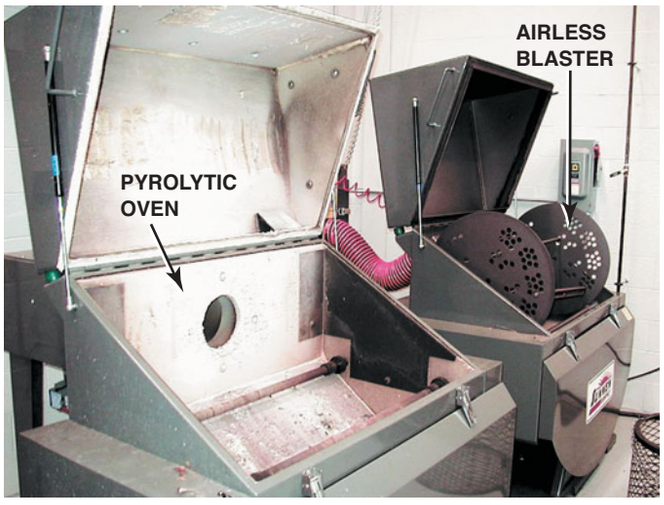
1. This process cleans the inside as well as the outside of the casting or part.
2. The waste generated is nonhazardous and is easy to dispose of. However, the heat in the oven usually discolors the metal, leaving it looking dull.

MICROBIAL CLEANING Microbial cleaning uses microbes that are living organisms (single-celled bacteria) that literally "eat" the hydrocarbons (grease and oils) off of the parts being cleaned. The typical microbial cleaning system includes three parts.

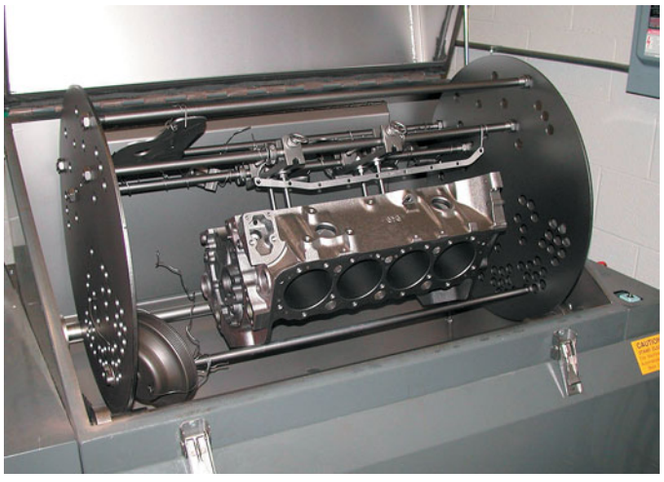
- A liquid assists the microbes by breaking the hydrocarbons to a smaller (molecular) size.
- The microbes, stored in a dormant phase until ready for use, give an indefinite shelf life to the product. Once the microbes come into contact with the liquid, they wake up from the dormant state and begin to feed.
- A third part is a blend of nutrients to ensure that the microbes start to multiply in the shortest amount of time to help speed the cleaning time needed.

Microbial cleaning is environmentally friendly, but is slower to clean parts. ● **SEE FIGURE 29–6**.

PYROLYTIC OVEN A **pyrolytic** (high-temperature) oven cleans engine parts by decomposing dirt, grease, and gaskets with heat in a manner similar to that of a self-cleaning oven. This method of engine



(a)



(b)

FIGURE 29–7 (a) A pyrolytic (high-temperature) oven cleans by baking the engine parts. After the parts have been cleaned, they are then placed into an airless blaster. This unit uses a paddle to scoop stainless steel shot from a reservoir and forces it against the engine part. The parts must be free of grease and oil to function correctly. (b) This cleaned engine block has been baked and shot blasted.

parts cleaning is the least hazardous method and is becoming the most popular because there is no hazardous waste associated with it. Labor costs are also reduced because the operator does not need to be present during the actual cleaning operation. ● **SEE FIGURE 29–7**.

TANK AND VAPOR CLEANING

COLD TANK CLEANING The cold soak tank is used to remove grease and carbon. The disassembled parts are placed in the tank so that they are *completely* covered with the chemical cleaning solution. After a soaking period, the parts are removed and rinsed until the milky appearance of the emulsion is gone. The parts are then dried with compressed air. The clean, dry parts are then usually given a very light coating of clean oil to prevent rusting. Carburetor cleaner, purchased with a basket in a bucket, is one of the most common types of cold soak agents in the automotive shop. Usually, there will be a layer of water over the chemical to prevent evaporation of the chemical. This water layer is called a **hydroseal.**

Parts washers are often used in place of soaking tanks. This equipment can move parts back and forth through the cleaning solution or pumps the cleaning solution over the parts. This movement, called **agitation,** keeps fresh cleaning solution moving past the soil to help it loosen. The parts washer is usually equipped with a safety cover held open by a low-temperature **fusible link.** If a fire occurs, the fusible link will melt and the cover will drop closed to snuff the fire out.



FIGURE 29–8 An ultrasonic cleaner being used to clean fuel injectors.

HOT TANK CLEANING The hot soak tank is used for cleaning heavy organic deposits and rust from iron and steel parts. The caustic cleaning solution used in the hot soak tank is heated to near 200°F (93°C) for rapid cleaning action. The solution must be inhibited when aluminum is to be cleaned. After the deposits have been loosened, the parts are removed from the tank and rinsed with hot water or steam cleaned, which dries them rapidly. They must then be given a light coating of oil to prevent rusting.

HINT: Fogging oil from a spray can does an excellent job of coating metal parts to keep them from rusting.

VAPOR CLEANING Vapor cleaning is popular in some automotive service shops. The parts to be cleaned are suspended in hot vapors above a perchloroethylene solution. The vapors of the solution loosen the soil from the metal so that it can be blown, wiped, or rinsed from the surface.

ULTRASONIC AND VIBRATORY CLEANING

ULTRASONIC CLEANING **Ultrasonic cleaning** is used to clean small parts that must be absolutely clean, such as hydraulic lifters and diesel injectors. The disassembled parts are placed in a tank of cleaning solution that is then vibrated at ultrasonic speeds to loosen all the soil from the parts. The soil goes into the solution or falls to the bottom of the tank. ● **SEE FIGURE 29–8**.

VIBRATORY CLEANING The vibratory method of cleaning is best suited for small parts. Parts are loaded into a vibrating bin with small odd-shaped ceramic or steel pieces, called media, with a cleaning solution of mineral spirits or water-based detergents that usually contain a lubricant additive to help the media pieces slide around more freely. The movement of the vibrating solution and the scrubbing action of the media do an excellent job of cleaning metal.

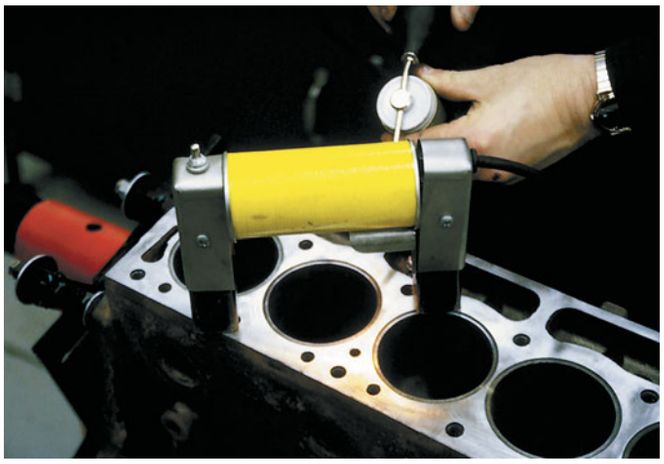


FIGURE 29–9 The top deck surface of a block is being tested using magnetic crack inspection equipment.

CRACK DETECTION

VISUAL INSPECTION After the parts have been thoroughly cleaned, they should be reexamined for defects. A magnifying glass is helpful in finding defects. Internal parts such as pistons, connecting rods, and crankshafts that have cracks should be replaced. Cracks in the block and heads, however, can often be repaired.

MAGNETIC CRACK DETECTION The process of detecting cracks using a magnetic field is commonly referred to by the brand name Magnafluxing. Cracks in engine blocks, cylinder heads, crankshafts, and other engine components are sometimes difficult to find during a normal visual inspection, which is why all remanufacturers and most engine builders use a crack detection procedure on critical engine parts.

Magnetic flux testing is the method most often used on steel and iron components. A metal engine part (such as a cast-iron cylinder head) is connected to a large electromagnet. Magnetic lines of force are easily conducted through the iron part and concentrate on the edges of a crack. A fine iron powder is then applied to the part being tested, and the powder will be attracted to the strong magnetic concentration around the crack. ● **SEE FIGURES 29–9 THROUGH 29–11.**

DYE-PENETRANT TESTING Dye-penetrant testing is often used on pistons and other parts constructed of aluminum or other nonmagnetic material. A dark red penetrating chemical is first sprayed on the component being tested. After cleaning, a white powder is sprayed over the test area. If a crack is present, the red dye will stain the white powder. Even though this method will also work on iron and steel (magnetic) parts, it is often used only on nonmagnetic parts because magnetic methods do not work on these parts.

FLUORESCENT-PENETRANT TESTING To be seen, fluorescent penetrant requires a black light. It can be used on iron, steel, or aluminum parts. Cracks show up as bright lines when viewed with a black light. The method is commonly called **Zyglo,** a trademark of the Magnaflux Corporation.

PRESSURE TESTING Cylinder heads and blocks are often pressure tested with air and checked for leaks. All coolant passages are blocked with rubber plugs or gaskets, and compressed air is applied to the water jacket(s). The head or block is then lowered into water, where air bubbles indicate a leak. For more accurate results, the water should be heated because the hot water expands the casting by about the same amount as an operating engine would. An alternative method involves running heated water with a dye through the cylinder or block. Any leaks revealed by the dyed water indicate a crack. ● **SEE FIGURES 29–12 AND 29–13.**

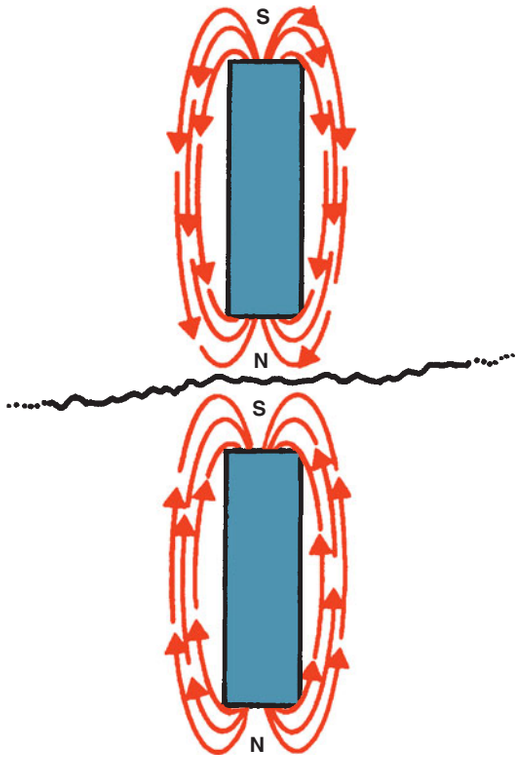


FIGURE 29–10 If the lines of force are interrupted by a break (crack) in the casting, then two magnetic fields are created and the powder will lodge in the crack.

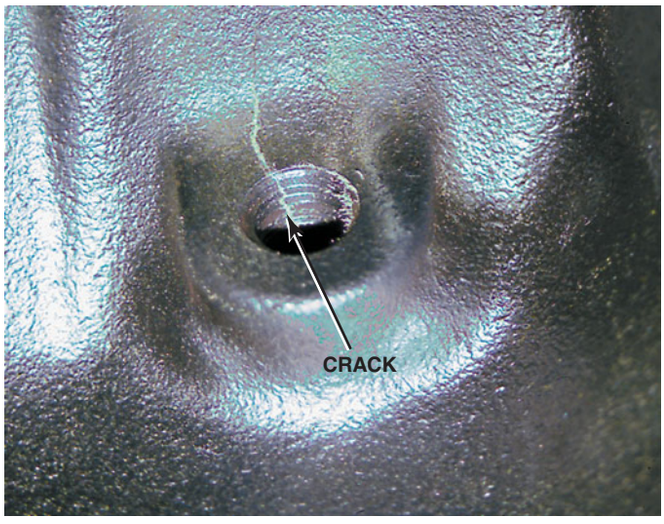


FIGURE 29–11 This crack in a vintage Ford 289, V-8 block was likely caused by the technician using excessive force trying to remove the plug from the block. The technician should have used heat and wax, not only to make the job easier, but also to prevent damaging the block.

CRACK REPAIR

CRACK CONCERNS Cracks in the engine block can cause coolant to flow into the oil or oil into the coolant. A cracked block can also cause coolant to leak externally from a crack that goes through

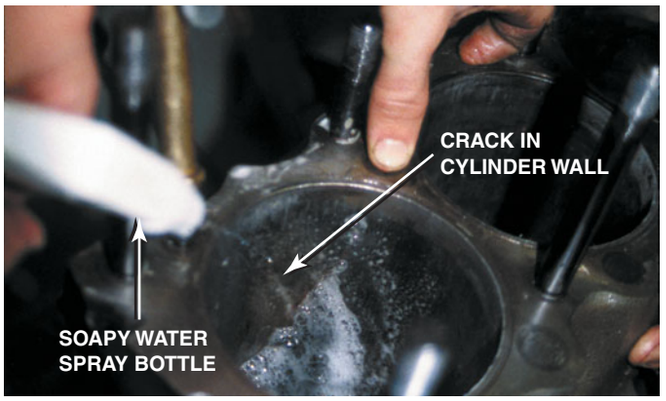


FIGURE 29–12 To make sure that the mark observed in the cylinder wall was a crack, compressed air was forced into the water jacket while soapy water was sprayed on the cylinder wall. Bubbles confirmed that the mark was indeed a crack.

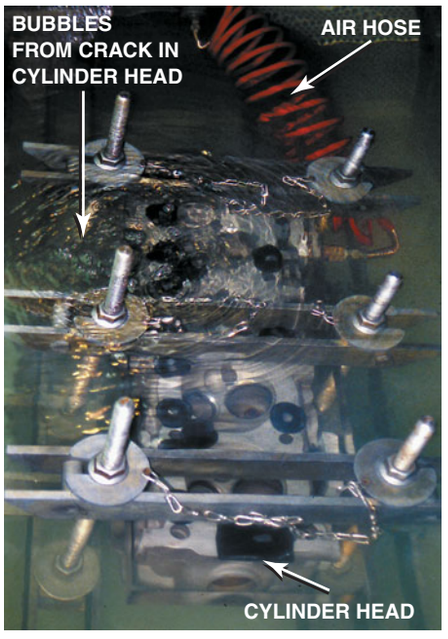


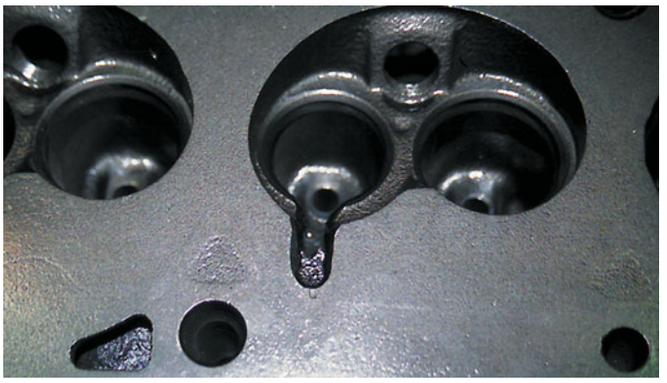
FIGURE 29–13 A cylinder head is under water and being pressure tested using compressed air. Note that the air bubbles indicate a crack.

to a coolant passage. Cracks in the head will allow coolant to leak into the engine, or they will allow combustion gases to leak into the coolant. Cracks across the valve seat cause hot spots on the valve, which will burn the valve face. A head with a crack will either have to be replaced or the crack will have to be repaired.

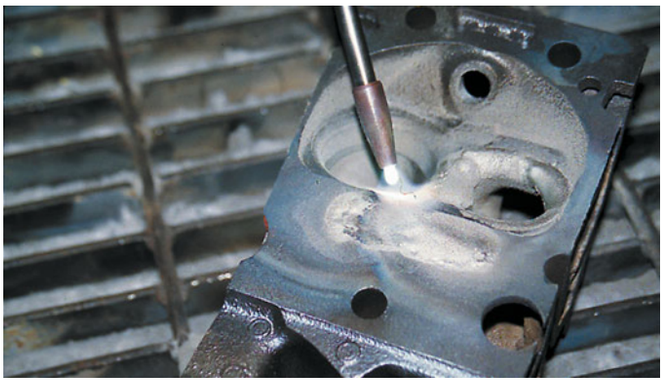
STOP DRILLING A hole can be drilled at each end of the crack to keep it from extending farther, a step sometimes called *stop drilling.* Cracks that do not cross oil passages, bolt holes, or seal surfaces can sometimes be left alone if stopped.

CRACK-WELDING CAST IRON It takes a great deal of skill to weld cast iron. The cast iron does not puddle or flow as steel does when it is heated. Heavy cast parts, such as the head and block, conduct heat away from the weld so fast that it is difficult to get the part hot enough to melt the iron for welding. When it does melt, a crack will often develop next to the edge of the weld bead. Welding can be done satisfactorily when the entire cast part is heated red-hot.

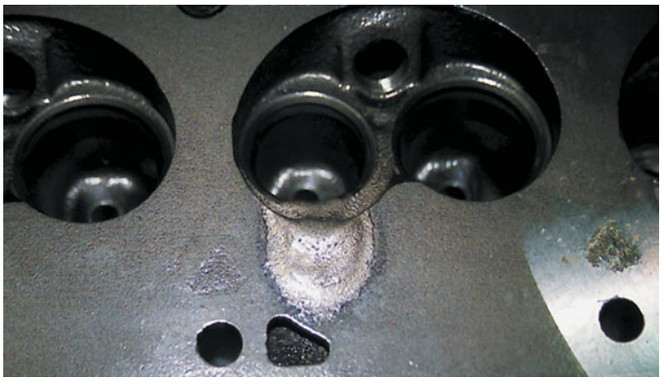
A new technique involves flame welding using a special torch. ● **SEE FIGURE 29–14.**



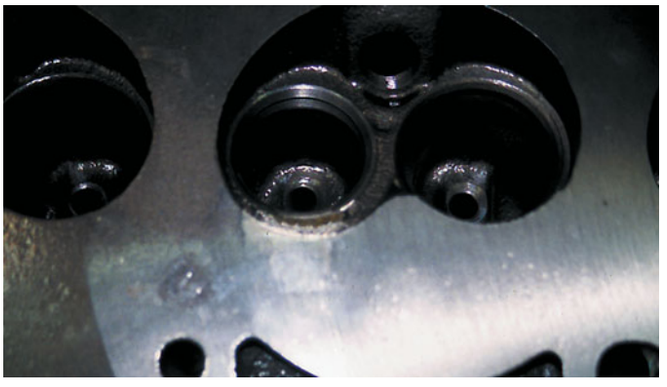
(a)



(b)



(c)



(d)

FIGURE 29–14 (a) Before welding, the crack is ground out using a carbide grinder. (b) Here the technician is practicing using the special cast-iron welding torch before welding the cracked cylinder head. (c) This is the finished welded crack before final machining. (d) Note the finished cylinder head after the crack has been repaired using welding.

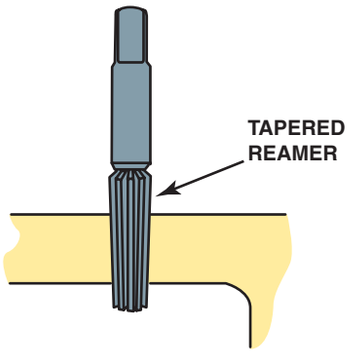


FIGURE 29–15 Reaming a hole for a tapered plug.

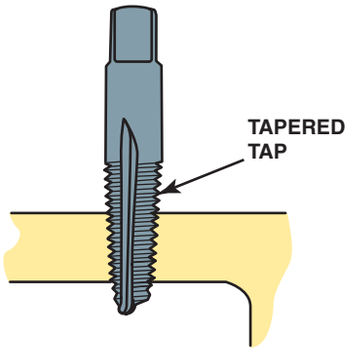


FIGURE 29–16 Tapping a tapered hole for a plug.

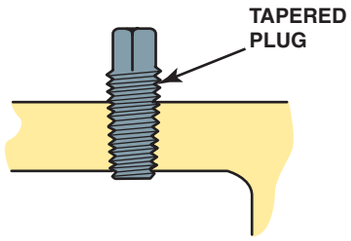


FIGURE 29–17 Screwing a tapered plug in the hole.

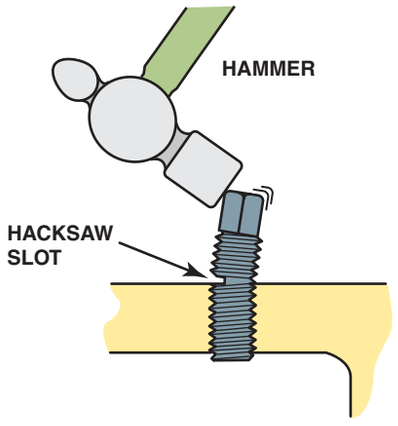


FIGURE 29–18 Cutting the plug with a hacksaw.

CRACK-WELDING ALUMINUM Cracks in aluminum can be welded using a Heli-arc® or similar welder that is specially designed to weld aluminum. The crack should be cut or burned out before welding begins. The old valve-seat insert should be removed if the crack is in or near the combustion chamber.

CRACK PLUGGING In the process of crack plugging, a crack is closed using interlocking tapered plugs. This procedure can be performed to repair cracks in both aluminum and cast-iron engine components. The ends of the crack are center punched and drilled with the proper size of tap drill for the plugs. The hole is reamed with a tapered reamer (● **FIGURE 29–15**) and is then tapped with a special tap to give full threads (● **FIGURE 29–16**).

The plug is coated with sealer; then it is tightened into the hole (● **FIGURE 29–17**), sawed about one-fourth of the way through, and broken off.

The saw slot controls the breaking point (● **FIGURE 29–18**).

If the plug should break below the surface, it will have to be drilled out and a new plug installed. The plug should go to the full depth or thickness of the cast metal. After the first plug is installed on each end, a new hole is drilled with the tap drill so that it cuts into the edge of the first plug. This new hole is reamed and tapped, and a plug is inserted as before. The plug should fit about one-fourth of the way into the first plug to lock it into place (● **FIGURE 29–19**).

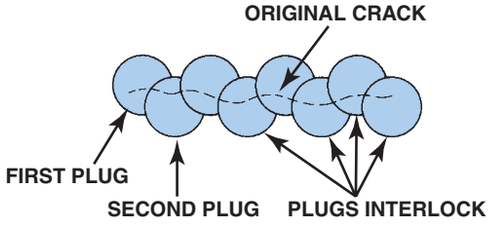
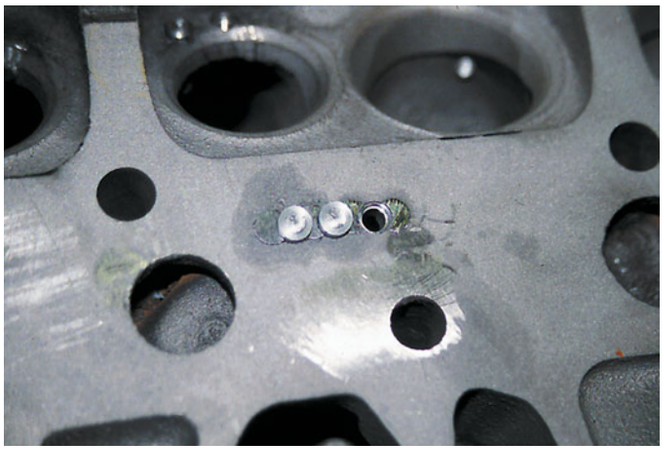
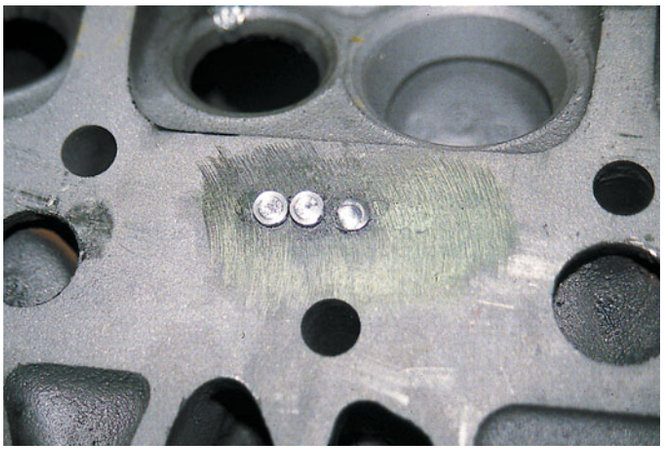


FIGURE 29–19 Interlocking plugs.

Interlocking plugs are placed along the entire crack, alternating slightly from side to side. The exposed ends of the plugs are peened over with a hammer to help secure them in place. The surface of the plugs is then ground or filed down nearly to the gasket surface. In the combustion chamber and at the ports, the plugs are ground down to the original surface using a hand grinder. The gasket surface of the head must be resurfaced after the crack has been repaired. ● **SEE FIGURE 29–20** for an example of a cylinder head repair using plugs.



(a)



(b)



(c)

FIGURE 29–20 (a) A hole is drilled and tapped for the plugs. (b) The plugs are installed. (c) After final machining, the cylinder head can be returned to useful service.

REVIEW QUESTIONS

1. Describe five methods that could be used to clean engines or engine parts.
2. Explain magnetic crack inspection, dye-penetrant testing, and fluorescent-penetrant testing methods and where each can be used.
3. How can engine block and cylinder heads be repaired if cracked?

CHAPTER QUIZ

1. Abrasive pads or discs should be used _____.
   a. On disassembled engine parts only
   b. According to the specified grit size for the material being cleaned
   c. But clean the part thoroughly to wash away the abrasive material
   d. All of the above
2. What actually does the cleaning when using steam?
   a. Heat from the steam
   b. Pressure behind the steam
   c. Abrasives used
   d. Both a and b
3. Aqueous-based cleaning means _____.
   a. Water based
   b. Abrasive based
   c. Strong chemical based
   d. All of the above
4. A pyrolytic oven is used to clean parts; however, caution should be used to limit the temperature, to prevent damaging engine parts. What are the maximum recommended temperatures?
   a. 300°F (150°C) for all engine parts
   b. 600°F (315°C) for aluminum parts
   c. 800°F (425°C) for cast iron
   d. Both b and c

5. Which media is best to use for cleaning parts as it does not need to be thoroughly cleaned after using?
   a. Baking soda **c.** Glass beads
   b. Stainless steel shot **d.** Aluminum shot

6. Cleaning chemicals are usually either a caustic material or an acid material. Which of the following statements is true?
   a. Both caustics and acids have a pH of 7 if rated according to distilled water.
   b. An acid is lower than 7 and a caustic is higher than 7 on the pH scale.
   c. An acid is higher than 7 and a caustic is lower than 7 on the pH scale.
   d. Pure water is a 1 and a strong acid is a 14 on the pH scale.

7. Many cleaning methods involve chemicals that are hazardous to use. The least hazardous method is generally considered to be the _____.
   a. Pyrolytic oven **c.** Hot soak tank
   b. Hot vapor tank **d.** Cold soak tank

8. Magnetic crack inspection _____.
   a. Uses a red dye to detect cracks in aluminum
   b. Uses a black light to detect cracks in iron parts
   c. Uses a fine iron powder to detect cracks in iron parts
   d. Uses a magnet to remove cracks from iron parts

9. Technician A says that engine parts should be cleaned before a thorough test can be done to detect cracks. Technician B says that pressure testing can be used to find cracks in blocks or cylinder heads. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

10. Plugging can be used to repair cracks _____.
   a. In cast-iron cylinder heads
   b. In aluminum cylinder heads
   c. In both cast-iron and aluminum cylinder heads
   d. Only in cast-iron blocks

chapter 30 CYLINDER HEAD AND VALVE GUIDE SERVICE

OBJECTIVES: After studying Chapter 30, the reader should be able to: • Prepare for ASE Engine Repair (A1) certification test content area "B" (Cylinder Head and Valve Train Diagnosis and Repair). • Identify combustion chamber types. • List the steps necessary to recondition a cylinder head. • Describe how to inspect and measure valve guides. • Discuss valve guide repair options.

KEY TERMS: Arithmetic average roughness height (RA) 287 • Bend 286 • Bronze guide liners 291 • Bronze guides 291 • Cam tunnel 286 • Cast-iron guides 291 • Concentric 289 • Crossflow head 281 • Distortion 286 • Fire deck 286 • Milling 287 • Oversize (OS) stems 290 • Port 283 • Porting (relieving) 284 • Quench area 281 • Root-mean-square (RMS) 287 • Siamese port 283 • Spark plug placement 281 • Spiral bronze alloy bushing 291 • Squish area 280 • Surface grinder 287 • Surface-to-volume ratio 281 • Thin-walled bronze alloy sleeve bushing 291 • Twist 286 • Unshrouding 284 • Valve duration 282 • Valve guide knurling 290 • Valve guides 289 • Valve seat inserts 289 • Valve shrouding 281 • Warpage 286

INTRODUCTION

The repair and reconditioning of cylinder heads represents the most frequent engine repair operation of any engine component. The highest temperatures and pressures in the entire engine are located in the combustion chamber of the cylinder head. Its valves must open and close thousands of times when the engine is operated.

CYLINDER HEADS

CONSTRUCTION Cylinder heads support the valves and valve train, and contain passages for the flow of intake, exhaust gases, coolant, and sometimes engine oil. In an overhead camshaft design engine, the cylinder head also supports all of the valve train components including the camshaft, rocker arms, or followers, as well as the intake and exhaust valves and valve guides. ● **SEE FIGURE 30–1.**

DESIGN FEATURES Most cylinder head designs incorporate the following design factors to achieve fast burning of the air-fuel mixture and to reduce exhaust emissions.

These factors include:

- **Squish area.** This is an area of the combustion chamber where the piston nearly contacts the cylinder head. When the piston is moving upward toward the cylinder head, the air-fuel mixture is rapidly pushed out of the squish area, causing turbulence. Turbulence helps mix the air and fuel, thereby ensuring a more uniform and complete combustion. ● **SEE FIGURE 30–2.**

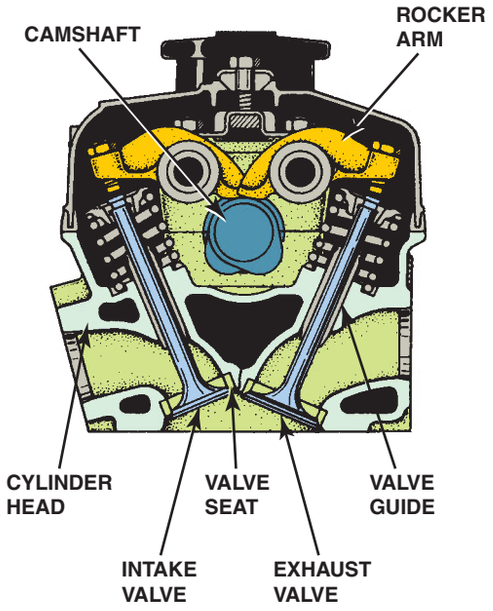


FIGURE 30–1 The seats and guides for the valves are in the cylinder head as well as the camshaft and the entire valve train if it is an overhead camshaft design.

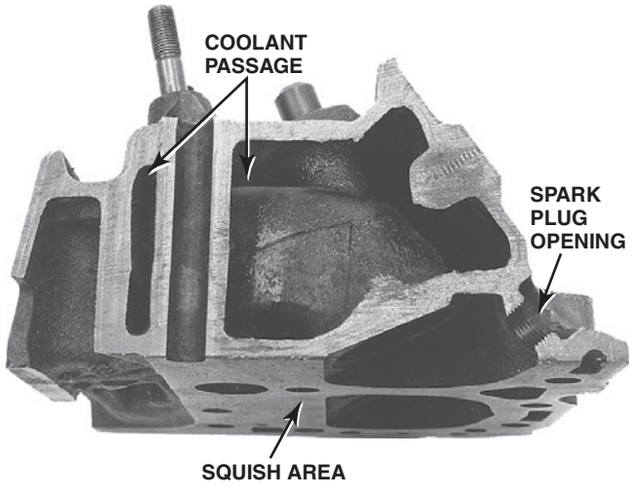


FIGURE 30–2 A wedge-shaped combustion chamber showing the squish area where the air-fuel mixture is squeezed, causing turbulence that pushes the mixture toward the spark plug.

- **Quench area.** The squish area can also be the quench area where the air-fuel mixture is cooled by the cylinder head. The quench area is the flat area of the combustion chamber that is above the flat area of the piston. As the piston moves upward on the compression stroke, the air-fuel mixture is forced from this area as the piston gets near the top. The quench area operates at lower temperatures than the rest of the combustion chamber and can cause the gasoline vapors to condense on these cooler surfaces, thereby helping to reduce detonation caused by the autoignition of the end gases in the combustion chamber.
- **Spark plug placement.** The best spark plug placement is at the center of the combustion chamber. ● **SEE FIGURE 30–3.**

  The closer to the center, the shorter the flames travel to all edges of the combustion chamber, which also reduces abnormal combustion (ping or spark knock). While it is best to have the spark plug in the center, some combustion chamber designs do not allow this, due to valve size, combustion chamber design, and valve placement. Some engines use two spark plugs per cylinder to achieve rapid combustion needed to meet exhaust emissions standards. ● **SEE FIGURE 30–4** for an example of a two-spark plug combustion chamber used in a hemispherical (Hemi) cylinder head design.

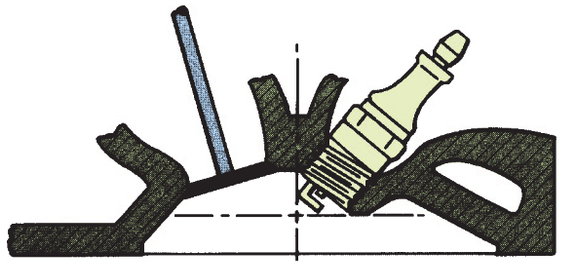


FIGURE 30–3 Locating the spark plug in the center of the combustion chamber reduces the distance the flame front must travel.

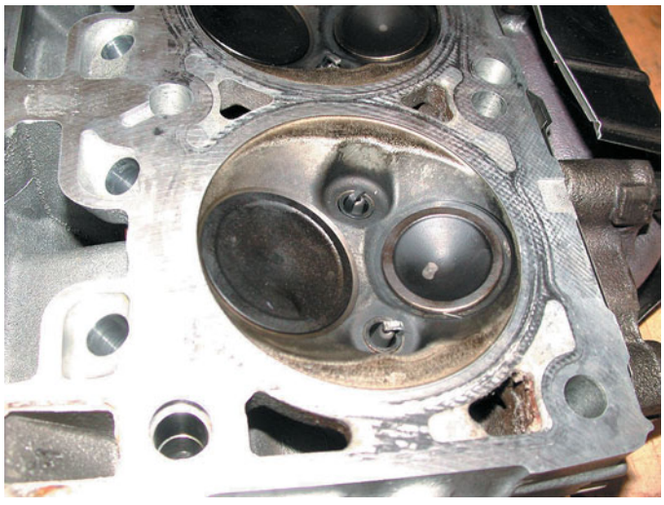


FIGURE 30–4 The combustion chamber of the 5.7 liter Chrysler Hemi cylinder head shows the two spark plugs used to ensure rapid burn for best power and economy with the lowest possible exhaust emissions.

- **Surface-to-volume ratio.** This ratio is an important design consideration for combustion chambers. A typical surface-to-volume ratio is 7.5:1, which means the surface area of the combustion chamber divided by the volume is 7.5. If the ratio is too high, there is a lot of surface area where fuel can adhere, causing an increase in unburned hydrocarbon (HC) emissions. The cool cylinder head causes some of the air-fuel mixture to condense, resulting in a layer of liquid fuel on the surfaces of the combustion chamber. This layer of condensed fuel will not burn because it is not surrounded by oxygen needed for combustion. As a result, this unburned fuel is pushed out of the cylinder by the piston on the exhaust stroke.
- **Valve shrouding.** Shrouding means that the valve is kept close to the walls of the combustion chamber to help increase mixture turbulence. Although shrouding the intake valve can help swirl and increase turbulence, it also reduces the flow into the engine at higher engine speeds. ● **SEE FIGURE 30–5.**
- **Crossflow valve placement.** Valve placement in the cylinder head is an important factor in breather efficiency. By placing the intake and the exhaust valves on the opposite sides of the combustion chamber, an easy path from the intake port through the combustion chamber to the exhaust port is provided. This is called a **crossflow head** design. ● **SEE FIGURE 30–6.**

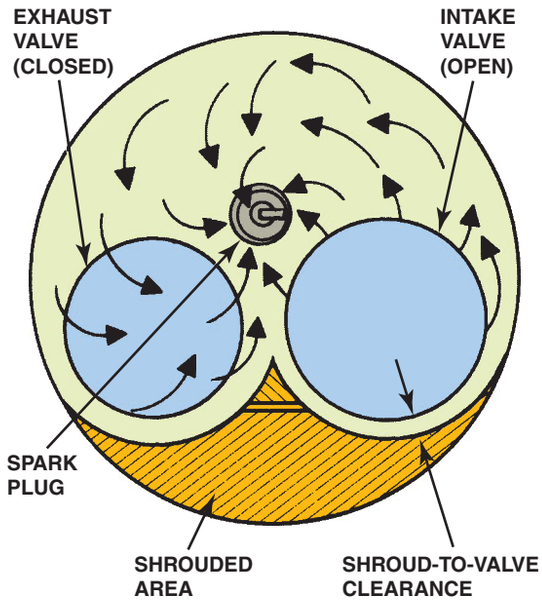


FIGURE 30–5 The shrouded area around the intake valve causes the intake mixture to swirl as it enters the combustion chamber.

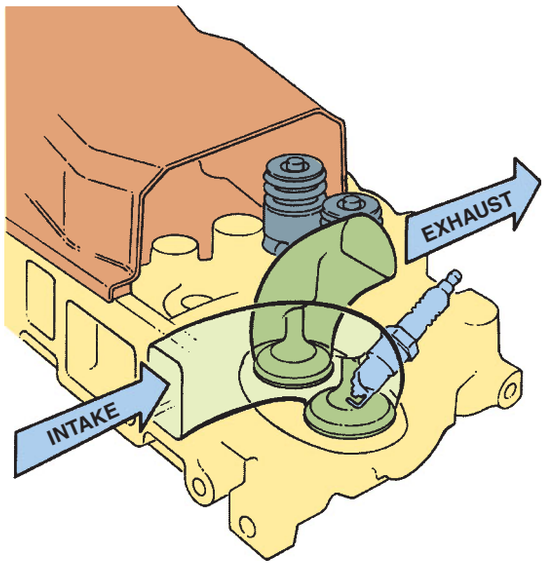


FIGURE 30–6 A typical cross flow cylinder head design, where the flow into and out of the combustion chamber is from opposite sides of the cylinder head.

COMBUSTION CHAMBER DESIGNS

Combustion chamber shape has an effect on engine power and efficiency. The combustion chamber is created as two parts.

- The upper part consists of the cylinder head and cylinder walls.
- The lower part is the top of the piston.

The most commonly used combustion chamber shapes include:

- **Wedge.** Commonly found on many two-valve pushrod engines (cam-in-block) designs
- **Pentroof.** Commonly found on many four-valve overhead camshaft design engines
- **Hemi.** Found on both cam-in-block and overhead camshaft design engines

FOUR-VALVE CYLINDER HEADS

Adding more than two valves per cylinder permits more gas to flow into and out of the engine with greater velocity without excessive valve duration. **Valve duration** is the number of degrees by which the crankshaft rotates when the valve is off the valve seat. Increased valve duration increases valve overlap. The valve overlap occurs when both valves are open at the same time at the end of the exhaust stroke and at the beginning of the intake stroke. At lower engine speeds, the gases can move back and forth between the open valves. Therefore, the greater valve duration hurts low engine speed performance and driveability, but it allows for more air-fuel mixture to enter the engine for better high-speed power.

The maximum amount of gas moving through the opening area of a valve depends on the distance around the valve and the degree to which it lifts open. ● **SEE FIGURE 30–7.**

Using normal opening lift of about 25% of the valve head diameter as an example, if the intake valve is 2 in. diameter, the normal amount of lift off the seat (not cam lobe height) is 25% of 2 in., or 1/2 (0.5) in. However, the amount of air-fuel mixture that can enter a cylinder depends on the total area around the valve, not just the amount of lift. The distance around a valve is calculated by the equation:

pi × D or
3.1416 × Valve diameter

● **SEE FIGURE 30–8.**

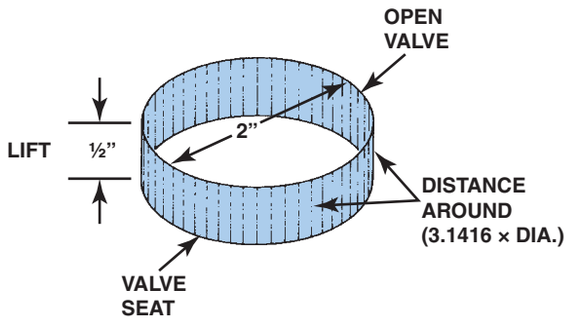


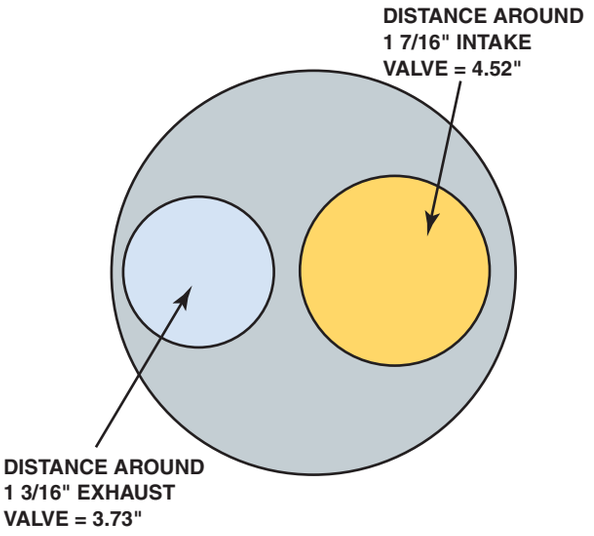
FIGURE 30–7 Method for measuring the valve opening space.

FREQUENTLY ASKED QUESTION

What Is Carbon Knock?

Carbon knock was a common occurrence in older engines that were equipped with carburetors and high compression ratios. As carburetors aged, the mixture would tend to be richer than normal, due to a leaking needle and seat, as well as a fuel-saturated float. This richer mixture would often cause carbon deposits to form in the combustion chamber. During light load conditions when the spark advance was greatest, a spark knock would occur, caused by a higher compression ratio due to the carbon deposits. This knocking was often very loud, sounding like a rod bearing noise, because in some cases the carbon deposits actually caused physical contact between the piston and the carbon. Many engines were disassembled in the belief that the cause of the knocking sound was a bearing, only to discover that the bearings were okay.

Carbon knock can still occur in newer engines, especially if there is a fault in the fuel system that would allow a much richer-than-normal air-fuel mixture, causing excessive carbon deposits to form in the combustion chamber. Often a decarbonization using chemicals will correct the knocking.



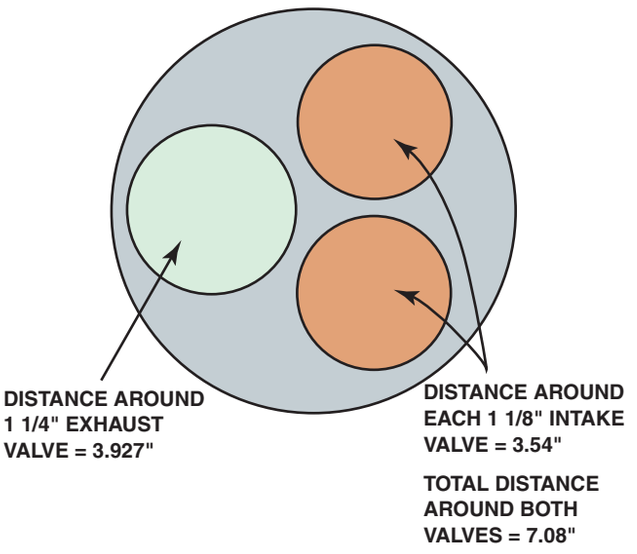


FIGURE 30–8 Comparing the valve opening areas between a two- and three-valve combustion chamber when the valves are open.

More total area under the valve is possible when two smaller valves are used rather than one larger valve at the same valve lift. The smaller valves allow smooth low-speed operation (because of increased velocity of the mixture as it enters the cylinder as a result of smaller intake ports). Good high-speed performance is also possible because of the increased valve area and lighter weight valves. ● **SEE FIGURE 30–9.**

When four valves are used, either the combustion chamber has a pentroof design, with each pair of valves in line, or it is hemispherical, with each valve on its own axis. ● **SEE FIGURE 30–10.**

Four valves on the pentroof design will be operated with dual overhead camshafts or with single overhead camshafts and rocker arms. When four valves are used, it is possible to place the spark plug at the center of the combustion chamber.

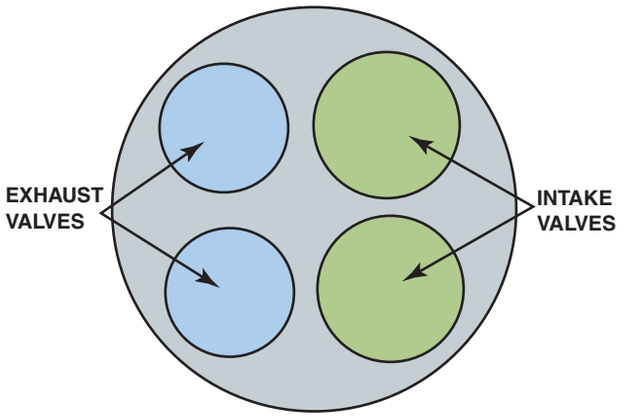


FIGURE 30–9 Typical four-valve head. The total area of opening of two small intake valves and two smaller exhaust valves is greater than the area of a two-valve head using much larger valves. The smaller valves also permit the use of smaller intake runners for better low-speed engine response.

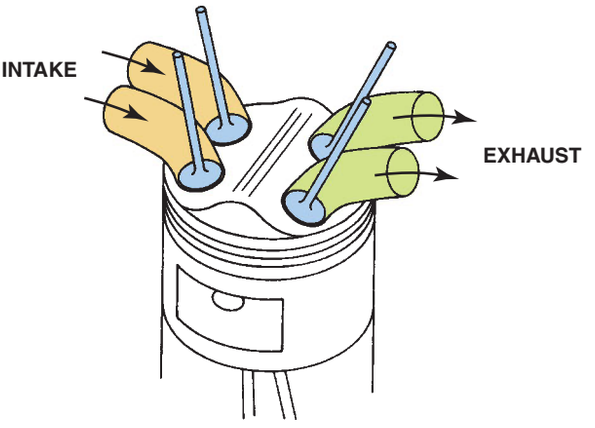


FIGURE 30–10 Four valves in a pentroof combustion chamber.

TECH TIP

Horsepower Is Airflow

To get more power from an engine, more air needs to be drawn into the combustion chamber. One way to achieve more airflow is to increase the valve and port size of the cylinder heads along with a change in camshaft lift and duration to match the cylinder heads. One popular, but expensive, method is to replace the stock cylinder heads with high-performance cast-iron or aluminum cylinder heads.

Some vehicle manufacturers, such as Audi, go to great expense to design high-flow rate cylinder heads by installing five-valve cylinder heads on some of their high-performance engines. ● **SEE FIGURE 30–11.**

INTAKE AND EXHAUST PORTS

PURPOSE AND FUNCTION The part of the intake or exhaust system passage that is cast in the cylinder head is called a **port.** Ports lead from the manifolds to the valves. The most desirable port shape is not always possible because of space requirements in the head. Space is required for the head bolt bosses, valve guides, cooling passages, and pushrod openings. Inline engines may have both intake and exhaust ports located on the same side of the engine. On some older engines two cylinders share the same port because of the restricted space available. Shared ports are called **Siamese ports.**

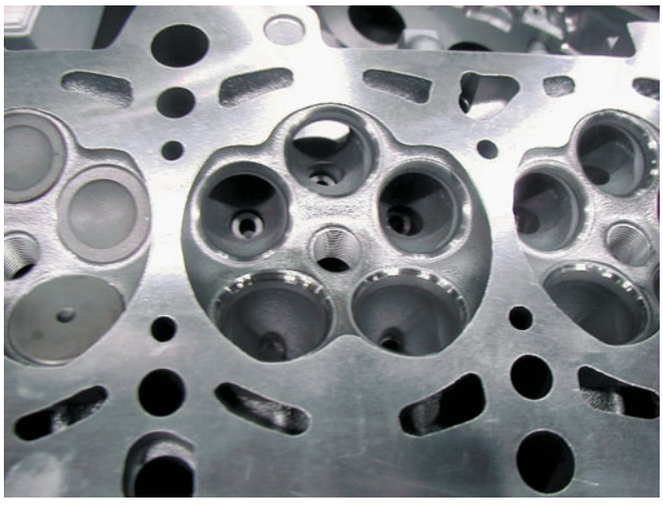


FIGURE 30–11 An Audi five-valve cylinder head, which uses three intake valves and two exhaust valves.

TECH TIP

Unshroud the Intake Valve for More Power

If an engine is being rebuilt for high performance, most experts recommend that the shrouded section around the intake valve be removed, thereby increasing the airflow and, therefore, the power that the engine can achieve, especially at higher engine speeds. This process is often called **unshrouding.**

INTAKE PORTS Larger ports and better breathing are possible in engines that have the intake port on one side of the head and the exhaust port on the opposite side. Sometimes a restricting hump within a port may actually increase the airflow capacity of the port.

It does this by redirecting the flow to an area of the port that is large enough to handle the flow. Modifications in the field, such as **porting or relieving,** would result in restricting the flow of such a carefully designed port.

The intake port in a cylinder head designed for use with a carburetor or throttle-body-type fuel injection is relatively long, whereas the exhaust port is short. On engines designed for use with port fuel injection, the cylinder head ports are designed to help promote swirl in the combustion chamber, as shown in ● **FIGURE 30–12.**

EXHAUST PORTS Like the intake ports, exhaust ports are designed to allow the free flow of exhaust gases from the engine. The length of the exhaust ports is shorter than the intake ports to help reduce the amount of heat transferred to the coolant. ● **SEE FIGURE 30–13.**

CYLINDER HEAD PASSAGES

COOLANT FLOW PASSAGES The engine is designed so that coolant will flow from the coolest portion of the engine to the warmest portion. The water pump takes the coolant from the radiator. The coolant is circulated through the block, where it is directed all around the cylinders. The coolant then flows upward through the gasket to the cooling passages cast into the cylinder head. The heated coolant is collected at a common point and returned to the radiator to be cooled and recycled.

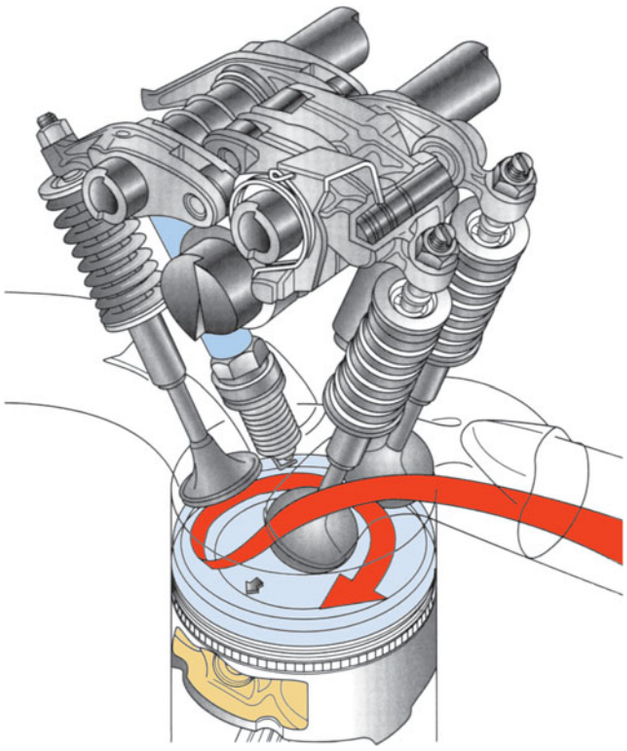


FIGURE 30–12 The intake manifold design and combustion chamber design both work together to cause the air-fuel mixture to swirl as it enters the combustion chamber.

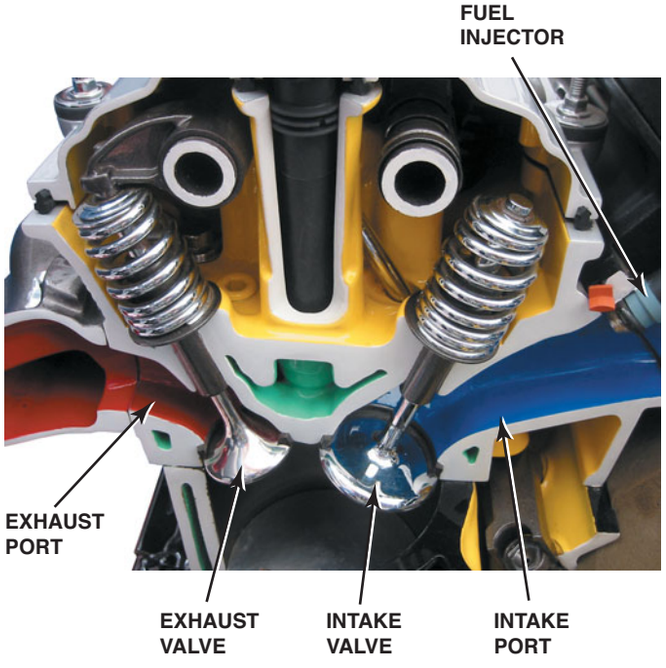


FIGURE 30–13 A port-injected engine showing the straight free-flowing intake and exhaust ports.

NOTE: Reversed-flow cooling systems, such as that used on the Chevrolet LT1 V-8, send the coolant from the radiator to the cylinder heads first. This results in a cooler cylinder head and allows for more spark advance without engine-damaging detonation.

Typical coolant passages in a head are shown in ● **FIGURE 30–14.**

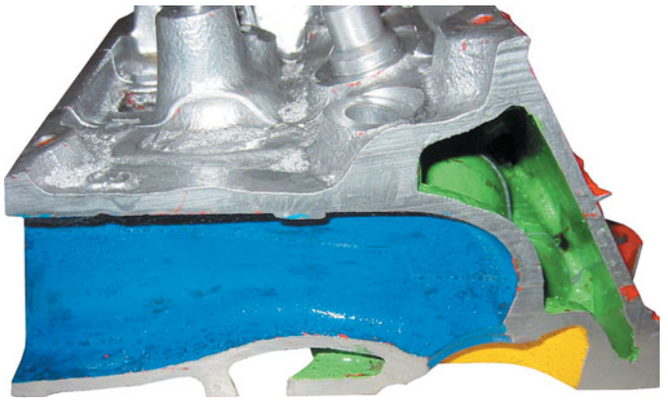


FIGURE 30–14 A cutaway head showing the coolant passages in green.

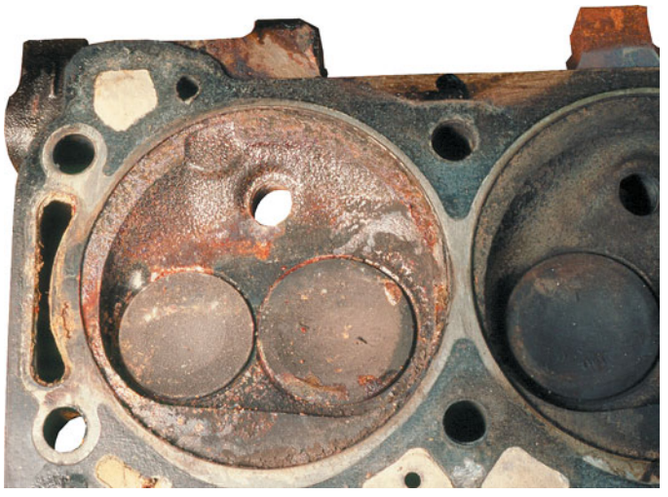


FIGURE 30–15 Coolant flows through the cylinder head, and the passages are sealed by the head gasket.

HEAD GASKET HOLES There are relatively large holes in the gasket surface of the head leading to the head cooling passages. The openings between the head and the block are usually too large for the correct coolant flow. When the openings are too large, the head gasket performs an important coolant flow function. Special-size and smaller holes are made in the gasket. These holes correct the coolant flow rate at each opening. Therefore, it is important that the head gasket be installed correctly for proper engine cooling. ● **SEE FIGURE 30–15.**

LUBRICATING OIL PASSAGES Lubricating oil is delivered to the overhead valve mechanism, either through the valve pushrods or through drilled passages in the head and block casting. There are special openings in the head gasket to allow the oil to pass between the block and head without leaking. After the oil passes through the valve mechanisms, it returns to the oil pan through oil return passages. Some engines have drilled oil return holes, but most engines have large cast holes that allow the oil to return freely to the engine oil pan. The cast holes are large and do not easily become plugged.

NOTE: Many aluminum cylinder heads have smaller-than-normal drainback holes. If an engine has excessive oil consumption, check the drain holes before removing the engine.

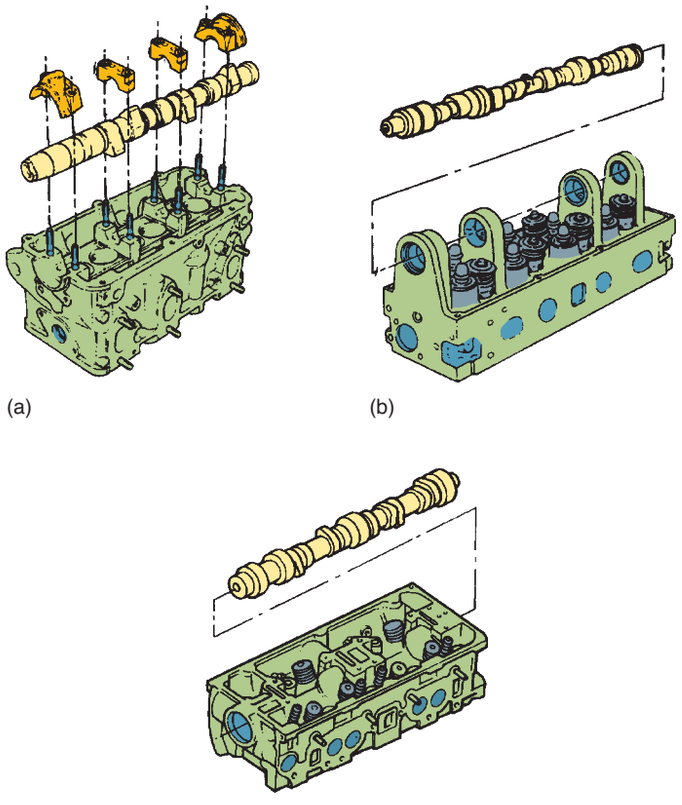


FIGURE 30–16 Overhead camshafts may be (a) held in place with bearing caps, (b) supported by towers, or (c) fitted into bearing bores machined directly into the head.

CYLINDER HEAD SERVICING

CYLINDER HEAD SERVICING SEQUENCE Although not all cylinder heads require all service operations, cylinder heads should be reconditioned using the following sequence.

1. Disassemble and thoroughly clean the heads. (See Chapter 25.)
2. Check for cracks and repair as necessary. (See Chapter 25.)
3. Check the surface that contacts the engine block and machine, if necessary. (See discussion later in this chapter.)
4. Check valve guides and replace or service, as necessary. (See discussion later in this chapter.)
5. Grind valves and reinstall them in the cylinder head with new valve stem seals. (See Chapter 27.)

DISASSEMBLING OVERHEAD CAMSHAFT HEAD The overhead camshaft will have either one-piece bearings in a solid bearing support or split bearings and a bearing cap. When one-piece bearings are used, the valve springs will have to be compressed with a fixture or the finger follower will have to be removed before the camshaft can be pulled out endwise. When bearing caps are used, they should be loosened alternately so that bending loads are not placed on either the cam or bearing caps. ● **SEE FIGURES 30–16 AND 30–17.**

VALVE TRAIN DISASSEMBLY Disassemble the cylinder head as discussed in Chapter 24. All valve train components that are to be reused must be kept together. As wear occurs, parts are worn together.

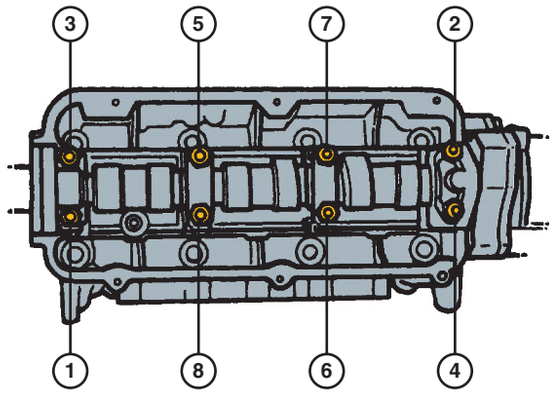


FIGURE 30–17 Always follow the specified loosening sequence to prevent valve spring tension from bending the camshaft.



FIGURE 30–18 Pushrods can be kept labeled if stuck through a cardboard box. Individual parts become worn together. Using cardboard is a crude but effective material to keep all valve train parts together and labeled exactly as they came from the engine.

- Be sure to keep the top part of the pushrod at the top.
- Keep the rocker arms with the same pushrods as they wear together.
- Intake and exhaust valve springs can be different and must be kept with the correct valve.

● SEE FIGURE 30–18.

CYLINDER HEAD INSPECTION The surface must be thoroughly cleaned and inspected as follows:

STEP 1 After removing the old gasket material, use a file and draw it across the surface of the head to remove any small burrs.

STEP 2 The head should be checked in five planes. Checking the cylinder head gasket surface in five planes checks the head for **warpage, distortion, bend,** and **twist.** **● SEE FIGURE 30–19.**

These defects are determined by trying to slide a 0.004 in. (0.1 mm) feeler gauge under a precision straightedge held against the head surface. The clearance between the cylinder head and the straightedge should not vary by over 0.002 in. (0.05 mm) in any 6 in. (15 cm) length, or by more than 0.004 in. overall. Always check the manufacturer's recommended specifications. **● SEE FIGURE 30–20.**

NOTE: The cylinder head surface that mates with the top deck of the block is often called the fire deck.

NOTE: Always check the cylinder head thickness and specifications to be sure that material can be safely removed from the surface. Some manufacturers do not recommend *any* machining, but rather require cylinder head replacement if cylinder head surface flatness is not within specifications.

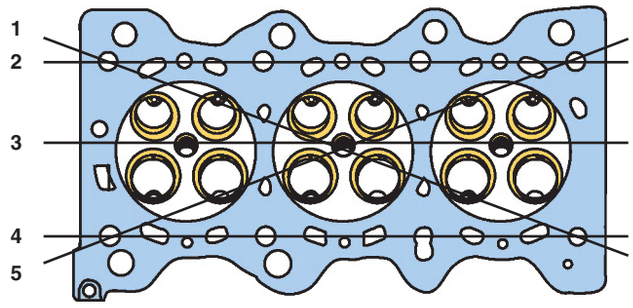


FIGURE 30–19 Cylinder heads should be checked in five planes for warpage, distortion, bend, and twist.

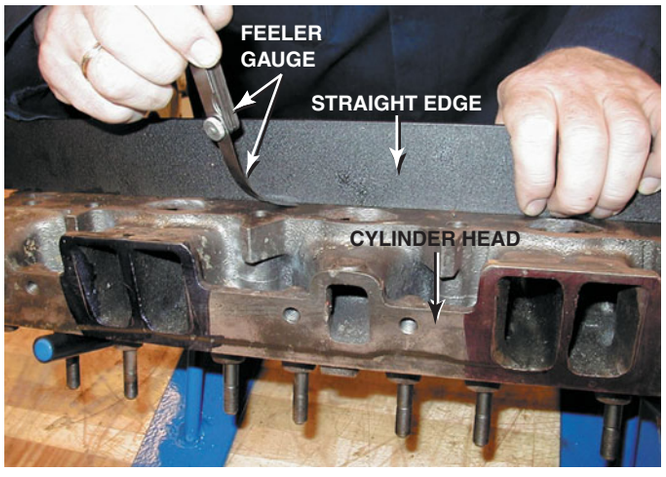


FIGURE 30–20 A precision ground straightedge and a feeler gauge are used to check the cylinder head for flatness.

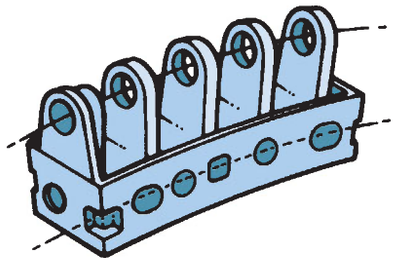


FIGURE 30–21 Warped overhead camshaft cylinder head. If the gasket surface is machined to be flat, the camshaft bearings will still not be in proper alignment. The solution is to straighten the cylinder head or to align bore the cam tunnel.

ALUMINUM CYLINDER HEAD STRAIGHTENING

PURPOSE AND FUNCTION Aluminum expands at about twice the rate of cast iron when heated. Aluminum cylinder heads used on cast-iron blocks can warp and/or crack if they are overheated. The expanding cylinder head first hits the head bolts. Further expansion of the head causes the head to expand upward and bow in the center. If a warped (bowed) cylinder head is resurfaced, the stresses of expansion are still present, and if the cylinder head uses an overhead camshaft, further problems exist. If the cylinder head is distorted into a D shape, the camshaft centerline bearing supports must also be restored. **● SEE FIGURE 30–21.**

To restore the straightness of the cam bearing bore (sometimes called the **cam tunnel**), align boring and/or honing may be necessary.

The best approach to restore a warped aluminum cylinder head (especially an overhead camshaft head) is to relieve the stress that has caused the warpage *and* to straighten the head before machining.

STEP 1 Determine the amount of warpage with a straightedge and thickness (feeler) gauge. Cut shim stock (thin strips of metal) to one-half of the amount of the warpage. Place shims of this thickness under each end of the head.

STEP 2 Tighten the center of the cylinder head down on a strong, flat base. A 2 in. thick piece of steel that is 8 in. wide by 20 in. long makes a good support for the gasket surface of the cylinder head (use antiseize compound on the bolt threads to help in bolt removal).

STEP 3 Place the head and base in an oven for five hours at 500°F (260°C). Turn the oven off and leave the assembly in the oven.

NOTE: If the temperature is too high, the valve seat inserts may fall out of the head! At 500°F, a typical valve seat will still be held into the aluminum head with a 0.002 in. interference fit based on calculations of thermal expansion of the aluminum head and steel insert.

Allow the head to cool in the oven for four to five hours to relieve any stress in the aluminum from the heating process. For best results, the cooling process should be allowed to occur overnight. Several cylinder heads can be "cooked" together.

If the cylinder head is still warped, the heating and cooling process can be repeated. After the head is straightened and the stress relieved, the gasket surface (fire deck) can be machined in the usual manner. To prevent possible camshaft bore misalignment problems, do not machine more than 0.01 to 0.015 in. (0.25 to 0.38 mm) from the head gasket surface.

CYLINDER HEAD RESURFACING

REFINISHING METHODS

Two common resurfacing methods are:

- Milling or broaching
- Grinding

A **milling** type of resurfacer uses metal-cutting tool bits fastened in a disc. This type is also called a *broach.* The disc is the rotating workhead of the mill.

The **surface grinder** type uses a large-diameter abrasive wheel. Both types of resurfacing can be done with table-type and with precision-type surfacers. With a table-type surfacer, the head or block is passed over the cutting head that extends slightly above a worktable. The abrasive wheel is dressed before grinding begins. The wheel head is adjusted to just touch the surface. At this point, the feed is calibrated to zero. This is necessary so that the operator knows exactly the size of the cut being made. Light cuts are taken. The abrasive wheel cuts are limited to 0.005 in. (0.015 mm). ● **SEE FIGURE 30–22.**

The abrasive wheel surface should be wire brushed after each five passes, and the wheel should be redressed after grinding each 0.1 in. (2.5 mm). The mill-type cutting wheel can remove up to 0.03 in. (0.075 mm) on each pass. A special mill-cutting tool or a dull grinding wheel is used when aluminum heads are being resurfaced.



FIGURE 30–22 A cast-iron cylinder head being resurfaced using a surface grinder.

TECH TIP

The Potato Chip Problem

Most cylinder heads are warped or twisted in the shape of a typical potato chip (high at the ends and dipped in the center). After a cylinder head is ground, the surface *should* be perfectly flat. A common problem involves grinding the cylinder head in both directions while it is being held on the table that moves to the left and right. Most grinders are angled by about 4 degrees. The lower part of the stone should be the cutting edge. If grinding occurs along the angled part of the stone, then too much heat is generated. This heat warps the head (or block) upward in the middle. The stone then removes this material, and the end result is a slight (about 0.0015 in.) depression in the center of the finished surface. To help prevent this from happening, always feed the grinder in the forward direction only (especially during removal of the last 0.003 in. of material).

NOTE: Resurfacing the cylinder head changes the compression ratio of the engine by about 1/10 point per 0.01 in. of removed material. For example, the compression ratio would be increased from 9.0:1 to 9.2:1 if 0.02 in. were removed from a typical cylinder head.

SURFACE FINISH

The surface finish of a reconditioned part is as important as the size of the part. Surface finish is measured in units called microinches (abbreviated "μ in."). The symbol in front of the inch abbreviation is the Greek letter *mu.* One microinch equals 0.000001 in., or 0.025 micrometer (μm). The finish classification in microinches gives the distance between the highest peak and the deepest valley. The usual method of expressing surface finish is by the **arithmetic average roughness height** (RA), that is, the average of the distances of all peaks and valleys from the mean (average) line. Surface finish is measured using a machine with a diamond stylus. ● **SEE FIGURE 30–23.**

Another classification of surface finish, which is becoming obsolete, is called the **root-mean-square (RMS).** The RMS is a slightly higher number and can be obtained by multiplying RA × 1.11.

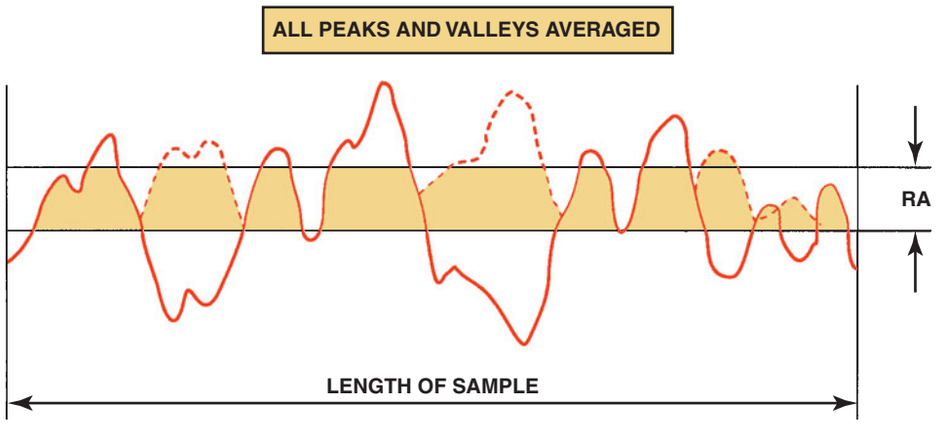


FIGURE 30–23 A graph showing a typical rough surface as would be viewed through a magnifying glass. RA is an abbreviation indicating the average height of all peaks and valleys.

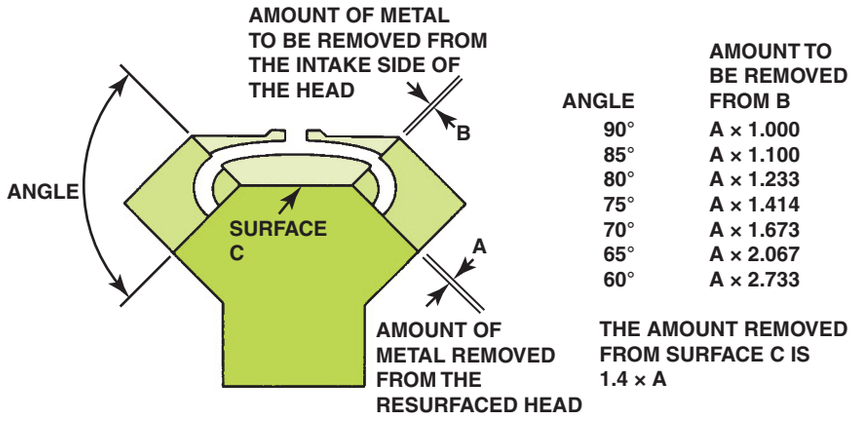


FIGURE 30–24 The material that must be removed for a good manifold fit.

Typical surface finish roughness recommendations for cast-iron and aluminum cylinder heads and blocks include the following:

Cast Iron

Maximum: 110 RA (125 RMS) (Rough surfaces can limit gasket movement and conformity.)

Minimum: 30 RA (33 RMS) (Smoother surfaces increase the tendency of the gasket to flow and *reduce* gasket sealing ability.)

Recommended range: 60 to 100 RA (65 to 110 RMS)

Aluminum

Maximum: 60 RA (65 RMS)

Minimum: 30 RA (33 RMS)

Recommended range: 50 to 60 RA (55 to 65 RMS)

The rougher the surface is, the higher the microinch finish measurement will be.

Typical preferred microinch finish standards for other engine components include the following:

Crank and rod journal: 10 to 14 RA (12 to 15 RMS)

Honed cylinder: 18 to 32 RA (20 to 35 RMS)

Connecting rod big end: 45 to 72 RA (50 to 80 RMS)

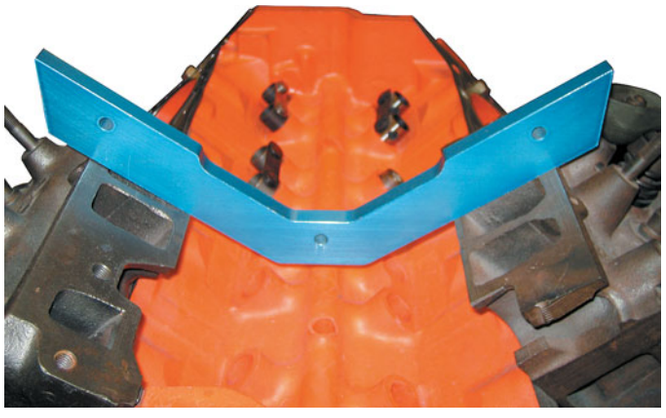


FIGURE 30–25 Using an intake manifold template to check for the proper angles after the cylinder heads have been machined.

INTAKE MANIFOLD ALIGNMENT

PURPOSE The intake manifold of a V-type engine may no longer fit correctly after the gasket surfaces of the heads are ground. The ports and the assembly bolt holes may no longer match. The intake manifold surface must be resurfaced to remove enough metal to rematch the ports and bolt holes. The amount of metal that must be removed depends on the angle between the head gasket surface and the intake manifold gasket surface. ● **SEE FIGURE 30–24.**

PROCEDURE Automotive machine shops that perform head resurfacing have tables that specify the exact amount of metal to be removed. It is usually necessary to also remove some metal from both the front and the back gasket surfaces of closed-type intake manifolds used on V-type engines. This is necessary to provide a good gasket seal that will prevent oil leakage from the lifter valley. ● **SEE FIGURE 30–25.**

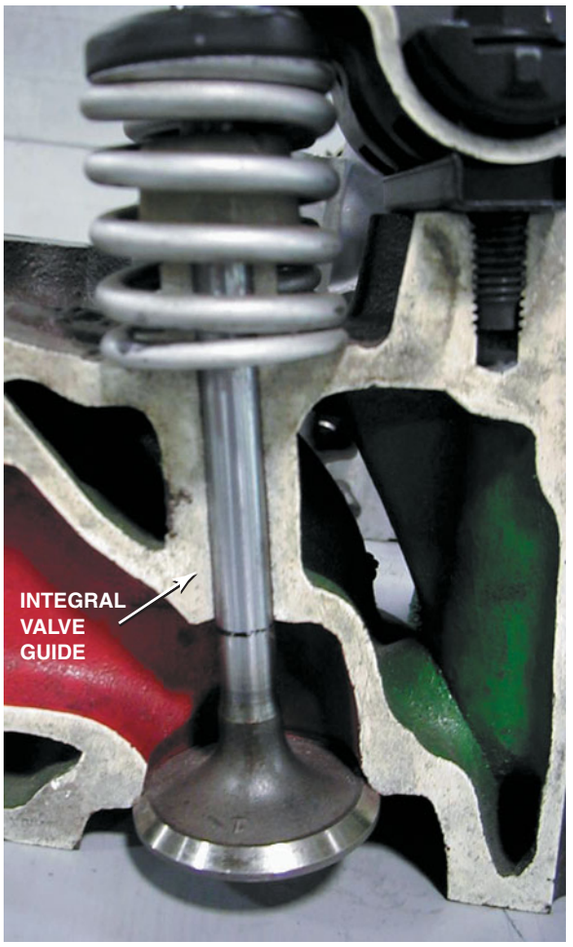


FIGURE 30–26 An integral valve guide is simply a guide that has been drilled into the cast-iron cylinder head.

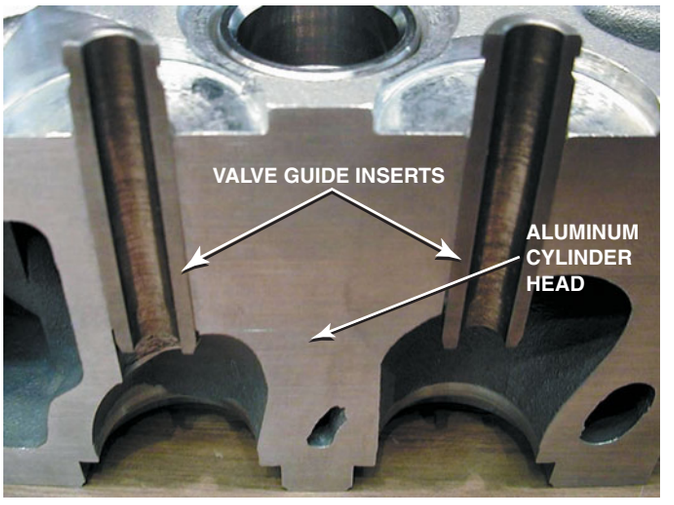


FIGURE 30–27 All aluminum cylinder heads use valve guide inserts.

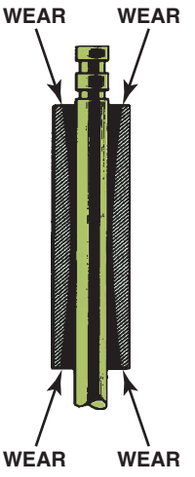


FIGURE 30–28 Valve guides often wear to a bell-mouth shape to both ends due to the forces exerted on the valve by the valve train components.

CAUTION: Do not remove any more material than is necessary to restore a flat cylinder head-to-block surface. Some manufacturers limit *total* material that can be removed from the block deck and cylinder head to 0.008 in. (0.2 mm). Removal of material from the cylinder head of an overhead camshaft engine shortens the distance between the camshaft and the crankshaft. This causes the valve timing to be *retarded* unless a special copper spacer shim is placed between the block deck and the gasket to restore proper crankshaft-to-camshaft centerline dimension.

VALVE GUIDES

TYPES The valve guide supports the valve stem so that the valve face will remain perfectly centered, or **concentric,** with the valve seat. The valve guide is generally integral with the head casting in cast-iron heads for better heat transfer and for lower manufacturing costs. ● **SEE FIGURE 30–26.**

Removable or pressed-in **valve guides** and **valve seat inserts** are always used in aluminum heads. ● **SEE FIGURE 30–27.**

No matter how good the valves or seats are, they cannot operate properly if the valve guide is not accurate. In use, the valve opening mechanism pushes the valve tip sideways. This is the major cause of valve stem and guide wear. The movement of the valve causes both the top and bottom ends of the guide to wear until the guide has bell-mouth shapes at both ends. ● **SEE FIGURE 30–28.**

VALVE STEM-TO-GUIDE CLEARANCE Engine manufacturers usually recommend the following valve stem-to-guide clearances.

- Intake valve: 0.001 to 0.003 in. (0.025 to 0.076 mm)
- Exhaust valve: 0.002 to 0.004 in. (0.05 to 0.1 mm)

Be sure to check the exact specifications for the engine being serviced. The exhaust valve clearance is greater than the intake valve clearance because the exhaust valve runs hotter and therefore expands more than the intake valve.

Excessive valve stem-to-guide clearance can cause excessive oil consumption. The intake valve guide is exposed to manifold vacuum that can draw oil from the top of the cylinder head down into the combustion chamber. In this situation, valves can also run hotter than usual because much of the heat in the valve is transferred to the cylinder head through the valve guide.

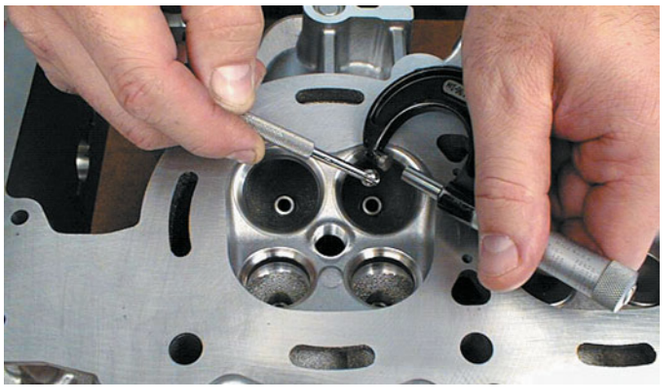


FIGURE 30–29 A small-hole gauge and a micrometer are being used to measure the valve guide. The guide should be measured in three places: at the top, middle, and bottom.



FIGURE 30–30 The diameter of the valve stem is being measured using a micrometer. The difference between the inside diameter of the valve guide and the diameter of the valve stem is the valve guide-to-stem clearance.

HINT: A human hair is about 0.002 in. (0.05 mm) in diameter. Therefore, the typical clearance between a valve stem and the valve guide is only the thickness of a human hair.

MEASURING VALVE GUIDES

Valves should be measured for stem wear before valve guides are measured. The valve guide is measured in the middle with a small-hole gauge. The gauge size is checked with a micrometer. The guide is then checked at each end.

The expanded part of the ball should be placed crosswise to the engine where the greatest amount of valve guide wear exists. The dimension of the valve stem diameter is subtracted from the dimension of the valve guide diameter. If the clearance exceeds the specified clearance, then the valve guide will have to be reconditioned. ● **SEE FIGURES 30–29 AND 30–30.**

Valve stem-to-guide clearance can also be checked using a dial indicator (gauge) to measure the amount of movement of the valve when lifted off the valve seat. ● **SEE FIGURE 30–31.**

OVERSIZE STEM VALVES

Some domestic vehicle manufacturers that have integral valve guides in their engines recommend reaming worn valve guides and installing new valves with **oversize (OS) stems.** When a valve guide is worn, the valve stem is also likely to be worn. In this case, new valves are required. If new valves are used, they can just as well have oversize stems as standard stems. Typically, available sizes include 0.003, 0.005, 0.015, and 0.03 in. OS. The valve guide is reamed or honed to the correct size to fit the oversize stem of the new valve.

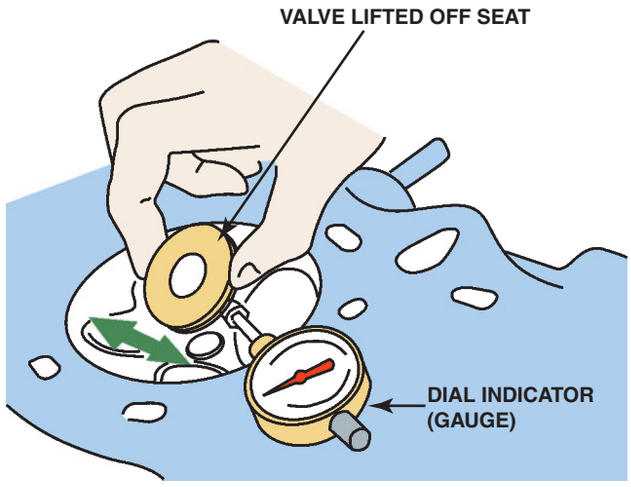


FIGURE 30–31 Measuring valve guide-to-stem clearance with a dial indicator while rocking the stem in the direction of normal thrust. The reading on the dial indicator should be compared to specifications because it does not give the guide-to-stem clearance directly. The valve is usually held open to its maximum operating lift.

? FREQUENTLY ASKED QUESTION

What Is Valve Guide Knurling?

In an old and now outdated process known as **valve guide knurling,** a tool is rotated as it is driven into the guide. The tool *displaces* the metal to reduce the hole diameter of the guide. Knurling is ideally suited to engines with integral valve guides (guides that are part of the cylinder head and are nonremovable). It is recommended that knurling not be used to correct wear exceeding 0.006 in. (0.15 mm). In the displacing process, the knurling tool pushes a small tapered wheel or dull threading tool into the wall of the guide hole. This makes a groove in the wall of the guide, similar to a threading operation without removing any metal.

The metal piles up along the edge of the groove just as dirt would pile up along the edge of a tire track as the tire rolled through soft dirt. (The dirt would be displaced from under the wheel to form a small ridge alongside the tire track.) ● **SEE FIGURE 30–32.**

The knurling tool is driven by an electric drill and an attached speed reducer that slows the rotating speed of the knurling tool. The reamers that accompany the knurling set will ream just enough to provide the correct valve stem clearance for commercial reconditioning standards. The valve guides are honed to size in the precision shop when precise fits are desired. Clearances of knurled valve guides are usually one-half of the new valve guide clearances. Such small clearance can be used because knurling leaves so many small oil rings down the length of the guide for lubrication.

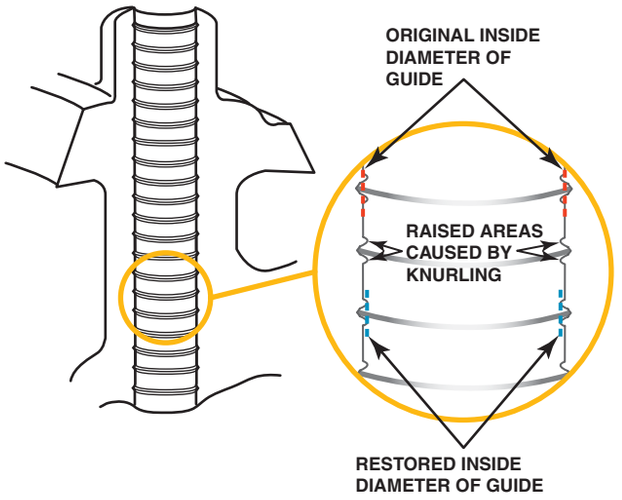


FIGURE 30–32 Sectional view of a knurled valve guide.

TECH TIP

Tight Is Not Always Right

Many engine manufacturers specify a valve stem-to-guide clearance of 0.001 to 0.003 in. (0.025 to 0.076 mm). However, some vehicles, especially those equipped with aluminum cylinder heads, may specify a much greater clearance. For example, many Chrysler 2.2 liter and 2.5 liter engines have a specified valve stem-to-guide clearance of 0.003 to 0.005 in. (0.076 to 0.127 mm). This amount of clearance feels loose to those technicians accustomed to normal valve stem clearance specifications. Although this large amount of clearance may seem excessive, remember that the valve stem increases in diameter as the engine warms up. Therefore, the *operating* clearance is smaller than the clearance measured at room temperature. Always double-check factory specifications before replacing a valve guide for excessive wear.

The resulting clearance of the valve stem in the guide is the same as the original clearance. The oil clearance and the heat transfer properties of the original valve and guide are not changed when new valves with oversize stems are installed.

NOTE: Many remanufacturers of cylinder heads use oversize valve stems to simplify production.

VALVE GUIDE REPLACEMENT

PURPOSE When an engine is designed with replaceable valve guides, their replacement is always recommended when the valve assembly is being reconditioned. The original valve guide height should be measured before the guide is removed so that the new guide can be properly positioned.

After the valve guide height is measured, the worn guide is pressed from the head with a proper fitting *driver.* ● **SEE FIGURE 30–33.**

The driver has a stem to fit the guide opening and a shoulder that pushes on the end of the guide. If the guide has a flange, care should be taken to ensure that the guide is pushed out from the correct end, usually from the port side and toward the rocker arm

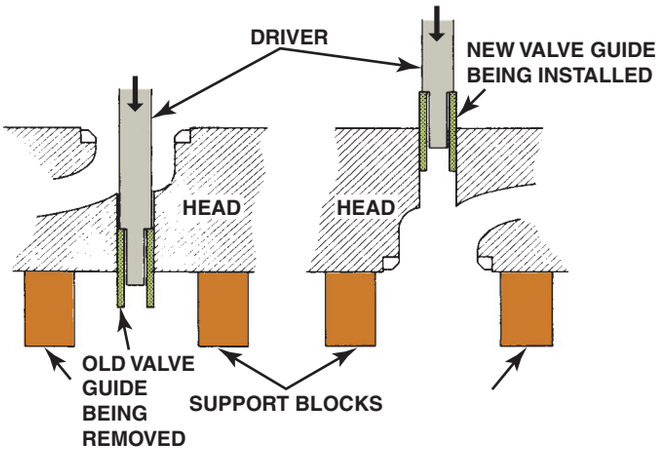


FIGURE 30–33 Valve guide replacement procedure.

side. The new guide is pressed into the guide bore using the same driver. Make sure that the guide is pressed to the correct depth. After the guides are replaced, they are reamed or honed to the proper inside diameter.

Replacement valve guides can also be installed to repair worn integral guides. Both **cast-iron** and **bronze guides** are available.

VALVE GUIDE SIZES Three common valve guide sizes are as follows:

- 5/16 or 0.313 in.
- 11/32 or 0.343 in.
- 3/8 or 0.375 in.

VALVE GUIDE INSERTS When the integral valve guide is badly worn, it can be reconditioned using an insert. This repair method is usually preferred in heavy-duty and high-speed engines. Two types of guide inserts are commonly used for guide repair.

- **Thin-walled bronze alloy sleeve bushing**
- **Spiral bronze alloy bushing**

The thin-walled bronze sleeve bushings are also called **bronze guide liners.** The valve guide rebuilding kit used to install each of these bushings includes all of the reamers, installing sleeves, broaches, burnishing tools, and cutoff tools that are needed to install and properly size the bushings.

The valve guide must be bored to a large enough size to accept the thin-walled insert sleeve. The boring tool is held in alignment by a rugged fixture. One type is shown in ● **FIGURE 30–34.**

Depending on the make of the equipment, the boring fixture is aligned with the valve guide hole, the valve seat, or the head gasket surface. First, the boring fixture is properly aligned. The guide is then bored, making a hole somewhat smaller than the insert sleeve that will be used. The bored hole is reamed to make a precise smooth hole that is still slightly smaller than the insert sleeve. The insert sleeve is installed with a press fit that holds it in the guide. The press fit also helps to maintain normal heat transfer from the valve to the head. The thin-walled insert sleeve is held in an installing sleeve. A driver is used to press the insert from the installing sleeve into the guide. A broach is then pressed through the insert sleeve to firmly seat it in the guide. The broach is designed to put a knurl in the guide to aid in lubrication. The insert sleeve is then trimmed to the valve guide length. Finally, the insert sleeve is reamed or honed to provide the required valve stem clearance. A very close clearance of 0.0005 in. (one-half of one-thousandth of an inch) (0.013 mm) is often used with the bronze thin-walled insert sleeve. ● **SEE FIGURE 30–35.**

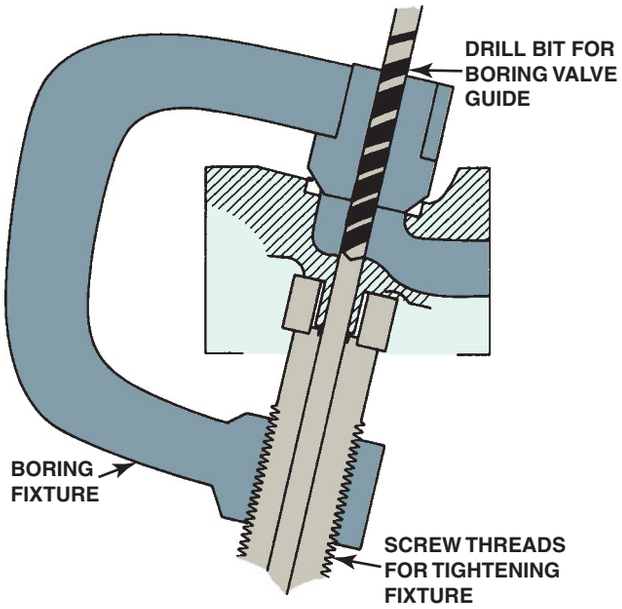


FIGURE 30–34 A type of fixture required to bore the valve guide to accept a thin-walled insert sleeve.

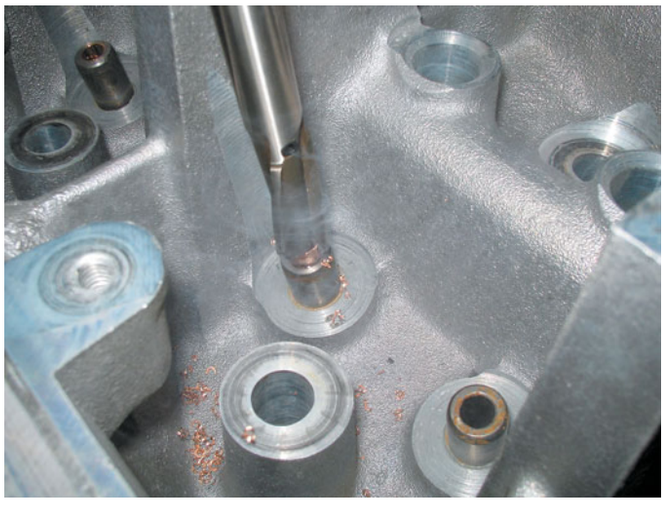


FIGURE 30–35 Trimming the top of the thin-walled insert.



FIGURE 30–36 Installed spiral bronze insert bushing.

TECH TIP

Right Side Up

When replacing valve guides, it is important that the recommended procedures be followed. Most manufacturers specify that replaceable guides be driven from the combustion chamber side toward the rocker arm side. For example, big block Chevrolet V-8 heads (396, 402, 427, and 454 cu.^{3}) have a 0.004 in. (0.05 mm) taper (small end toward the combustion chamber).

Other manufacturers, however, may recommend driving the old guide from the rocker arm side to prevent any carbon buildup on the guide from damaging the guide bore. Always check the manufacturer's recommended procedures before attempting to replace a valve guide.

SPIRAL BRONZE INSERT BUSHINGS The spiral bronze alloy insert bushing is screwed into a thread that is put in the valve guide. The tap used to put cut threads in the valve guide has a long pilot ahead of the thread-cutting portion of the tap. This aids in restoring the original guide alignment. The long pilot is placed in the guide from the valve seat end. A power driver is attached to the end of the pilot that extends from the spring end of the valve guide. The threads are cut in the guide from the seat end toward the spring end as the power driver turns the tap, pulling it toward the driver. The tap is stopped before it comes out of the guide, and the power driver is removed. The thread is carefully completed by hand to avoid breaking either the end of the guide or the tap. An installed spiral bronze insert bushing can be seen in ● **FIGURE 30–36.**

The spiral bronze bushing is tightened on an inserting tool. This holds it securely in the wound-up position so that it can be screwed into the spring end of the guide. It is screwed in until the bottom of the bushing is flush with the seat end of the guide. The holding tool is removed, and the bushing material is trimmed to one coil *above* the spring end of the guide. The end of the bushing is temporarily secured with a plastic serrated bushing retainer and a worm gear clamp. This holds the bushing in place as a broach is driven through the bushing to firmly seat it in the threads. The bushing is reamed or honed to size before the temporary bushing retainer is removed. The final step is to trim the end of the bushing with a special cutoff tool that is included in the bushing installation tool set. This type of spiral bronze bushing can be removed by using a pick to free the end of the bushing. It can then be stripped out and a new bushing inserted in the original threads in the guide hole. New threads do not have to be put in the guide. The spiral bushing design has natural spiral grooves to hold oil for lubrication. The valve stem clearances are the same as those used for knurling and for the thin-walled insert (about one-half of the standard recommended clearance).

REVIEW QUESTIONS

1. What is meant by the term *crossflow head*?
2. What is a Siamese port?
3. What is the recommended cylinder head reconditioning sequence?
4. What are the advantages of using four valves per cylinder?

CHAPTER QUIZ

1. Cylinder heads with four valves flow more air than those with two valves because they _____.
   a. Have a greater open area
   b. Use a higher lift camshaft
   c. Increase the velocity of the air
   d. Both a and c

2. Two technicians are discussing a Hemi engine. Technician A says that a Hemi is an engine with a hemispherical-shaped combustion chamber. Technician B says that all Hemi engines are cam-in-block designs. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B

3. Technician A says that an Audi five-valve engine uses three intake valves and two exhaust valves. Technician B says that it uses three exhaust valves and two intake valves. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B

4. The gasket surface of a cylinder head, as measured with a precision straightedge, should have a maximum variation of _____.
   a. 0.002 in. in any 6 in. length, or 0.004 in. overall
   b. 0.001 in. in any 6 in. length, or 0.004 in. overall
   c. 0.020 in. in any 10 in. length, or 0.02 in. overall
   d. 0.004 in. in any 10 in. length, or 0.008 in. overall

5. A warped aluminum cylinder head can be restored to useful service by _____.
   a. Grinding the gasket surface and then align honing the camshaft bore
   b. Heating it in an oven at 500°F with shims under each end, allowing it to cool, and then machining it
   c. Heating it to 500°F for five hours and cooling it rapidly before final machining
   d. Machining the gasket surface to one-half of the warped amount and then heating the head in an oven and allowing it to cool slowly

6. Some vehicle manufacturers recommend repairing integral guides with _____.
   a. OS stem valves
   b. Knurling
   c. Replacement valve guides
   d. Valve guide inserts

7. Typical valve stem-to-guide clearance is _____.
   a. 0.03 to 0.045 in. (0.8 to 1 mm)
   b. 0.015 to 0.02 in. (0.4 to 0.5 mm)
   c. 0.005 to 0.01 in. (0.13 to 0.25 mm)
   d. 0.001 to 0.004 in. (0.03 to 0.05 mm)

8. What other engine component may have to be machined if the cylinder heads are machined on a V-type engine?
   a. Exhaust manifold
   b. Intake manifold
   c. Block deck
   d. Distributor mount (if the vehicle is so equipped)

9. Which type of valve guide is most used in a cast-iron head?
   a. Integral
   b. Bronze
   c. Powdered metal (PM)
   d. Thin-walled sleeve type

10. Which statement is true about surface finish?
    a. Cast-iron surfaces should be smoother than aluminum surfaces.
    b. The rougher the surface, the higher the microinch finish measurement.
    c. The smoother the surface, the higher the microinch finish measurement.
    d. A cylinder head should be much smoother than a crankshaft journal.

chapter 31

VALVE AND SEAT SERVICE

OBJECTIVES: **After studying Chapter 31, the reader should be able to:** • Prepare for ASE Engine Repair (A1) certification test content area "B" (Cylinder Head and Valve Train Diagnosis and Repair). • Discuss various engine valve types and materials. • Describe how to test valve springs. • Explain the purpose, function, and operation of valve rotators. • List the steps necessary to reface a valve. • Describe how to reface or replace valve seats. • Discuss how to measure and correct installed height and valve stem height.

KEY TERMS: Expandable pilots 303 • Finishing stone 304 • Free rotators 299 • Hard seat stones 304 • Inertia friction welding 295 • Insert seats 296 • Installed height 307 • Integral seat 296 • Locks 294 • Poppet valve 294 • Positive rotators 299 • Retainer 294 • Roughing stone 304 • Stellite® 294 • Tapered pilots 303 • Thermal shock 297 • Three-angle valve job 302 • Throating angle 302 • Topping angle 302 • Total indicator runout (TIR) 304 • Truing 300 • Valve face 294 • Valve face angle 301 • Valve float 299 • Valve guide 294 • Valve seat 294 • Valve spring 294 • Valve spring inserts (VSI) 307 • Valve spring surge 299 • Valve stem height 307 • Variable rate springs 299

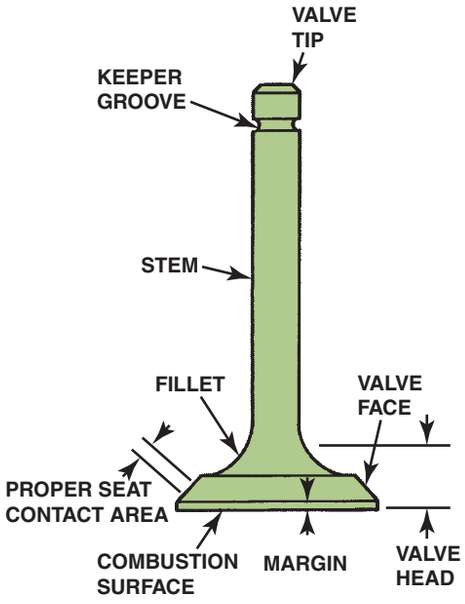


FIGURE 31–1 Identification of the parts of a valve.

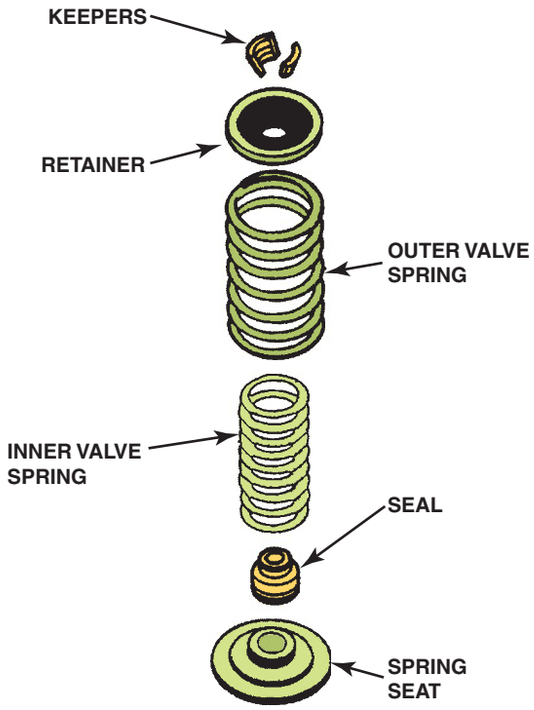


FIGURE 31–2 Typical valve spring and related components. Dual valve springs are used to reduce valve train vibrations and a spring seat is used to protect aluminum heads.

INTAKE AND EXHAUST VALVES

TERMINOLOGY

Automotive engine valves are of a **poppet valve** design. The term *poppet* refers to the shape of the valve and their operation in automotive engines. The valve is opened by means of a valve train that is operated by a cam. The cam is timed to the piston position and crankshaft cycle. The valve is closed by one or more springs.

Typical valves are shown in ● **FIGURE 31–1**.

Intake valves control the inlet of cool, low-pressure induction charges. Exhaust valves handle hot, high-pressure exhaust gases. This means that exhaust valves are exposed to more severe operating conditions. They are, therefore, made from much higher quality materials than the intake valves, which makes them more expensive.

The valve is held in place and is positioned in the head by the **valve guide.** The portion of the valve that seals against the **valve seat** in the cylinder head is called the **valve face.** The face and seat will have an angle of either 30 or 45 degrees, which are the nominal angles; actual service angles may vary. Most engines use a nominal 45-degree valve and seat angle.

PARTS INVOLVED

- A **valve spring** holds the valve against the seat.
- The valve *keepers* (also called **locks**) secure the spring **retainer** to the stem of the valve. For valve removal, it is necessary to compress the spring and remove the valve keepers. Then the spring, valve seals, and valve can be removed from the head. A typical valve assembly is shown in ● **FIGURE 31–2**.

VALVE SIZE RELATIONSHIPS

Extensive testing has shown that a normal relationship exists between the different dimensions of valves.

- **Intake valves.** Engines with cylinder bores that measure from 3 to 8 in. (80 to 200 mm) will have intake valve head diameters that measure approximately 45% of the bore size. The intake valve must be larger than the exhaust valve to handle the same mass of gas. The larger intake valve controls low-velocity, low-density gases. The distance the valve opens is close to 25% of the valve head diameter.
- **Exhaust valves.** The exhaust valve head diameter is approximately 38% of the cylinder bore size. Exhaust valve heads are, therefore, approximately 85% of the size of intake valve heads. The exhaust valve, however, controls high-velocity, high-pressure, denser gases. These gases can be handled by a smaller valve.

● **SEE FIGURE 31–3**.

VALVE MATERIALS

- **Alloy steel.** Alloys used in exhaust valve materials are largely of chromium for oxidation resistance, with small amounts of nickel, manganese, and nitrogen added. Heat-treating is used whenever it is necessary to produce special valve properties.
- **Stellite®.** An alloy of nickel, chromium, and tungsten, **Stellite®** is nonmagnetic. Some valves use this product just only on the tip of the valve to help reduce wear in places where the rocker arm contacts the valve stem on engines that do not use a roller rocker arm. Stellite® is also used on some valve faces.
- **Inconal®.** A type of alloy containing nickel, chrome, and iron and is used mostly in racing engines.
- **Titanium.** About half the weight of conventional valves, titanium reduces the tension on valve springs resulting in higher RPM engine operation. The valve stems are often moly coated to help prevent sticking in the valve guide.
- **Stainless steel.** Used in many heavy-duty applications, stainless steel often uses chrome-plated valve stems and Stellite tips to improve long-term durability.
- **Aluminized.** The valve is aluminized where corrosion may be a problem. Aluminized valve facing reduces valve recession

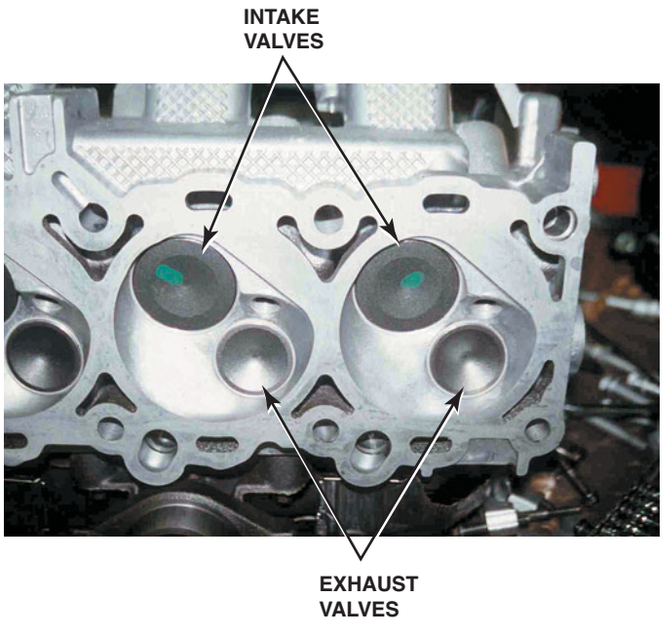


FIGURE 31–3 The intake valve is larger than the exhaust valve because the intake charge is being drawn into the combustion chamber at a low speed due to differences in pressure between atmospheric pressure and the pressure (vacuum) inside the cylinder. The exhaust is actually pushed out by the piston and, therefore, the size of the valve does not need to be as large, leaving more room in the cylinder head for the larger intake valve.

TECH TIP

Hot Engine + Cold Weather = Trouble

Serious valve damage can occur if cold air reaches hot exhaust valves soon after the engine is turned off. An engine equipped with exhaust headers and/or straight-through mufflers can allow cold air a direct path to the hot exhaust valve. The exhaust valve can warp and/or crack as a result of rapid cooling. This can easily occur during cold windy weather when the wind can blow cold outside air directly up the exhaust system. Using reverse-flow mufflers with tailpipes and a catalytic converter reduces the possibilities of this occurring.

when unleaded gasoline is used. Aluminum oxide forms to separate the valve steel from the cast-iron seat to keep the face metal from sticking.

TWO-MATERIAL VALVES Some exhaust valves are manufactured from two different materials when a one-piece design cannot meet the desired hardness and corrosion resistance specifications. The joint cannot be seen after valves have been used. The valve heads are made from special alloys that can operate at high temperatures, have physical strength, resist lead oxide corrosion, and have indentation resistance. These heads are welded to stems that have good wear resistance properties. These types of valves are usually welded together using a process called **inertia friction welding.** Inertia friction welding is performed by spinning one end and then forcing the two pieces together until the materials reach their melting temperature. Then the parts are held together until they fuse, resulting in a uniform weld between two different materials. ● **FIGURE 31–4** shows an inertia welded valve before final machining.

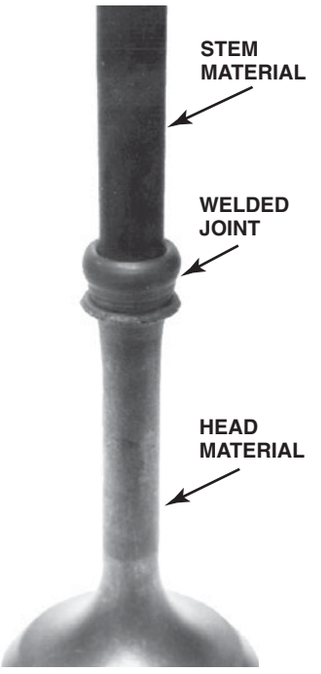


FIGURE 31–4 Inertia welded valve stem and head before machining.

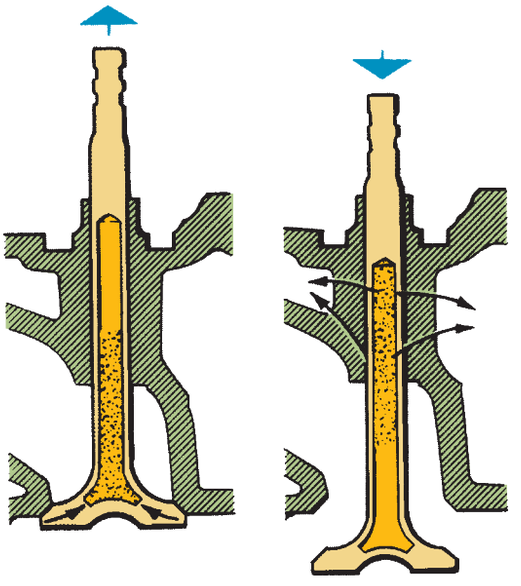


FIGURE 31–5 A sodium-filled valve uses a hollow stem, which is partially filled with metallic sodium (a liquid when hot) to conduct heat away from the head of the valve.

WARNING

If a sodium-filled valve is damaged and the sodium leaks out, it can cause a fire if exposed to water. Sodium reacts violently when exposed to water and burns uncontrollably.

SODIUM-FILLED VALVES Some heavy-duty applications use hollow stem exhaust valves that are partially filled with metallic sodium. The sodium in the valve becomes a liquid at operating temperatures. As it splashes back and forth in the valve stem, the sodium transfers heat from the valve head to the valve stem. The heat goes through the valve guide into the coolant. In general, a one-piece valve design using properly selected materials will provide satisfactory service for automotive engines. ● **SEE FIGURE 31–5.**

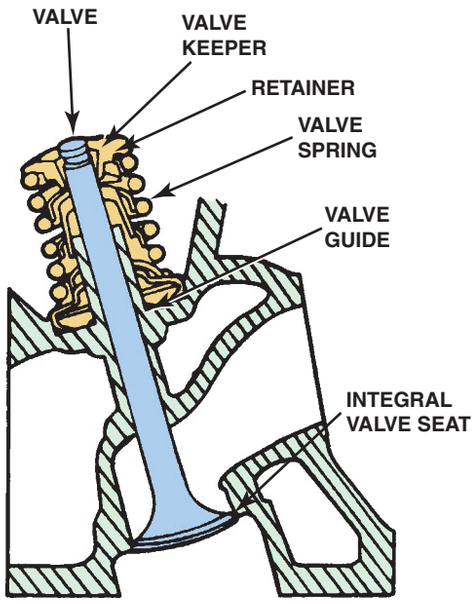


FIGURE 31–6 Integral valve seats are machined directly into the cast-iron cylinder head and are induction hardened to prevent wear.

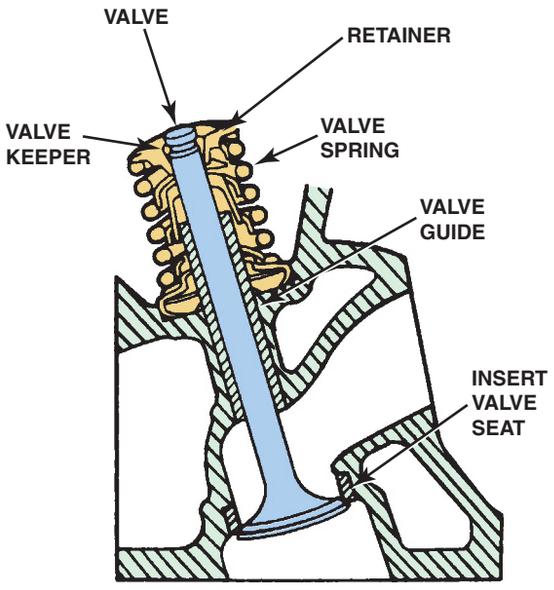


FIGURE 31–7 Insert valve seats are a separate part that is interference fitted to a counterbore in the cylinder head.

VALVE SEATS

INTEGRAL SEATS The valve face closes against a valve seat to seal the combustion chamber. The seat is generally formed as part of the cast-iron head of automotive engines, called an **integral seat.** ● **SEE FIGURE 31–6**.

The seats are usually induction hardened so that unleaded gasoline can be used. This minimizes valve recession as the engine operates. Valve recession is the wearing away of the seat, so that the valve sits farther into the head.

INSERT SEATS An **insert seat** fits into a machined recess in the steel or aluminum cylinder head. Insert seats are used in *all* aluminum head engines and in applications for which corrosion and wear resistance are critical. Aluminum heads also include insert valve guides.

The exhaust valve seat runs as much as 180°F (100°C) *cooler* in aluminum heads than in cast-iron heads, because aluminum conducts heat faster than cast iron. Insert seats are also used to recondition integral valve seats that have been badly damaged. ● **SEE FIGURE 31–7**.

VALVE FAULT DIAGNOSIS

Careful inspection of the cylinder head and valves can often reveal the root cause of failure.

POOR VALVE SEATING Poor seating results from too small a valve lash, hard carbon deposits, valve stem deposits, excessive valve stem-to-guide clearances, or out-of-square valve guide and seat. A valve seat recession can result from improper valve lash adjustments on solid lifter engines. It can also result from misadjustments on a valve train using hydraulic lifters. The valve clearance will also be reduced as a result of valve head cupping or valve face and seat wear. ● **FIGURE 31–8** shows typical intake valve and seat wear.

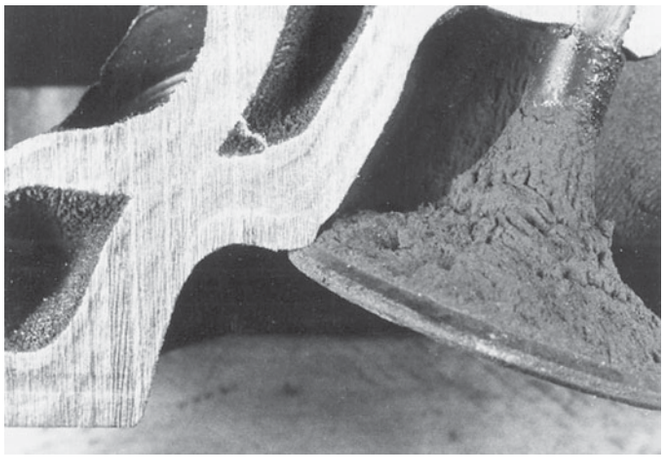


FIGURE 31–8 Typical intake valve seat wear.

CARBON DEPOSITS If there is a large clearance between the valve stem and guide or faulty valve stem seals, too much oil will go down the stem. This will increase deposits, as shown on the intake valve in ● **FIGURE 31–9**.

In addition, a large valve guide clearance will allow the valve to cock or lean sideways, especially with the effect of the rocker arm action. Continued cocking keeps the valve from seating properly and causes it to leak, burning the valve face. ● **SEE FIGURE 31–10**.

Sometimes, the cylinder head will warp slightly as the head is tightened to the block deck during assembly. In other cases, heating and cooling will cause warpage. When head warpage causes valve guide and seat misalignment, the valve cannot seat properly and it will leak, burning the valve face.

EXCESSIVE TEMPERATURES High valve temperatures occur when the valve does not seat properly. Root causes include the following:

1. Cooling system passages in the head may be partially blocked by faulty casting or by deposits built up from the coolant. A corroded head gasket will change the coolant flow. This can cause overheating when the coolant is allowed to flow to the wrong places.
2. Extremely high temperatures are also produced by preignition and by detonation. These conditions are the result of abnormal



FIGURE 31–9 Carbon deposits on the intake valve are often caused by oil getting past the valve stems or fuel deposits.

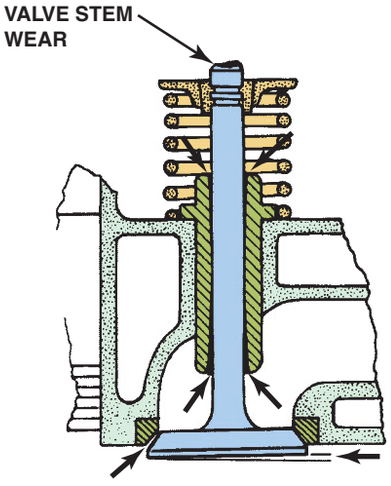


FIGURE 31–10 Excessive wear of the valve stem or guide can cause the valve to seat in a cocked position.



FIGURE 31–11 Valve face guttering caused by thermal shock.

combustion. Both of these produce a very rapid increase in temperature that can cause uneven heating. The rapid increase in temperature will give a **thermal shock** to the valve. (A thermal shock is a sudden change in temperature.) The shock will often cause radial cracks in the valve. The cracks will allow the combustion gases to escape and gutter the valve face. ● **SEE FIGURE 31–11**.

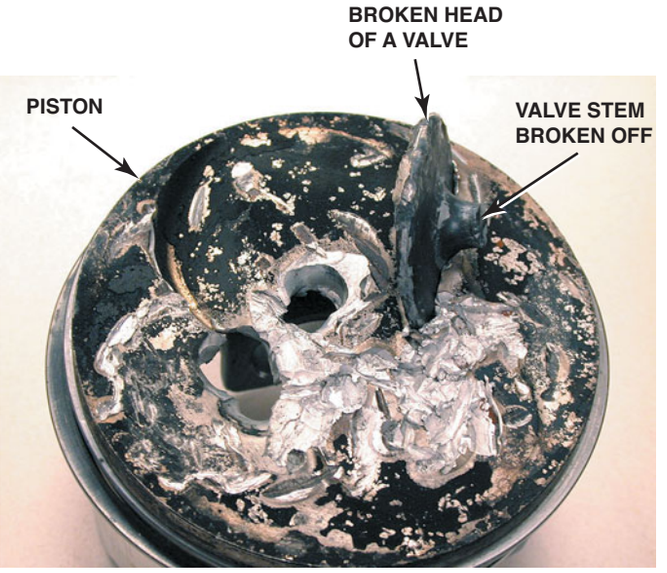


FIGURE 31–12 Note the broken piston caused by a valve breaking from the stem.

VALVE SEAT EROSION Valve seats can wear especially in those engines that were designed for use with leaded gasoline (prior to 1975). Without lead, the valve movement against the seat tears away tiny iron oxide particles during engine operation. The valve movement causes these particles of iron oxide to act like valve grinding compound, cutting into the valve seat surface. As the valve seat is eroded, the valve recedes farther into the cylinder head. When the valve seat erodes, the valve lash decreases. This can lead to valve burning because the valve may not close all the way.

HIGH-VELOCITY SEATING High-velocity seating is indicated by excessive valve face wear, valve seat recession, and impact failure. It can be caused by excessive lash in mechanical lifters and by collapsed hydraulic lifters. Lash allows the valve to hit the seat without the effects of the cam ramp to ease the valve onto its seat. Excessive lash may also be caused by wear of parts, such as the cam, lifter base, pushrod ends, rocker arm pivot, and valve tip. Weak or broken valve springs allow the valves to float away from the cam lobes so that the valves are uncontrolled as they hit the seat.

Impact breakage may occur under the valve head or at the valve keeper grooves. The break lines radiate from the starting point. Impact breakage may also cause the valve head to fall into the combustion chamber. In most cases, it will ruin the piston before the engine can be stopped. This situation causes catastrophic engine damage and is described in the field by several terms, including:

- Sucking a valve
- Dropping a valve
- Swallowing a valve

● **SEE FIGURE 31–12**.

VALVE SPRINGS

PURPOSE AND FUNCTION A valve spring holds the valve against the seat when the valve is not being opened. One end of the valve spring is seated against the head. The other end of the spring is attached under compression to the valve stem through a valve spring retainer and a valve spring keeper (lock). ● **SEE FIGURE 31–13**.

TECH TIP

Valve Seat Recession and Engine Performance

If unleaded fuel is used in an engine without hardened valve seats, valve seat recession is likely to occur over time. Without removing the cylinder heads, how can a technician identify valve seat recession?

As the valve seat wears up into the cylinder head, the valve itself also is located farther up in the head. As this wear occurs, the valve clearance (lash) *decreases.* If hydraulic lifters are used on the engine, this wear will go undetected until the reduction in valve clearance finally removes all clearance (bottoms out) in the lifter. When this occurs, the valve does not seat fully, and compression, power, and fuel economy are drastically reduced. With the valve not closing completely, the valve cannot release its heat and will burn or begin to melt. If the valve burns, the engine will miss and not idle smoothly.

If solid lifters are used on the engine, the decrease in valve clearance will first show up as a rough idle only when the engine is hot. As the valve seat recedes farther into the head, low power, rough idle, poor performance, and lower fuel economy will be noticed sooner than if the engine were equipped with hydraulic lifters.

To summarize, refer to the following symptoms as valve seat recession occurs.

1. Valve lash (clearance) decreases (valves are *not* noisy).
2. The engine idles roughly when hot as a result of reduced valve clearance.
3. Missing occurs, and the engine exhibits low power and poor fuel economy, along with a rough idle, as the valve seat recedes farther into the head.
4. As valves burn, the engine continues to run poorly; the symptoms include difficulty in starting (hot and cold engine), backfiring, and low engine power.

HINT: If valve lash is adjustable, valve burning can be prevented by adjusting the valve lash regularly. Remember, as the seat recedes, the valve itself recedes, which decreases the valve clearance. Many technicians do not think to adjust valves unless they are noisy. If, during the valve adjustment procedure, a *decrease* in valve lash is noticed, then valve seat recession could be occurring.

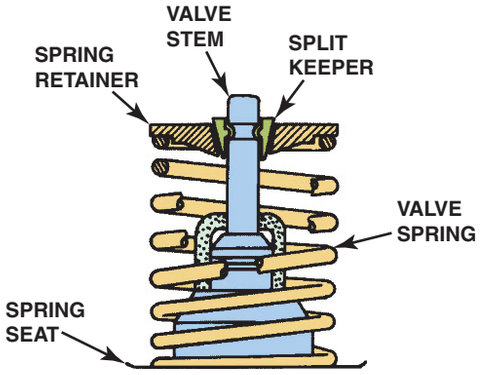


FIGURE 31–13 A retainer and two split keepers hold the spring in place on the valve. A spring seat is used on aluminum heads. Otherwise, the spring seat is a machined area in the head.

SPRING MATERIALS AND DESIGN

Valves usually have a single inexpensive valve spring. The springs are generally made of chromium vanadium alloy steel. When one spring cannot control the valve, another spring or damper is added. Some valve springs use a flat coiled damper inside the spring. The damper helps to reduce valve seat wear. This eliminates spring surge and adds some valve spring tension. The normal valve spring winds up as it is compressed. This causes a small but important turning motion as the valve closes on the seat. The turning motion helps to keep the wear even around the valve face. ● **SEE FIGURE 31–14.**

Multiple valve springs are used where large camshaft lobe lifts are required and a single spring does not have enough strength to control the valve.

- If dual coil springs are wrapped in same direction, they are used for extra tension.

FREQUENTLY ASKED QUESTION

What Is Valve Float?

Valve float occurs when the valve continues to stay open after the camshaft lobe has moved from under the lifter. This happens when the inertia of the valve train overcomes the valve spring tension at high engine speeds. ● **SEE FIGURE 31–15.**

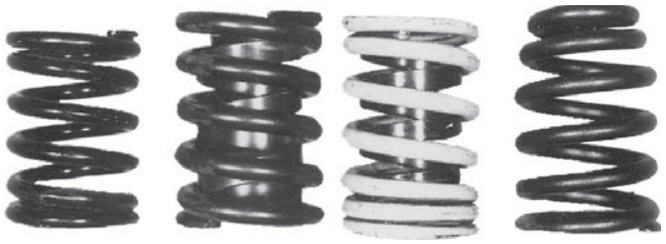


FIGURE 31–14 Valve spring types (*left to right*): coil spring with equally spaced coils; spring with damper inside spring coil; closely spaced spring with a damper; taper wound coil spring.

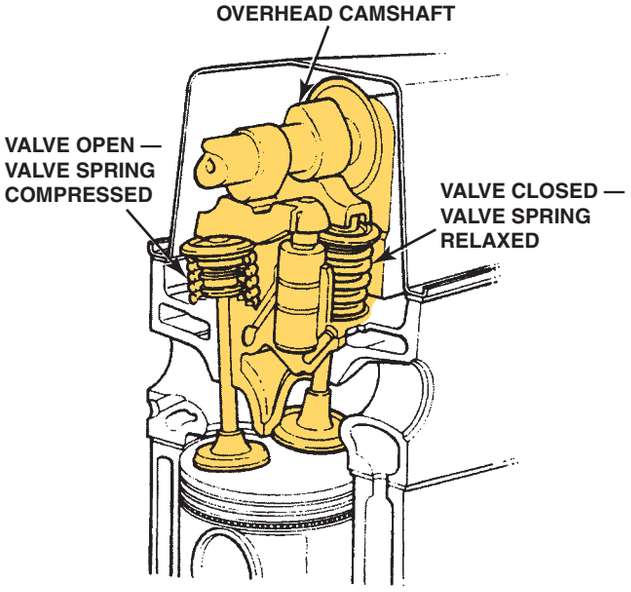


FIGURE 31–15 Valve springs maintain tension in the valve train when the valve is open to prevent valve float, but must not exert so much tension that the cam lobes and lifters begin to wear.

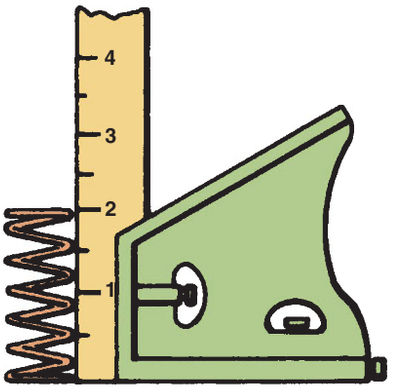


FIGURE 31–16 All valve springs should be checked for squareness by using a square on a flat surface and rotating the spring while checking. The spring should be replaced if more than 1/16 in. (1.6 mm) is measured between the top of the spring and the square.

- If the inner spring or flat damper is wrapped in the opposite direction, it is used as a damper to control spring oscillations. This is done to control valve spring surge and to prevent excessive valve rotation. These are sometimes called *surge dampers.*

  Valve spring surge is the tendency of a valve spring to vibrate.

VARIABLE RATE SPRINGS

Variable rate springs, also called *progressive rate* or *variable pitch springs,* have uneven spacing between the coils. Where nonprogressive rate (linear) valve springs provide the same rate through all heights, a variable rate valve spring has a different spring rate depending on how much it is compressed. One advantage of using a variable rate spring is that it provides a low seat pressure and still provides the rate needed for high lift camshaft designs. This type of spring is used to help control valve surge.

VALVE SPRING INSPECTION

Valve springs close the valves after they have been opened by the cam. They must close squarely to form a tight seal and to prevent valve stem and guide wear. It is necessary, therefore, that the springs be square and have the proper amount of closing force. The valve springs are checked for squareness by rotating them on a flat surface with a square held against the side. They should be within 1/16 in. (1.6 mm) of being square. Out-of-square springs will have to be replaced. ● **SEE FIGURE 31–16**.

Only the springs that are square should be checked to determine their compressed force. The surge damper is often specified to be *removed* from the valve spring when the spring force is being checked. Check service information for the exact procedure to follow for the engine being checked. A valve spring scale is used to measure the valve spring force at a specific height measurement. ● **SEE FIGURE 31–17**.

Another type uses a torque wrench on a lever system to measure the valve spring force. Valve springs are checked for the following:

1. Free height (or length) without being compressed, should be within 1/16 (0.06) in. of specifications.
2. Pressure with valve closed and height as per specifications
3. Pressure with valve open and height as per specifications

Most specifications allow for variations of plus or minus 10% from the published figures.

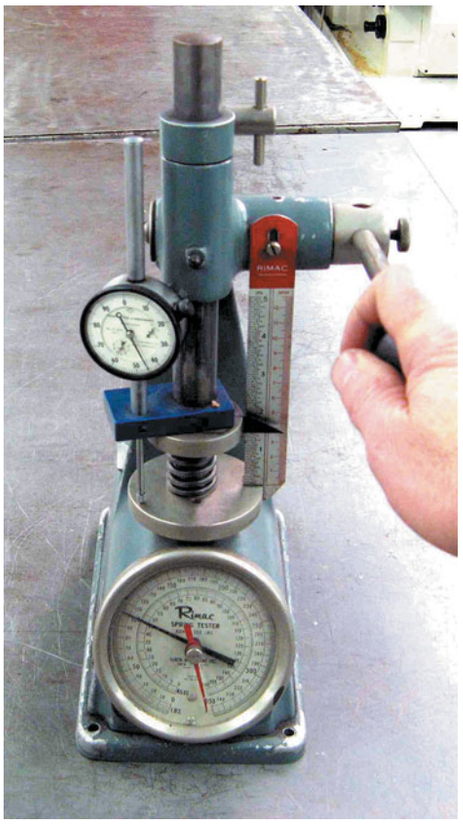


FIGURE 31–17 One popular type of valve spring tester used to measure the compressed force of valve springs. Specifications usually include (1) free height (height without being compressed), (2) pressure at installed height with the valve closed, and (3) pressure with the valve open to the height specified.

VALVE KEEPERS AND ROTATORS

VALVE KEEPERS

Valve keepers (locks) are used on the end of the valve stem to retain the spring. The inside surfaces of the keeper use a variety of grooves or beads. The design depends on the holding requirements. The outside of the keeper fits into a cone-shaped seat in the center of the valve spring retainer. ● **SEE FIGURE 31–18**.

VALVE ROTATORS

Some valve spring retainers have built-in devices called valve rotators. They cause the valve to rotate in a controlled manner as it is opened. The purposes and functions of valve rotators include the following:

- Help prevent carbon buildup from forming by providing a "wiping" action of the valve face
- Reduce hot spots on the valves by constantly turning them
- Help to even out the wear on the valve face and seat
- Improve valve guide lubrication

  The two types of valve rotators are free and positive.
- **Free rotators** simply take the pressure off the valve to allow engine vibration to rotate the valve. ● **SEE FIGURE 31–19**.
- The opening of the valve forces the valve to rotate. One type of **positive rotator** uses small steel balls and slight ramps. Each ball moves down its ramp to turn the rotator sections as

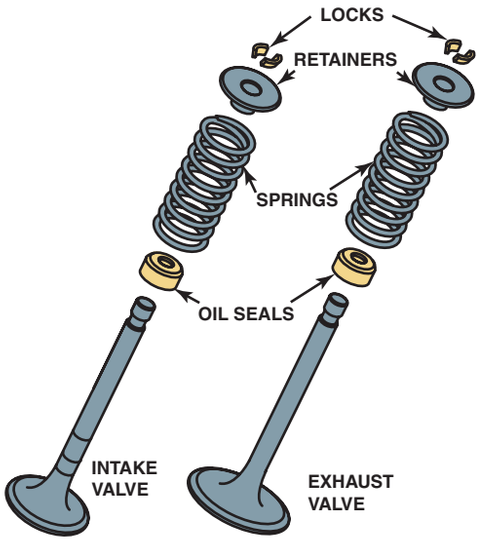


FIGURE 31–18 Valve keepers (also called locks) are tapered so they wedge into a tapered hole in the retainer.

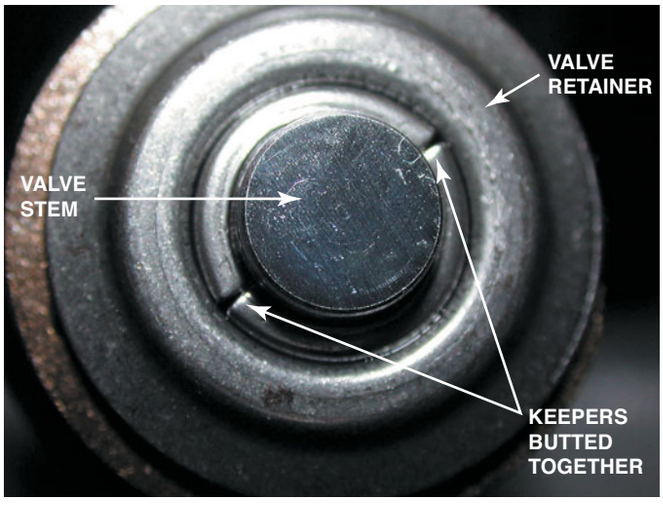


FIGURE 31–19 Notice that there is no gap between the two keepers (ends butted together). As a result, the valve is free to rotate because the retainer applies a force, holding the keepers in place but not tight against the stem of the valve. Most engines, however, do not use free rotators and, therefore, have a gap between the keepers.

the valve opens. A second type uses a coil spring. The spring lies down as the valve opens. This action turns the rotator body in relation to the collar. Valve rotators are only used when it is desirable to increase the valve service life, because rotors cost more than plain retainers. ● **SEE FIGURE 31–20**.

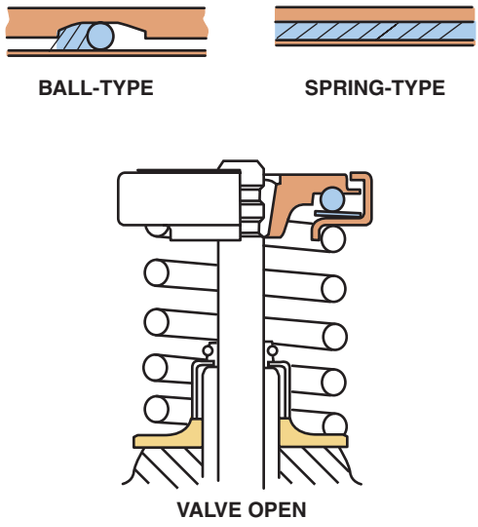


FIGURE 31–20 Type of valve rotator operation. Ball-type operation is on the left and spring-type operation is on the right.

VALVE RECONDITIONING PROCEDURE

After proper cleaning, inspection, and measurement procedures have been completed, valve reconditioning, usually called a "valve job," can be performed using the following sequence.

STEP 1 The valve stem is lightly ground and chamfered. This step helps to ensure that the valve will rest in the collet (holder of the valve stem during valve grinding) of the valve grinder correctly. This process is often called **truing** the valve tip.

STEP 2 The face of the valve is ground to the proper angle using a valve grinder.

STEP 3 The valve seat is ground in the head. (The seat must be matched to the valve that will be used in that position.)

STEP 4 Valve spring installed height and valve stem height are checked and corrected as necessary.

STEP 5 After a thorough cleaning, the cylinder head should be assembled with new valve stem seals installed.

The rest of the chapter discusses valve face and seat reconditioning, and cylinder head reassembly.

VALVE FACE GRINDING

PURPOSE AND FUNCTION Each valve grinder operates somewhat differently. The operation manual that comes with the grinder should be followed for lubrication, adjustment, and specific operating procedures. The general procedures given in the following paragraphs apply to all valve resurfacer equipment. Set the

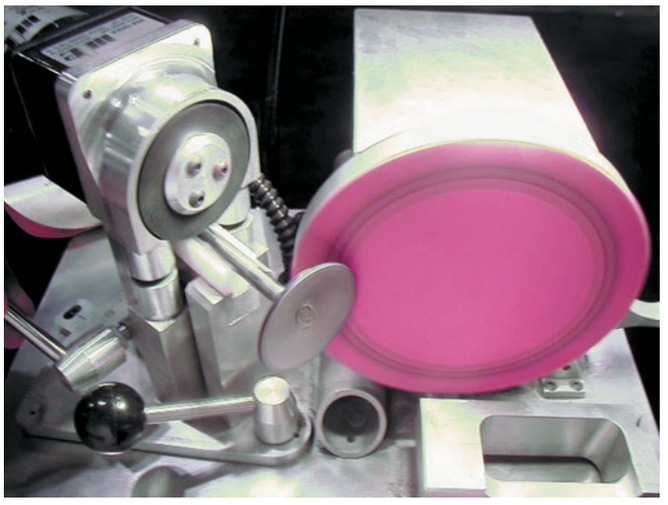


FIGURE 31–21 Resurfacing the face of a valve. Both the valve and the grinder stone or disc are turned to ensure a smooth surface finish on the face of the valve.

grinder head at the **valve face angle** as specified by the vehicle manufacturer.

CAUTION: Safety glasses should *always* be worn for valve and seat reconditioning work. During grinding operations, fine hot chips fly from the grinding stones.

NOTE: Some valve grinders use the end of the valve to center the valve while grinding. If the tip of the valve is not square with the stem, the face of the valve may be ground improperly.

The valve stem is clamped in the work head as close to the fillet under the valve head as possible to prevent vibrations. The work head motor is turned on to rotate the valve. The wheel head motor is turned on to rotate the grinding wheel. The coolant flow is adjusted to flush the material away, but not so much that it splashes.

For best results perform the following:

- The rotating grinding wheel is fed slowly to the rotating valve face.
- Light grinding is done as the valve is moved back and forth across the grinding wheel face.
- Do not feed the valve into the grinding stone more than 0.001 to 0.002 in. at one time.
- The valve is never moved off the edge of the grinding wheel. It is ground only enough to clean the face. ● **SEE FIGURE 31–21**.

MARGIN The margin is the distance between the head of the valve and the seat of the valve. This distance should be 0.03 in. (0.8 mm). Some vehicle manufacturers specify a minimum margin of less than 0.03 in. for some engines, especially for intake valves. Always check service information for the exact specifications for the engine being serviced. ● **SEE FIGURE 31–22**.

NOTE: To help visualize a 0.03 in. margin, note that this dimension is equal to about 1/32 in. or the thickness of a U.S. dime.

Intake valves can usually perform satisfactorily with a margin less than 0.03 in. Always check the engine manufacturer's specifications for the cylinder being serviced. Aluminized valves will lose their corrosion resistance properties when ground. For satisfactory service, aluminized valves must be replaced if they require refacing.

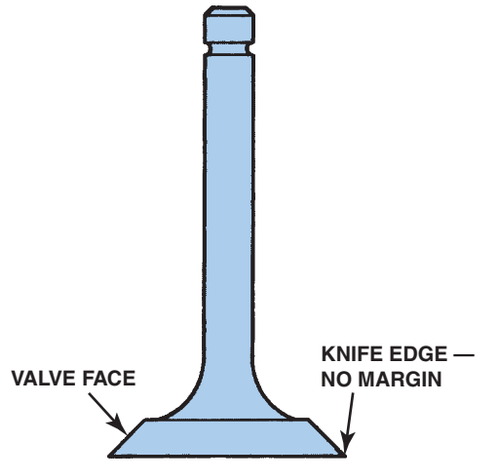


FIGURE 31–22 Never use a valve that has been ground to a sharp edge. This weakens the valve and increases the chance of valve face burning.

TECH TIP

Grinding the Valves for More Power

A normal "valve job" includes grinding the face of the valve to clean up any pits and grinding the valve stems to restore the proper stem height. However, a little more airflow in and out of the cylinder head can be accomplished by performing two more simple grinding operations.

- Use the valve grinder and adjust to 30 degrees (for a 45-degree valve) and grind a transition between the valve face and the valve stem area of the valve. While this step may reduce some desirable swirling of the air-fuel mixture at lower engine speeds, it also helps increase cylinder filling, especially at times when the valve is not fully open.
- Chamfer or round the head of the valve between the top of the valve and the margin on the side. By rounding this surface, additional airflow into the cylinder is achieved. ● **SEE FIGURE 31–23**.

VALVE SEAT RECONDITIONING

PURPOSE AND FUNCTION The valve seats are reconditioned at the following times:

- After the cylinder head has been properly cleaned, resurfaced, and the valve guides have been resized or reconditioned
- When the valve guides have been replaced

The final valve seat width and position are checked with the valve that is to be used on the seat being reconditioned.

VALVE SEAT ANGLES Valve seats will have a normal seat angle of either 45 or 30 degrees.

- **45 degrees.** This is the most commonly used, and the narrow 45-degree valve seats will crush carbon deposits to prevent buildup of deposits on the seat and the valve heat will transfer to the seat and cylinder head.

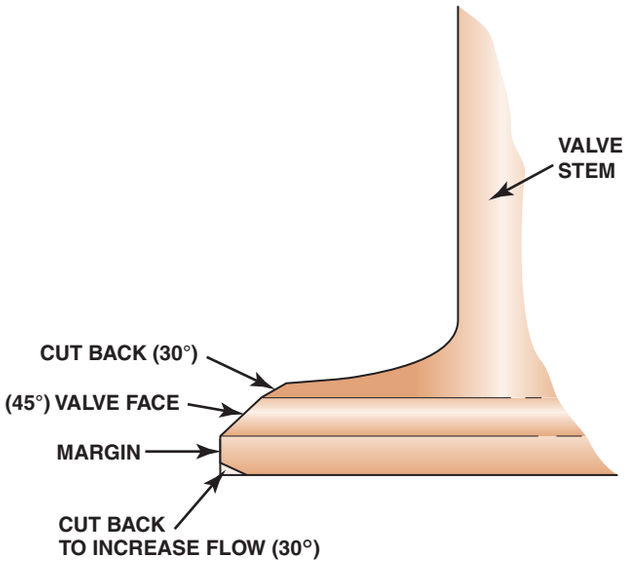


FIGURE 31–23 After grinding the 45-degree face angle, additional airflow into the engine can be accomplished by grinding a transition between the face angle and the stem, and by angling or rounding the transition between the margin and the top of the valve.

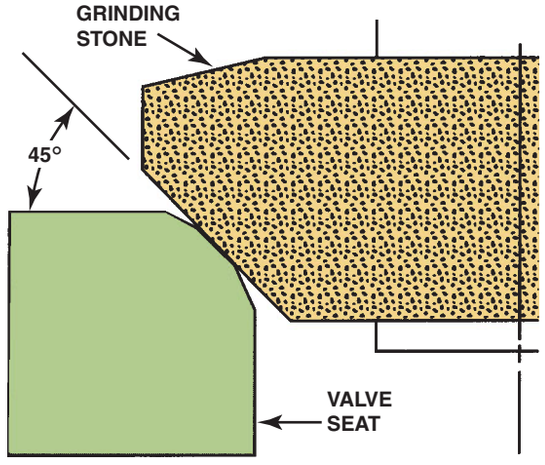


FIGURE 31–24 Grinding a 45-degree angle establishes the valve seat in the combustion chamber.

- **30 degrees.** Usually used on intake valves only. The 30-degree valve seat is more likely to burn than a 45-degree seat because some deposits can build up to keep the valve from seating properly. The 30-degree valve seat will, however, allow more gas flow than a 45-degree valve seat when both are opened to the same amount of lift. ● **SEE FIGURE 31–24**.

INTERFERENCE ANGLE

Ideally, the valve face and valve seat should have exactly the same angle. This is impossible, especially on exhaust valves, because the valve head becomes much hotter than the seat and so the valve expands more than the seat. This expansion causes the hot valve to contact the seat in a different place on the valve than it did when it was cold.

As a result of its shape, the valve does not expand evenly when heated. This uneven expansion also affects the way in which the hot valve contacts the seat. In valve and valve seat reconditioning, the valve is often ground with a face angle 1 degree less than the seat angle to compensate for the change in hot seating. This angle is called an *interference angle.* It makes a positive seal at the combustion chamber edge of the seat when the engine is first started after a valve job.

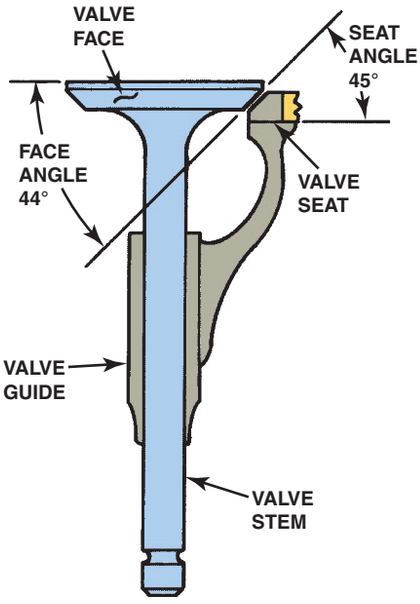


FIGURE 31–25 Some vehicle manufacturers recommend that the valve face be resurfaced at a 44-degree angle and the valve seat at a 45-degree angle. This 1-degree difference is known as the interference angle.

- As the engine operates, the valve will peen itself on the seat. In a short time, it will make a matched seal. After a few thousand miles, the valve will have formed its own seat.
- The interference angle has another benefit. The valve and seat are reconditioned with different machines. Each machine must have its angle set before it is used for reconditioning.
- It is nearly impossible to set the exact same angles on both valve and seat reconditioning machines. Making an interference angle will ensure that any slight angle difference favors a tight seal at the combustion chamber edge of the valve seat when the valve servicing has been completed. ● **SEE FIGURE 31–25**.

VALVE SEAT WIDTH

As the valve seats are resurfaced, their widths increase. The resurfaced seats must be narrowed to make the seat width correct and to position the seat properly on the valve face. The normal automotive engine cylinder head valve seat is from 1/16 to 3/32 in. (1.5 to 2.5 mm) wide. There should be at least 1/32 in. (0.8 mm) of the ground valve face extending above the seat, called *overhang.*

Some manufacturers recommend having the valve seat contact the middle of the valve face. In all cases, the valve seat width and the contact with the valve face match the manufacturer's specifications. ● **SEE FIGURE 31–26**.

THREE-ANGLE VALVE JOB

A **three-angle valve job** means that the valve seats are ground three times.

- The first angle is the angle of the valve seat specified by the vehicle manufacturer, usually 45 degrees.
- The second angle uses a 60-degree stone or cutter to remove material right below the valve seat to increase flow in or out of the combustion chamber. This angle is called the **throating angle.** ● **SEE FIGURE 31–27**.
- The third angle uses a 30-degree stone or cutter to smooth the transition between the valve seat and the cylinder head, again to increase flow in or out of the combustion chamber. This angle is called the **topping angle.** ● **SEE FIGURE 31–28**.

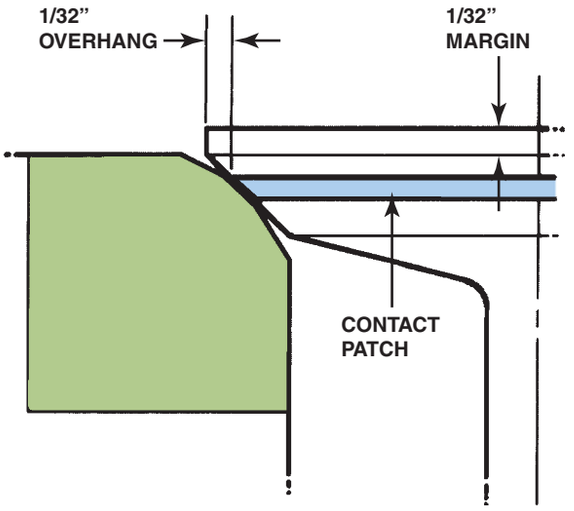


FIGURE 31–26 The seat must contact evenly around the valve face. For good service life, both margin and overhang should be at least 1/32 in. (0.8 mm).

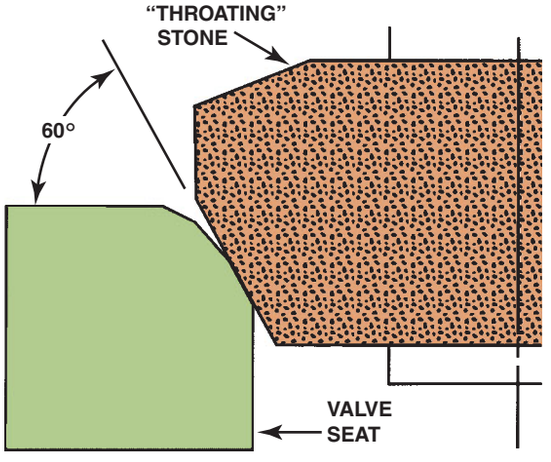


FIGURE 31–27 Grinding a 60-degree angle removes metal from the bottom to raise and narrow the seat.

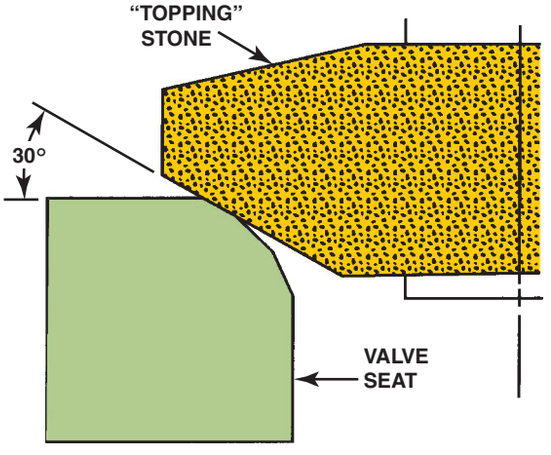


FIGURE 31–28 Grinding a 30-degree angle removes metal from the top to lower and narrow the seat.

The three stones or cutters can be used in combination to create the desired seat width and where it contacts the face of the valve. The 60-degree throating stone will rise and narrow the seat. The 45-degree stone will widen the seat, and the 30-degree stone will lower and narrow the seat. ● **SEE FIGURE 31–29**.

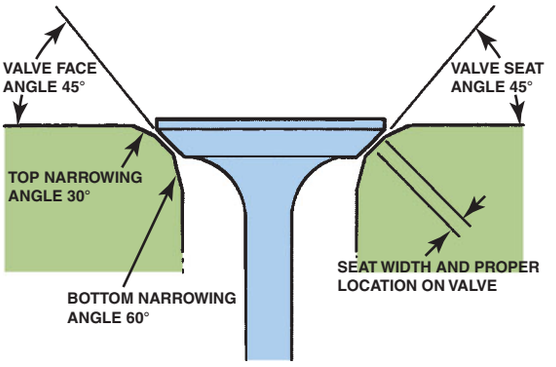


FIGURE 31–29 A typical three-angle valve job using 30-, 45-, and 60-degree stones or cutters.

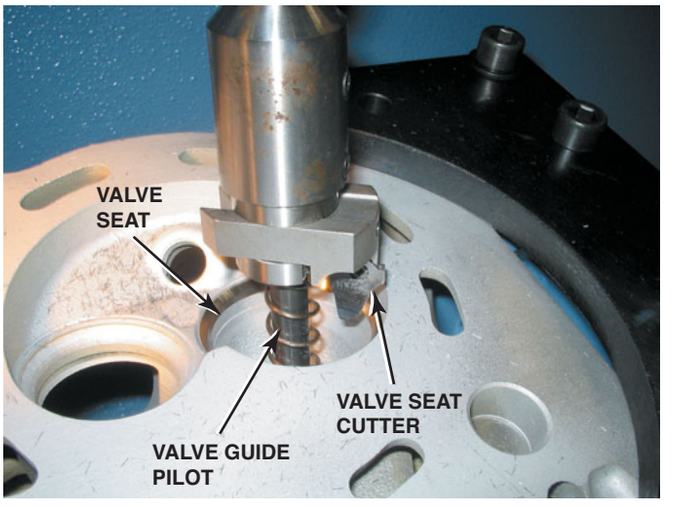


FIGURE 31–30 A valve guide pilot being used to support a valve seat cutter.

VALVE GUIDE PILOTS

TYPES OF PILOTS

Valve seat reconditioning equipment uses a pilot in the valve guide to align the stone holder or cutter in the exact same location as the valve stem. This ensures accurate valve seat-to-valve face sealing. Two types of pilots used include:

- **Tapered pilots** locate themselves in the least worn section of the guide. They are made in standard sizes and in oversize increments of 0.001 in., usually up to 0.004 in. OS. The largest pilot that will fit into the guide is used for valve seat reconditioning. This type of pilot restores the seat to be as close to the original position as possible when used with worn valve guides.
  - ● **SEE FIGURE 31–30**.
- **Expandable pilots** used with seating equipment are of two types. One type of adjustable pilot expands in the center of the guide to fit like a tapered pilot. The other expands to contact the ends of the guide where there has been the greatest wear. The valve itself will align in the same way as the pilot.

NOTE: If the guide is not reconditioned, the valve will match the seat when an expandable pilot is used.

The pilot and guide should be thoroughly cleaned.

VALVE SEAT GRINDING STONES

TYPES OF STONES Three basic types of grinding stones are used. All are used dry.

- A **roughing stone** is used to rapidly remove large amounts of seat metal. This would be necessary on a badly pitted seat or when installing new valve seat inserts. The roughing stone is sometimes called a seat *forming stone.*
- After the seat forming stone, a **finishing stone** is used to put the proper finish on the seat. The finishing stone is also used to recondition cast-iron seats that are only slightly worn.
- **Hard seat stones** are used on hard Stellite® exhaust seat inserts.

NOTE: Stellite® is a nonmagnetic hard alloy used for valve seats in heavy-duty applications.

The stone diameter and face angle must be correct. The diameter of the stone must be larger than the valve head, but it must be small enough that it does not contact the edge of the combustion chamber. The angle of the grinding surface of the stone must be correct for the seat. When an interference angle is used with reground valves, it is common practice to use a seat with the standard seat angle. The interference angle is ground on the valve face. In some cases, such as with an aluminized valve, the valve has the standard angle and the seat is ground to give the interference angle. The required seat angle must be determined *before* the seat grinding stone is dressed.

DRESSING THE GRINDING STONE The selected grinding stone is installed on the stone holder. The holder and grinding stone assembly is rotated with the driver. The diamond is adjusted so that it just touches the stone face. The diamond dressing tool is moved slowly across the face of the spinning stone, taking a very light cut. Dressing the stone in this way will give it a clean, sharp cutting surface. It is necessary to redress the stone at the following times.

- Each time a stone is placed on a holder
- At the beginning of each valve job
- Any time the stone is not cutting smoothly and cleanly while grinding valve seats

GRINDING THE VALVE SEAT The typical procedure includes the following steps.

STEP 1 The valve seat should be cleaned before grinding. This keeps the grinding dust from filling the grinding stone.

STEP 2 The pilot is then placed in the valve guide. A drop of oil is placed on the end of the pilot to lubricate the holder.

STEP 3 The holder, with the dressed grinding stone, is placed over the pilot. The driver should be supported so that no driver weight is on the holder. This allows the stone abrasive and the metal chips to fly out from between the stone and seat to give fast, smooth grinding.

STEP 4 Grinding is done in short bursts, such as two to three seconds each burst. Check to see if the seat is properly ground at the end of each burst. This procedure helps prevent the seat from being ground too deep.

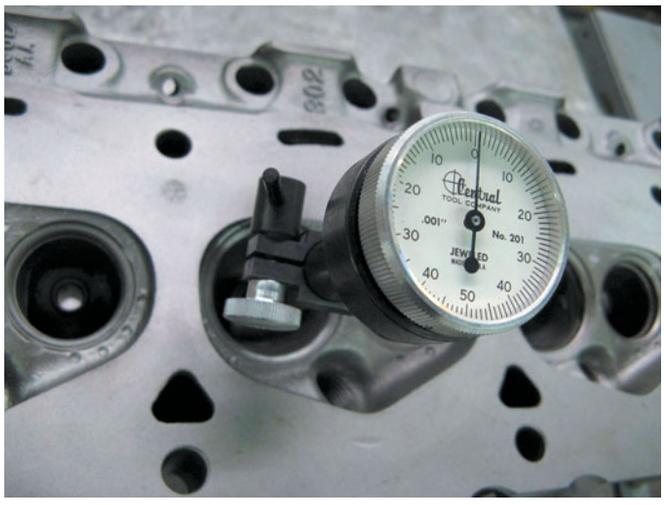


FIGURE 31–31 Checking valve seat concentricity using a dial indicator.

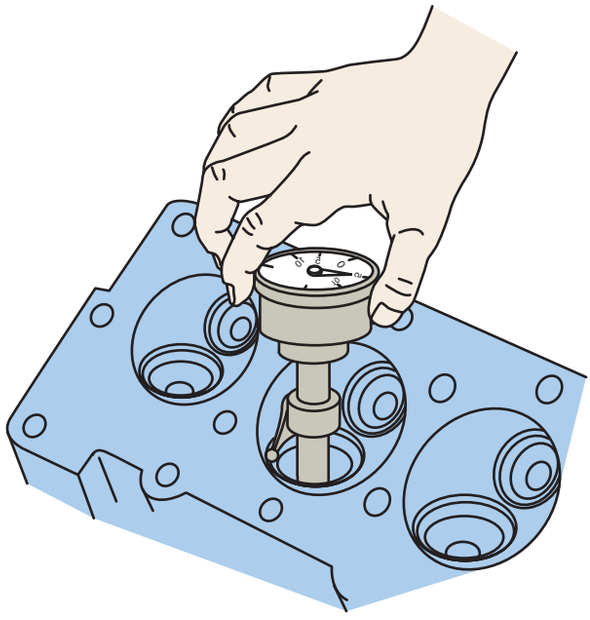


FIGURE 31–32 Typical dial indicator type of micrometer for measuring valve seat concentricity.

STEP 5 The holder and stone should be lifted from the seat between each grinding burst to check the condition of the seat. The finished seat should be bright and smooth across the entire surface, with no pits or roughness remaining. Some of the induction hardness from the exhaust valve seat may extend over into the intake seat. It may be necessary to apply a slight pressure on the driver toward the hardened spot to form a concentric seat.

STEP 6 Check the seat with a dial indicator gauge to make sure that it is concentric within 0.002 in. (0.05 mm) before the seat is finished. The dial gauge measurement of the valve seat is very important. The maximum acceptable variation is 0.002 in., called the **total indicator runout (TIR)** of the valve seat. ● **SEE FIGURES 31–31 AND 31–32.**

NARROWING THE VALVE SEAT The valve seat becomes wider as it is ground. It is therefore necessary to narrow the seat so that it will contact the valve properly. The seat is *topped* with

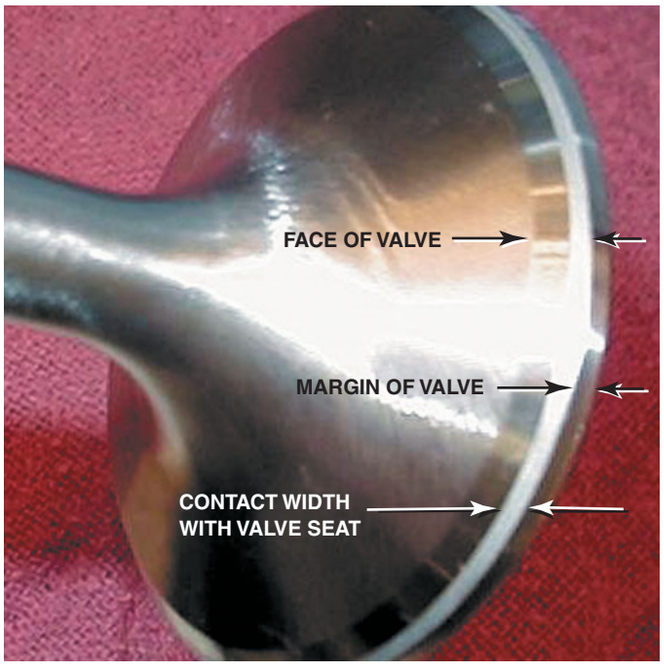


FIGURE 31–33 After the valve face and the valve seat are ground (reconditioned), lapping compound is used to smooth the contact area between the two mating surfaces. Notice that the contact is toward the top of the face. For maximum life, the contact should be in the middle of the face.

a grinding stone dressed to 15 degrees less than the seat angle. Therefore, use:

- A 30-degree stone to narrow a 45-degree seat angle
- A 15-degree stone for a 30-degree seat angle

Topping lowers the top edge of the seat. The amount of topping required can best be checked by measuring the maximum valve face diameter using dividers. The dividers are then adjusted to a setting 1/16 in. smaller to give the minimum valve face overhang. The seat is measured and then topped with short grinding bursts, as required, to equal the diameter set on the dividers. The seat width is then measured. If it is too wide, the seat must be *throated* with a stone with a 60-degree angle. This removes metal from the port side of the seat, raising the lower edge of the seat. Generally accepted seat widths are as follows:

- For intake valves: 1/16 in. or 0.0625 in. (about the thickness of a nickel) (1.5 mm)
- For exhaust valves: 3/32 in. or 0.0938 in. (about the thickness of a dime and a nickel together) (2.4 mm)

The completed seat must be checked with the valve that is to be used on the seat. This can be done using lapping compound or by marking across the valve face at four or five places with a felt-tip marker. The valve is then inserted in the guide so that the valve face contacts the seat. The valve is rotated 20 to 30 degrees and then removed. The location of the seat contact on the valve is observed where the felt-tip marking has been rubbed off from the valve. Valve seating can be seen in ● **FIGURE 31–33**.

Valve seat grinding is complete when each of the valve seats has been properly ground, topped, and throated.

To summarize:

- Using a 30-degree topping stone (for a 45-degree seat) *lowers* the upper outer edge and narrows the seat.
- Using a 60-degree throating stone *raises* the lower inner edge and narrows the seat.
- Using a 45-degree stone *widens* the seat.

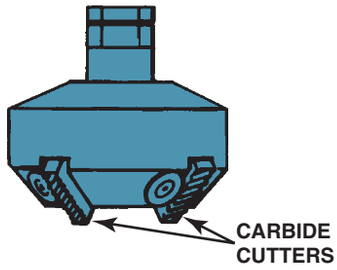


FIGURE 31–34 A cutter is used to remove metal and form the valve seat angles.

VALVE SEAT CUTTERS

Some vehicle manufacturer and automotive service technicians recommend the use of valve seat cutters rather than valve seat grinders. ● **SEE FIGURE 31–34**.

The valve seats can be reconditioned to commercial standards in much less time when using the cutters rather than the grinders. The advantages of using a seat cutter compared to a grinding stone include:

- A number of cutting blades are secured at the correct seat angle in the cutting head of this valve seat reconditioning tool.
- The cutter angle usually includes the interference angle so that new valves with standard valve face angles can be used without grinding the new valve face.
- The cutters do not require dressing as stones do.
- The cutter is rotated by hand or by using a special speed reduction motor. Only metal chips are produced.
- The finished seat is checked for concentricity and fit against the valve face.

CAUTION: A cutter should only be rotated clockwise. If a cutter is rotated counterclockwise, damage to the cutting surfaces ruins the cutter.

VALVE SEAT TESTING

PURPOSE After the valves have been refaced and the guides and valve seats have been resurfaced, the valves should be inspected for proper sealing and to ensure that the valve seat is concentric with the valve face.

METHODS Following are methods often used to check valve face-to-seat concentricity and valve seating.

1. Vacuum testing can be done by applying vacuum to the intake and/or exhaust port using a tight rubber seal and a vacuum pump. A good valve face-to-seat seal is indicated by maintaining at least 28 in. Hg of vacuum. This method also tests for leakage around the valve guides. Put some engine oil around the guides; if vacuum increases, valve guides may have excessive clearance.
2. The ports or chamber can be filled with mineral spirits or some other suitable fluid. A good seal should not leak fluid for at least 45 seconds.
3. Valve seating can be checked by applying air pressure to the combustion chamber and checking for air leakage past the valve seat.

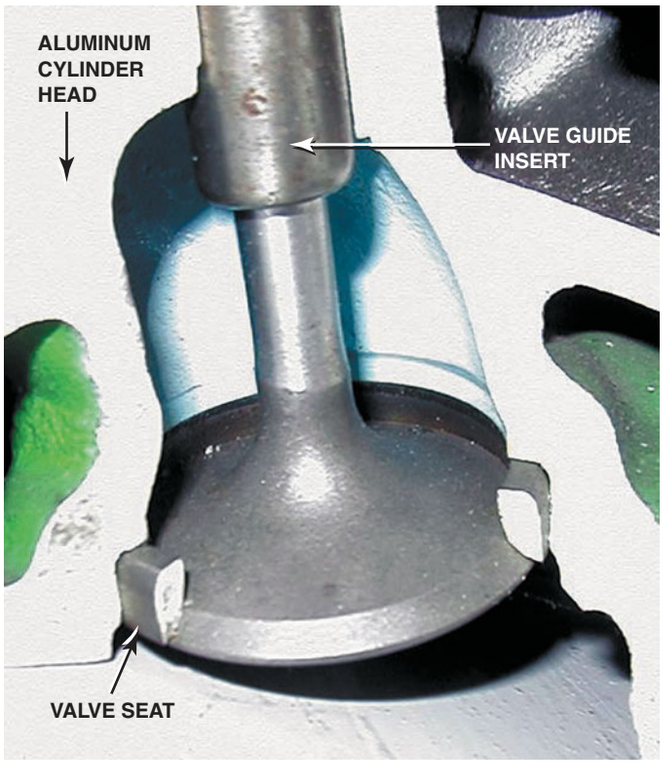


FIGURE 31–35 All aluminum cylinder heads use valve seat inserts. If an integral valve seat (cast-iron head) is worn, it can be replaced with a replacement valve seat by machining a pocket (counterbore) to make a place for the new insert seat.

TECH TIP

The MIG Welder Seat Removal Trick

A quick and easy method to remove insert valve seats is to use a *metal inert gas (MIG)* welder, also called a *gas metal arc welder (GMAW).* After the valve has been removed, use the MIG welder and lay a welding bead around the seat area of the insert. As the welder cools, it shrinks and allows the insert to be easily removed from the cylinder head. The weld bead also provides a surface that can be used to pry the seat from the cylinder head.

4. The valves can be lapped using valve grinding compound and looking at the "parting line" between the valve face on the valve and the valve seat in the cylinder head.

VALVE SEAT REPLACEMENT

PURPOSE Valve seats need to be replaced if they are cracked or if they are burned or eroded too much to be reground. ● **SEE FIGURE 31–35.**

It may not be possible to determine whether a valve seat needs to be replaced before an attempt is made to recondition the valve seat. Valve seat replacement is accomplished by using a pilot in the valve guide. This means that the valve guide must be reconditioned *before* the seat can be replaced.

- Damaged insert valve seats are removed and the seat counterbore is cleaned to accept a new oversize seat insert.

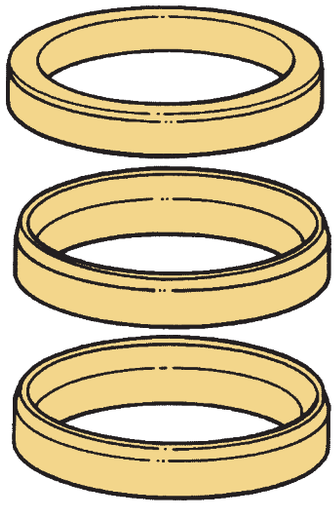


FIGURE 31–36 Insert valve seats are rings of metal driven into the head.

- Damaged integral valve seats must be counterbored to make a place for the new insert seat.

INSERT SEAT REMOVAL METHODS The old insert seat is removed by one of several methods.

- A small pry bar can be used to snap the seat from the counterbore.
- It is sometimes easier to do this if the old seat is drilled to weaken it. Be careful not to drill into the head material.
- Sometimes, an expandable hook-type puller is used to remove the seat insert. See the Tech Tip, "The MIG Welder Seat Removal Trick." The seat counterbore must be cleaned before the new, oversize seat is installed. The replacement inserts have a 0.002 to 0.003 in. (0.05 to 0.07 mm) interference fit in the counterbore. The counterbores are cleaned and properly sized, using the same equipment described in the following paragraph for installing replacement seats in place of faulty integral valve seats.

TYPES OF VALVE SEATS If an insert is being replaced, the new insert must be of the same type of material as the original insert or better. Insert exhaust valve seats operate at temperatures that are 100°F to 150°F (56°C to 83°C) hotter than those of integral seats up to 900°F (480°C). Upgraded valve and valve seat materials are required to give the same service life as that of the original seats. Removable valve seats are available in different materials, including:

- Cast iron
- Stainless steel
- Nickel cobalt
- Powdered metal (PM)
  - ● **SEE FIGURE 31–36.**

REPLACING AN INTEGRAL VALVE SEAT A counterbore cutting tool is selected that will cut the correct diameter for the outside of the insert. The diameter of the bore is smaller than the outside diameter of the seat insert. The procedure usually includes the following steps.

STEP 1 The cutting tool is positioned securely in the tool holder so that it will cut the counterbore at the correct diameter.

STEP 2 The tool holder is attached to the size of pilot that fits the valve guide. The tool holder feed mechanism is screwed together so that it has enough threads to properly feed the cutter into the head. This assembly is placed in the valve guide so that the cutting tool rests on the seat that is to be removed.

TECH TIP

Use the Recommended Specifications

A technician replaced valve seat inserts in an aluminum cylinder head. The *factory* specification called for a 0.002 in. interference fit (the insert should be 0.002 in. larger in diameter than the seat pocket in the cylinder head). Shortly after the engine was started, the seat fell out, ruining the engine.

The technician should have used the interference fit specification supplied with the replacement seat insert. Interference fit specifications depend on the type of material used to make the insert. Some inserts for aluminum heads require as much as 0.007 in. interference fit. Always refer to the specification from the manufacturer of the valve inserts when replacing valve seats in aluminum cylinder heads.

STEP 3 The new insert is placed between the support fixture and the stop ring. The stop ring is adjusted against the new insert so that cutting will stop when the counterbore reaches the depth of the new insert.

STEP 4 The boring tool is turned by hand or with a reduction gear motor drive. It cuts until the stop ring reaches the fixture.

STEP 5 The support fixture and the tool holder are removed. The pilot and the correct size of adapter are placed on the driving tool.

STEP 6 The seats should be cooled with dry ice to cause them to shrink. Each insert should be left in the dry ice until it is to be installed. This will allow it to be installed with little chance of metal being sheared from the counterbore. Sheared chips could become jammed under the insert, keeping it from seating properly. The chilled seat is placed on the counterbore.

STEP 7 The driver with a pilot is then quickly placed in the valve guide so that the seat will be driven squarely into the counterbore. The driver is hit with a heavy hammer to seat the insert.

STEP 8 Heavy blows are used to start the insert, and lighter blows are used as the seat reaches the bottom of the counterbore.

STEP 9 The installed valve seat insert is peened in place by running a peening tool around the metal on the outside of the seat. The peened metal is slightly displaced over the edge of the insert to help hold it in place.

VALVE STEM HEIGHT

DEFINITION **Valve stem height** is the distance the valve stem is above the spring seat. Valve stem height is a different measurement from installed height. ● **SEE FIGURE 31–37**.

- Valve stem height is important to maintain for all engines, but especially for overhead camshaft engines.
- When the valve seat and the valve face are ground, the valve stem extends deeper into the combustion chamber and extends higher or farther into the cylinder head.
- The valve is put in the head, and the length from the tip to the valve spring seat is measured.

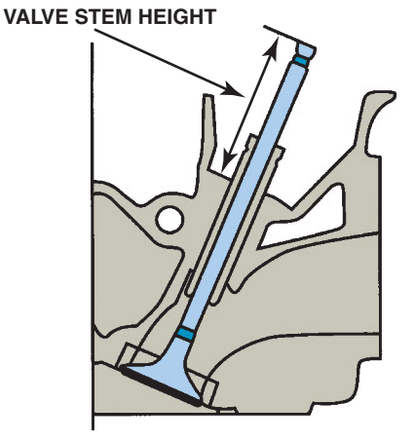


FIGURE 31–37 Valve stem height is measured from the spring seat to the tip of the valve after the valve seat and valve face have been refinished. If the valve stem height is too high, up to 0.02 in. can be ground from the tips of most valves.

- The tip is ground to shorten the valve stem length to compensate for the valve face and seat grinding.
- The valve will not close if the valve tip extends too far from the valve guide on engines that have hydraulic lifters and nonadjustable rocker arms.
- If the valve is too long, the tip may be ground by as much as 0.02 in. (0.5 mm) to reduce its length. If more grinding is required, the valve must be replaced. If it is too short, the valve face or seat may be reground, within limits, to allow the valve to seat deeper.
- Where excessive valve face and seat grinding has been done, shims can be placed under the rocker shaft on some engines as a repair to provide correct hydraulic lifter plunger centering. These shims must have the required lubrication holes to allow oil to enter the shaft.

INSTALLED HEIGHT

DEFINITION **Installed height** is the distance between the valve spring seat and the underside of the valve spring retainer. When the valves and/or valve seats have been machined, the valve projects farther than before on the rocker arm side of the head. The valve face is slightly recessed into the combustion chamber side of the head. The valve spring tension is, therefore, reduced because the spring is not as compressed as it was originally.

CORRECTING INSTALLED HEIGHT To restore original valve spring tension, special valve spring spacers, inserts, or shims are installed under the valve springs. These shims are usually called **valve spring inserts (VSI).** Valve spring inserts are generally available in three different thicknesses.

- **0.015 in. (0.38 mm).** Used for balancing valve spring pressure
- **0.03 in. (0.75 mm).** Generally used for new springs on cylinder heads that have had the valve seats ground and valves refaced
- **0.06 in. (1.5 mm).** Necessary to bring assembled height to specifications (These thicker inserts may be required if the seats have been resurfaced more than once.)

STEP 1 To determine the exact thickness of insert to install, measure the valve spring installed height. ● **SEE FIGURE 31–38**.

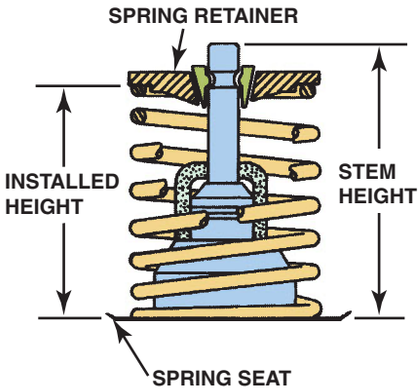


FIGURE 31–38 Installed height is determined by measuring the distance from the spring seat to the bottom of the valve spring retainer.



FIGURE 31–39 Valve spring inserts are used to restore proper installed height.

STEP 2 If the installed height is greater than specifications, select the valve spring insert (shim) that brings the installed height to within specifications. Be sure to install the valve spring inserts with the grooves facing toward the cylinder head. These are used to allow air to flow between the cylinder and the insert to help insulate the valve springs. Most inserts are labeled with the message, "This Side Up," which means toward the valve spring. ● **SEE FIGURE 31–39**.

CAUTION: Do not use more than one valve spring insert. If the correct installed height cannot be achieved using one insert, replace the valve seat to restore the proper installed height.

VALVE STEM SEALS

PURPOSE AND FUNCTION

Leakage past the valve guides is a major oil consumption problem in any overhead valve or overhead cam engine. A high vacuum exists in the intake port, as shown in ● **FIGURE 31–40**.

Most engine manufacturers use valve stem seals on the exhaust valve, because a weak vacuum in the exhaust port area can draw oil into the exhaust stream, as illustrated in ● **FIGURE 31–41**.

Valve stem seals are used on overhead valve engines to control the amount of oil used to lubricate the valve stem as it moves in the guide. The stem and guide will scuff if they do not have enough oil. Too much oil will cause excessive oil consumption and will cause heavy carbon deposits to build up on the spark plug nose and on the valves.

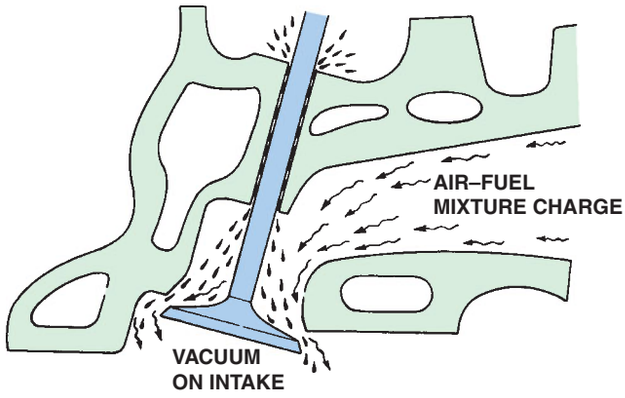


FIGURE 31–40 Engine vacuum can draw oil past the valve guides and into the combustion chamber. The use of valve stem seals limits the amount of oil that is drawn into the engine. If the seals are defective, excessive blue (oil) smoke is most often observed during engine start-up.

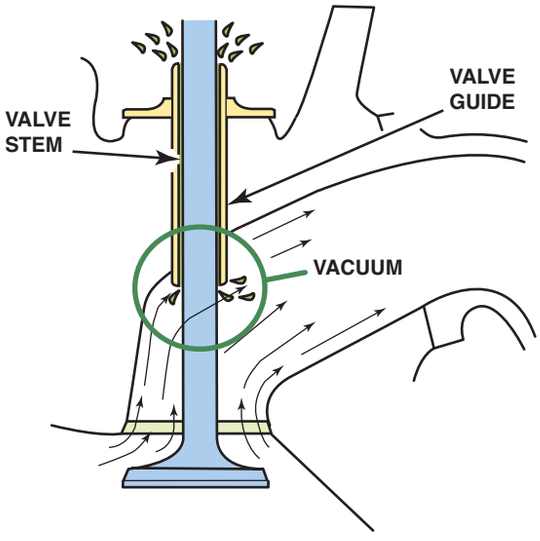
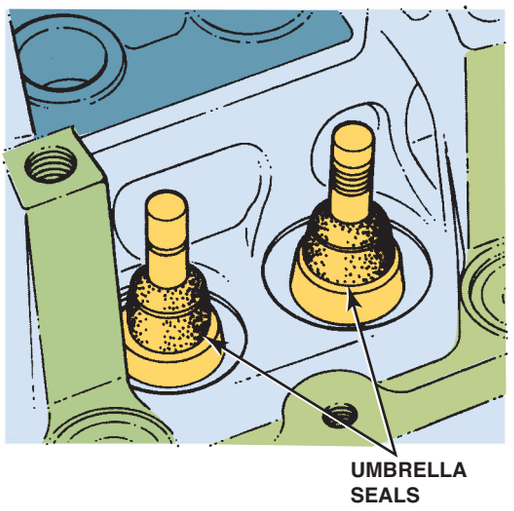


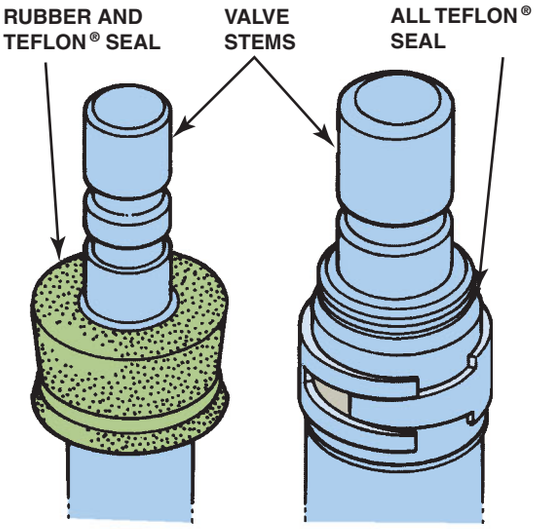
FIGURE 31–41 Engine oil can also be drawn past the exhaust valve guide because of a small vacuum created by the flow of exhaust gases. Any oil drawn past the guide would simply be forced out through the exhaust system and not enter the engine. Some engine manufacturers do not use valve stem seals on the exhaust valves.

TYPES OF VALVE STEM SEALS

The types of valve stem seals include the following:

- The *umbrella valve stem seal* holds tightly on the valve stem and moves up and down with the valve. Any oil that spills off the rocker arms is deflected out over the valve guide, much as water is deflected over an umbrella. As a result, umbrella valve stem seals are often called *deflector valve stem seals.* ● **SEE FIGURE 31–42**.
- The *O-ring valve stem seal* used on Chevrolet engines keeps oil from leaking between the valve stem and valve spring retainer. The oil is deflected over the retainer and shield. The assembly controls oil like an umbrella-type oil seal. Both types of valve stem seals allow only the correct amount of oil to reach the valve guide to lubricate the valve stem. The rest of the oil flows back to the oil pan. ● **SEE FIGURE 31–43**.
- *Positive valve stem seals* hold tightly around the valve guide, and the valve stem moves through the seal. The Teflon® wiping ring wipes the excess oil from the valve stem. ● **SEE FIGURES 31–44 AND 31–45**.





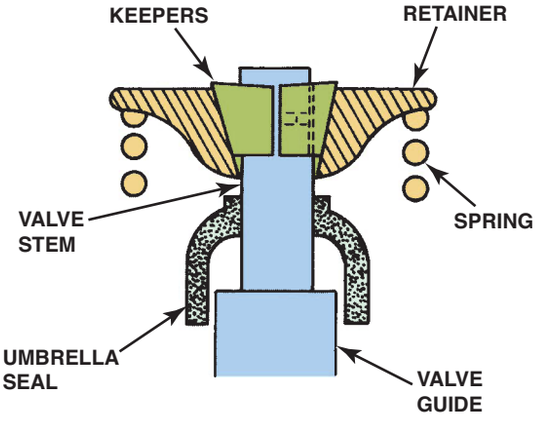


FIGURE 31–42 Umbrella seals install over the valve stems and cover the guide.

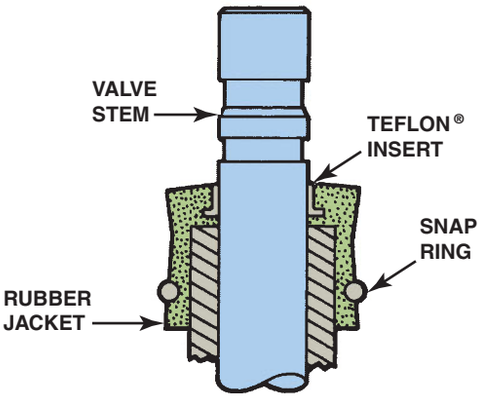


FIGURE 31–44 Positive valve stem seals are the most effective type because they remain stationary on the valve guide and wipe the oil from the stem as the valve moves up and down.

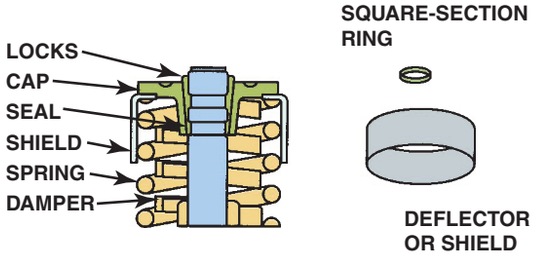


FIGURE 31–43 A small square cut O-ring is installed under the retainer in a groove in the valve under the groove(s) used for the keepers (locks).

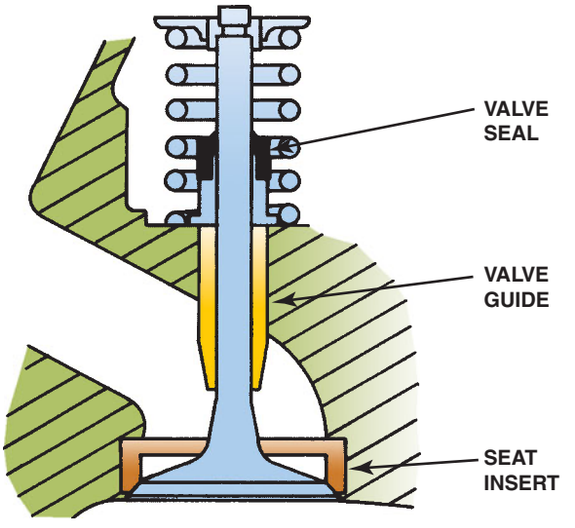


FIGURE 31–45 The positive valve stem seal is installed on the valve guide.

TECH TIP

Purchase Engine Parts from a Known Manufacturer

It is interesting to note that an automotive service technician cannot tell the difference between these synthetic rubber valve stem seals if they have come out of the same mold for the same engine. Often suppliers that package gasket sets for sale at a low price will include low-temperature Nitrile, even when the engine needs higher-temperature polyacrylate. The best chances of getting the correct valve stem seal material for an engine is to purchase gaskets and seals packaged by a major brand gasket company.

VALVE SEAL MATERIALS

Valve stem seals are made from many different types of materials. They may be made from nylon or Teflon, but most valve stem seals are made from synthetic rubber. Three types of synthetic rubbers are in common use.

- Nitrile (Nitril)
- Polyacrylate
- Viton



FIGURE 31–46 An assortment of shapes, colors, and materials of positive valve stem seals.

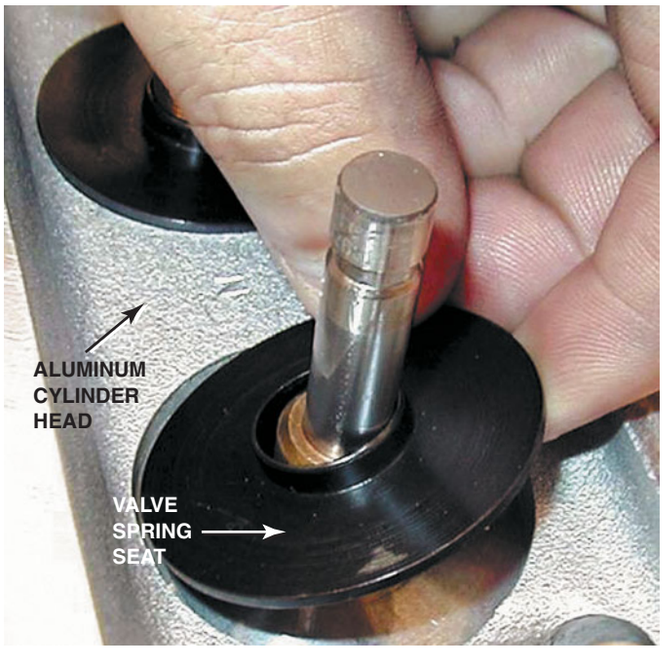


FIGURE 31–47 A metal valve spring seat must be used between the valve spring and the aluminum cylinder head. Many Chrysler aluminum cylinder heads use a combination valve spring seat and valve stem seal.

Nitrile is the oldest valve stem seal material. It has a low cost and a low useful temperature. Engine temperatures have increased with increased emission controls and improved efficiencies, which made it necessary to use premium polyacrylate, even with its higher cost. In many cases, it is being retrofit to the older engines because it will last much longer than Nitrile. Diesel engines and engines used for racing, heavy trucks, and trailer towing, along with turbocharging, operate at still higher temperatures. These engines may require expensive Viton valve stem seals that operate at higher temperatures. ● **SEE FIGURE 31–46.**

INSTALLING THE VALVES

PROCEDURE Assembling a cylinder head includes the following steps.

STEP 1 Clean the reconditioned cylinder head thoroughly with soap and water to wash away any remaining grit and metal shavings from the valve grinding operation.

STEP 2 Valves are assembled in the head, one at a time. The valve guide and stem are given a liberal coating of engine oil, and the valve is installed in its guide.

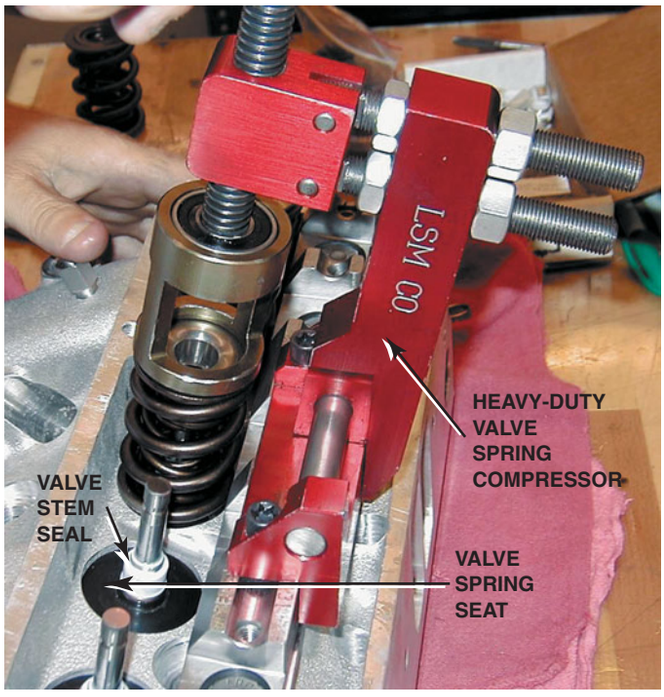


FIGURE 31–48 Assembling a race engine using a heavy-duty valve spring compressor.

TECH TIP

Check Before Bolting It On

Using new assembled cylinder heads, whether aluminum or cast iron, is a popular engine buildup option. However, experience has shown that metal shavings and casting sand are often found inside the passages.

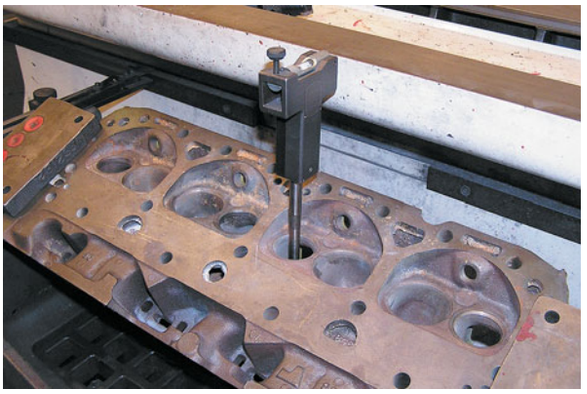
Before bolting on these "ready to install" heads, disassemble them and clean all passages. Often machine shavings are found under the valves. If this debris were to get into the engine, the results would be extreme wear or damage to the pistons, rings, block, and bearings. This cleaning may take several hours, but how much is your engine worth?

STEP 3 Umbrella and positive valve stem seals are installed. Push umbrella seals down until they touch the valve guide. Use a plastic sleeve over the tip of the valve when installing positive seals to prevent damage to the seal lip. Make sure that the positive seal is fully seated on the valve guide and that it is square.

STEP 4 Hold the valve against the seat as the valve spring seat or insert, valve spring, valve seal, and retainer are placed over the valve stem. One end of the valve spring compressor pushes on the retainer to compress the spring. Install the valve spring seat if assembling an aluminum head. ● **SEE FIGURE 31–47.**

STEP 5 The O-ring type of valve stem seal, if used, is installed in the lower groove. The valve keepers are installed while the valve spring is compressed. Using grease helps to keep them attached to the valve stem as the valve spring compressor is released.

STEP 6 Release the valve spring compressor slowly and carefully while making sure that the valve keepers seat properly between the valve stem grooves and the retainer. ● **SEE FIGURE 31–48.**



1 After the valve guide has been replaced or checked for being within specification, insert a pilot into the valve guide.



2 Level the bubble on the pilot by moving the cylinder head, which is clamped to a seat/guide machine.



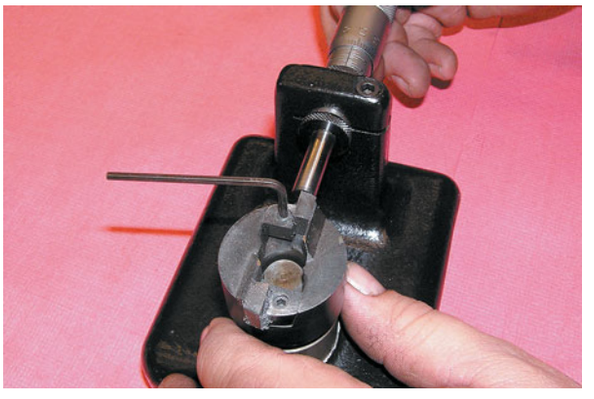
3 Select the proper guide for the application. Consult guide manufacturer's literature for recommendations.



4 Select the correct cutter and check that the cutting bits are sharp.

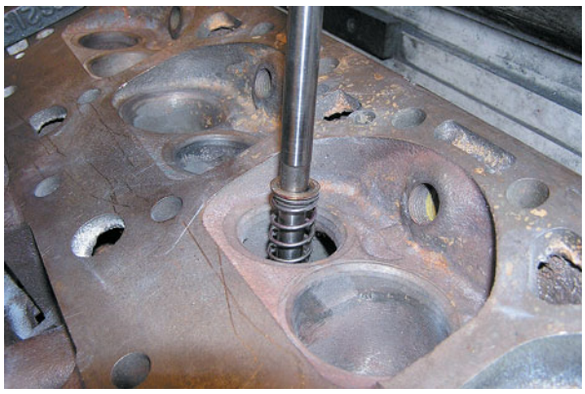


5 Carefully measure the exact outside diameter (O.D.) of the valve seat.



6 Adjust the depth of the cutter bit to achieve the specified interference fit for the valve seat.

CONTINUED ▶



7 Install the pilot into the valve guide to support the seat cutter.



8 Install the seat cutter onto the pilot.



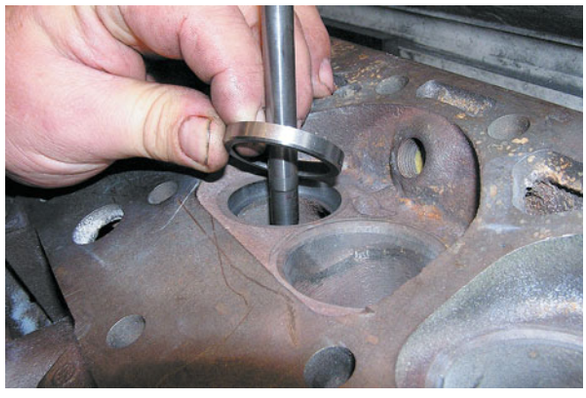
9 Adjust the depth of cut, using the new valve seat to set it to the same depth as the thickness of the seat.



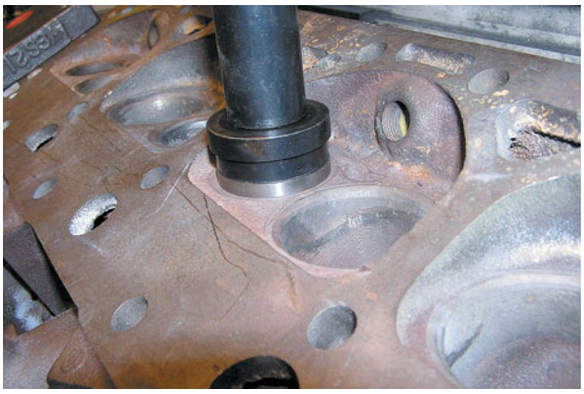
10 With the cylinder head still firmly attached to the seat and guide machine, start the cutter motor and cut the head until it reaches the stop.



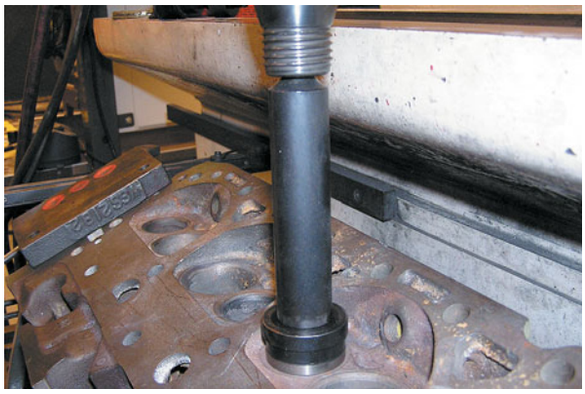
11 The finish cut valve seat pocket. Be sure to use a vacuum to remove all of the metal shavings from the cutting operation.



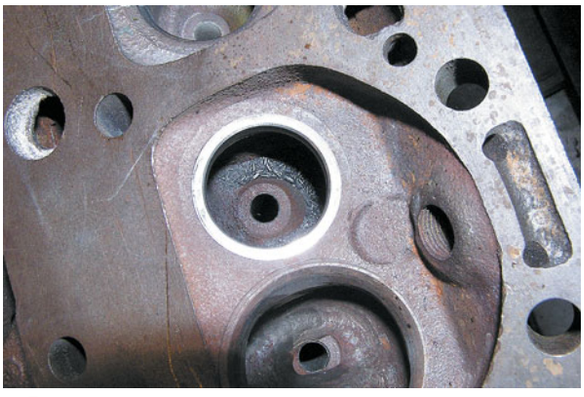
12 Place the chilled valve seat over the pilot being sure that the chamfer is facing toward the head as shown.



13 Install the correct size driver onto the valve seat.



14 Using the air hammer or press, press the valve seat into the valve pocket.



15 A new valve seat is now ready to be machined or cut.

REVIEW QUESTIONS

1. What is the procedure for grinding valves?
2. When is the valve tip ground? How do you know how much to remove from the tip?
3. What is an interference angle between the valve and the seat?
4. Describe the difference between cutting and grinding valve seats.
5. How is a valve seat insert installed?
6. How are the correct valve spring inserts (shims) selected and why are they used?

CHAPTER QUIZ

1. In a normally operating engine, intake and exhaust valves are opened by a cam and closed by the _____.
   a. Rocker arms or cam follower **c.** Lifters (tappets)
   b. Valve spring **d.** Valve guide and/or pushrod
2. If an interference angle is machined on a valve or seat, this angle is usually _____.
   a. 1 degree **c.** 1 to 3 degrees
   b. 0.005 degree **d.** 0.5 to 0.75 degree
3. Never remove more material from the tip of a valve than _____.
   a. 0.001 in. **c.** 0.02 in.
   b. 0.002 in. **d.** 0.05 in.
4. A valve should be discarded if the margin is less than _____ after refacing.
   a. 0.001 in. **c.** 0.03 in.
   b. 0.006 in. **d.** 0.06 in.
5. A valve seat should be concentric to the valve guide to a maximum TIR of _____.
   a. 0.006 in. **c.** 0.002 in.
   b. 0.004 in. **d.** 0.00015 in.
6. To lower and narrow a valve seat that has been cut at a 45-degree angle, use a cutter or stone of what angle?
   a. 60 degrees **c.** 30 degrees
   b. 45 degrees **d.** 15 degrees
7. Valve spring inserts (shims) are designed to _____.
   a. Increase installed height of the valve
   b. Decrease installed height of the valve
   c. Adjust the correct valve spring installed height
   d. Decrease valve spring pressure to compensate for decreased installed height
8. The proper relationship between intake and exhaust valve diameter is _____.
   a. Intake valve size is 85% of exhaust valve size
   b. Exhaust valve size is 85% of intake valve size
   c. Exhaust valve size is 38% of intake valve size
   d. Intake valve size is 45% of exhaust valve size
9. Dampers (damper springs) are used inside some valve springs to _____.
   a. Prevent valve spring surge
   b. Keep the valve spring attached to the valve
   c. Decrease valve spring pressure
   d. Retain valve stem seals
10. Umbrella-type valve stem seals _____.
    a. Fit tightly onto the valve guide
    b. Fit on the valve face to prevent combustion leaks
    c. Fit tightly onto the valve stem
    d. Lock under the valve retainer

chapter 32

CAMSHAFTS AND VALVE TRAINS

OBJECTIVES: After studying Chapter 32, the reader should be able to: • Prepare for the ASE Engine Repair (A1) certification test content area "B" (Cylinder Head and Valve Train Diagnosis and Repair). • Describe how the camshaft and valve train function. • Discuss valve train noise and its causes. • Explain how a hydraulic lifter works. • Describe the purpose and function of variable valve timing.

KEY TERMS: Aerated 328 • Asymmetrical 320 • Bucket 323 • Cam chucking 319 • Cam follower 323 • Cam-in-block 315 • Camshaft bearings 315 • Camshaft duration 323 • Composite camshaft 315 • Double roller chain 318 • Dual overhead camshaft (DOHC) 315 • Finger follower 323 • Flat-link type 317 • Freewheeling engine 318 • Hydraulic lash adjusters (HLA) 323 • Hydraulic valve lifter 327 • Interference engine 318 • Lobe 315 • Lobe centers 324 • Lobe displacement angle (LDA) 324 • Lobe lift 319 • Lobe separation 324 • Lobe spread 324 • Morse type 317 • Oil control valve (OCV) 330 • Overhead camshaft (OHC) 315 • Overhead valve (OHV) 315 • Pump-up 327 • Ramp 327 • Roller chain type 318 • Scavenging 330 • Seat duration 330 • Silent chain type 317 • Single overhead camshaft (SOHC) 315 • Solid valve lifter 327 • Symmetrical 320 • Thrust plate 319 • Total indicator runout (TIR) 329 • Valve cam phases (VCP) 332 • Valve (camshaft) overlap 324 • Valve float 327 • Valve lash 327 • Variable valve timing (VVT) 331 • Variable valve timing and lift electronic control (VTEC) 334

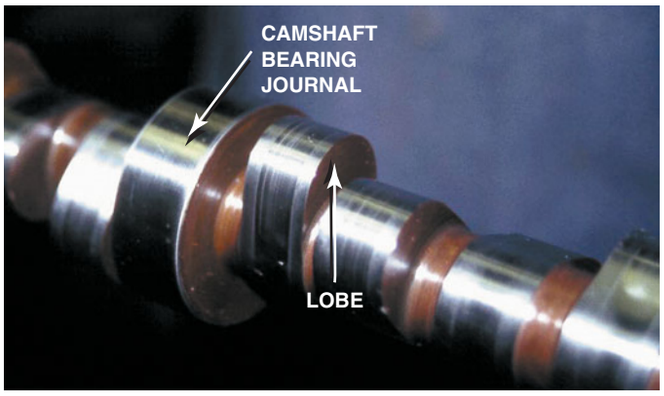


FIGURE 32–1 This high-performance camshaft has a lobe that opens the valve quickly and keeps it open for a long time.

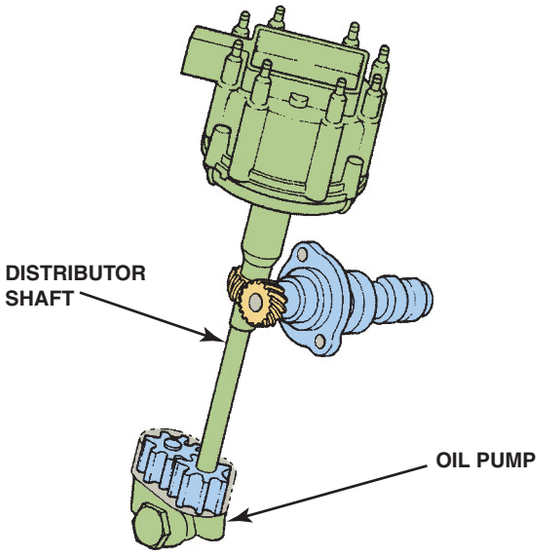


FIGURE 32–2 In many engines, the camshaft drives the distributor and the oil pump through a shaft from the end of the distributor.

CAMSHAFT

PURPOSE AND FUNCTION

The major function of a camshaft is to open the valves. Camshafts have eccentric shapes called **lobes** that open the valve against the force of the valve springs. The valve spring closes the valve when the camshaft rotates off of the lobe. The camshaft lobe changes rotary motion (camshaft) to linear motion (valves). Cam shape or contour is the major factor in determining the operating characteristics of the engine.

OPERATION

The camshaft is driven by:

- Timing gears
- Timing chains
- Timing belts

The gear or sprocket on the camshaft has twice as many teeth, or notches, as the one on the crankshaft. This results in two crankshaft revolutions for each revolution of the camshaft. *The camshaft turns at one-half the crankshaft speed in all four-stroke cycle engines.*

Cam lobe shape has more control over engine performance characteristics than any other single engine part. Engines identical in every way except cam lobe shape may have completely different operating characteristics and performance. ● **SEE FIGURE 32–1**.

The camshaft may also operate the following:

- Mechanical fuel pump (carburetor-equipped engines)
- Oil pump
- Distributor (if equipped)

● **SEE FIGURE 32–2**.

CAMSHAFT LOCATION

There are two basic areas where the camshaft can be located in an engine.

- **In the engine block.** This design is called the **cam-in-block** design. The camshaft is supported in the block by **camshaft bearings** and driven by the crankshaft with a gear or sprocket and chain drive. Engines with the cam located in the block are called pushrod or **overhead valve (OHV)** engines. ● **SEE FIGURE 32–3**.
- **Overhead.** Overhead camshafts are either belt or chain driven from the crankshaft and are located in the cylinder head(s). This arrangement is called **overhead camshaft (OHC)** design. If there is a single overhead camshaft for *each bank* of cylinders, the engine is classified as a **single overhead camshaft (SOHC)** engine design. If an engine uses two overhead camshafts per bank of cylinders, this type of engine design is called a **dual overhead camshaft (DOHC).**

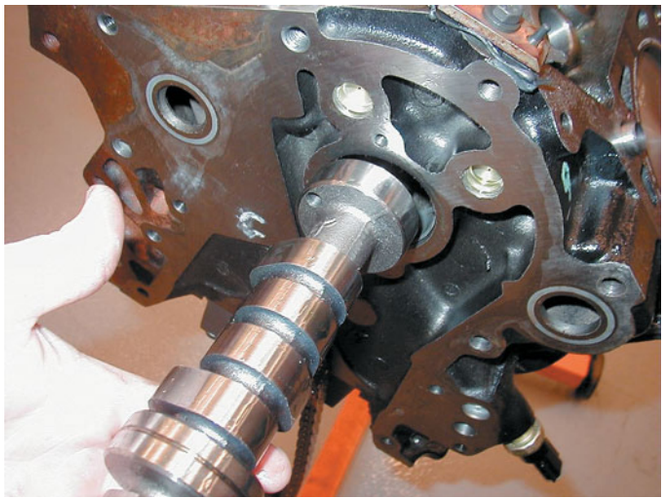


FIGURE 32–3 The camshaft rides on bearings inside the engine block above the crankshaft on a typical cam-in-block engine.

CAMSHAFT DESIGN

CONSTRUCTION

The camshaft is usually a one-piece casting from chilled cast iron for many production engines that includes:

- Lobes
- Bearing journals
- Accessory drive gear

● **SEE FIGURE 32–4**.

Other types of camshaft construction include:

- Forged steel (often used in diesel engines)
- Steel machined from a solid billet
- **Composite camshafts,** which use a lightweight tubular shaft with hardened steel lobes press-fitted over the shaft (The

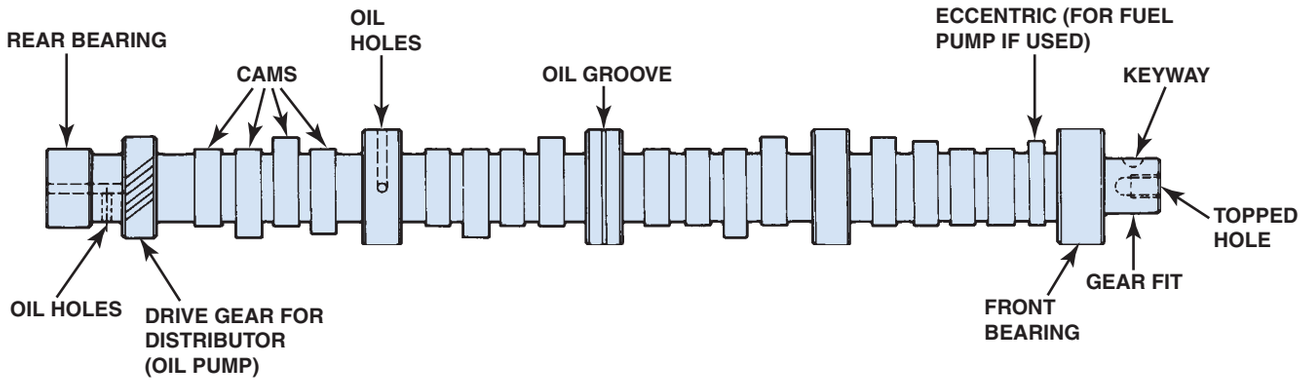


FIGURE 32–4 Parts of a cam and camshaft terms (nomenclature).

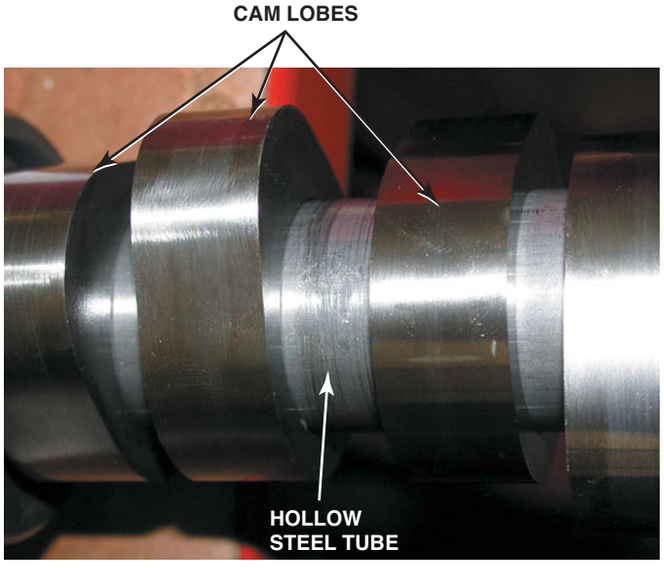


FIGURE 32–5 A composite camshaft is lightweight and yet flexible, because the hollow tube can absorb twisting forces and the lobes are hard enough to withstand the forces involved in opening valves.

actual production of these camshafts involves placing the lobes over the tube shaft in the correct position. A steel ball is then drawn through the hollow steel tube, expanding the tube and securely locking the cam lobes in position. ● **SEE FIGURE 32–5.)**

CAMSHAFT BEARING JOURNALS On pushrod engines, camshaft-bearing journals must be larger than the cam lobe so that the camshaft can be installed in the engine through the cam bearings. Some overhead cam engines have bearing caps on the cam bearings. These cams can have large cam lobes with small bearing journals. Cam bearings on some engines are progressively smaller from the front journal to the rear. Other engines use the same size of camshaft bearing on all the journals.

HARDNESS Older automotive camshafts were used with flat or convex-faced lifters and made from hardened alloy cast iron. It resists wear and provides the required strength. The very hardness of the camshaft causes it to be susceptible to chipping as the result of edge loading or careless handling.

Cast-iron camshafts have about the same hardness throughout. If reground, they should be recoated with a phosphate coating.

Steel camshafts are usually constructed from SAE 4160 or 4180 steel and are usually induction hardened. Induction hardening involves heating the camshaft to cherry red in an electric field (heating occurs by electrical induction). The heated camshaft is then dropped into oil. The rapid cooling hardens the surface. Camshafts can also be hardened by using the following methods.

- Liquid nitriding, which hardens to 0.001 to 0.0015 in. thick
- Gas nitriding, which hardens to 0.004 to 0.006 in. thick

Typical camshaft hardness should be 42 to 60 on the Rockwell "c" scale.

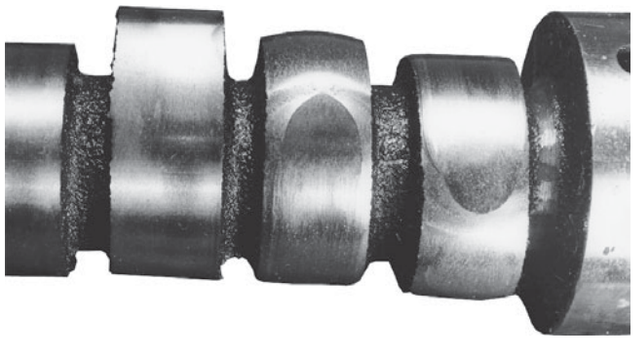


FIGURE 32–6 Worn camshaft with two lobes worn to the point of being almost round.

NOTE: Rockwell is a type of hardness test, and the *c* represents the scale used. The higher the number, the harder the surface. The abbreviation *Rc60,* therefore, indicates Rockwell hardness of 60 as measured on the "c" scale.

If this outer hardness wears off, the lobes of the camshaft are easily worn until they are almost completely rounded. ● **SEE FIGURE 32–6.**

CAMSHAFT LUBRICATION Some engines transfer lubricating oil from the main oil gallery to the crankshaft around the camshaft journal or around the outside of the camshaft bearing. Cam bearing clearance is critical in these engines. If the clearance is too great, oil will leak out and the crankshaft bearings will not get enough oil. Other engines use drilled holes in the camshaft bearing journals to meter lubricating oil to the overhead rocker arm. Oil goes to the rocker arm each time the holes line up between the bearing oil gallery passage and the outlet passage to the rocker arm.

FUEL PUMP ECCENTRICS An eccentric cam lobe for the mechanical fuel pump is often cast as part of the camshaft used in older engines before fuel injection. ● **SEE FIGURE 32–7.**

Some engines use a steel cup type of eccentric that is bolted to the front of the cam drive gear. This allows a damaged fuel pump eccentric to be replaced without replacing an entire camshaft.

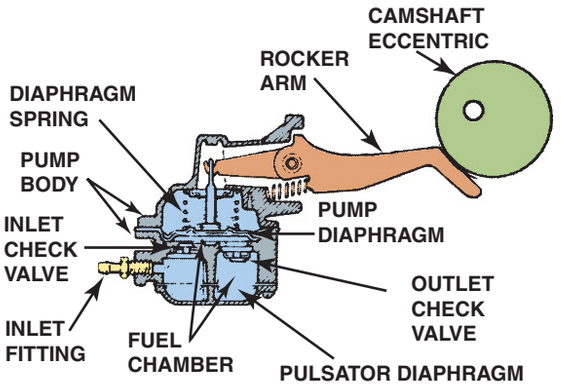


FIGURE 32–7 The fuel pump rocker arm rides on the camshaft eccentric.

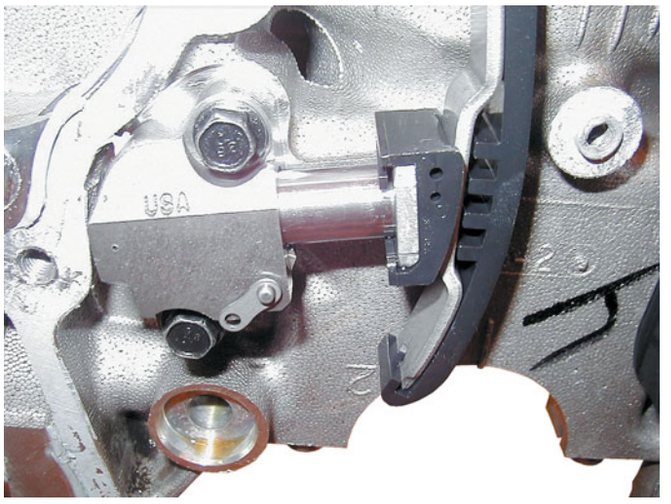


FIGURE 32–8 A timing chain hydraulic tensioner.

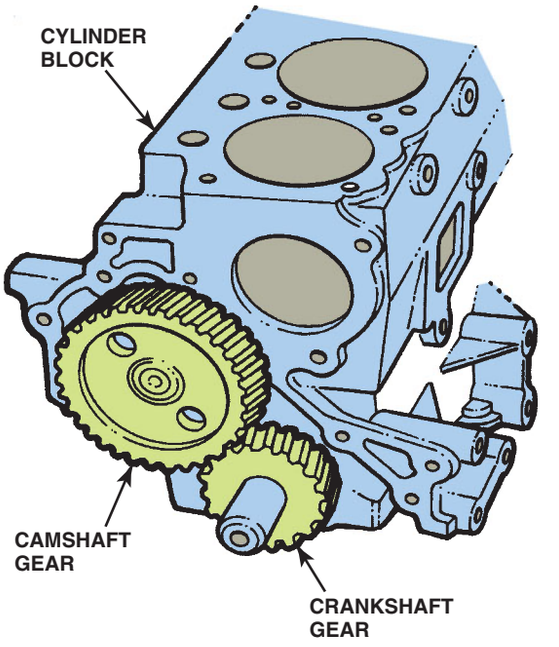


FIGURE 32–9 The larger camshaft gear is usually made from fiber and given a helical cut to help reduce noise. By making the camshaft gear twice as large as the crankshaft gear, the camshaft rotates one revolution for every two of the crankshaft.



FIGURE 32–10 A replacement silent chain and sprockets. The original camshaft sprocket was aluminum with nylon teeth to help control noise. This replacement set will not be noticeably louder than the original and should give the owner many thousands of miles of useful service.

CAMSHAFT DRIVES

PURPOSE AND FUNCTION

The crankshaft drives the camshaft with one of the following:

- Timing gears
- Sprockets and chains
- Sprockets and timing belts

Timing chains often have tensioners (dampers) pressing on the unloaded side of the chain. The tensioner pad is a Nylatron molding that is filled with molybdenum disulfide to give it low friction. The tensioner is held against the chain by either a spring or hydraulic oil pressure. ● **SEE FIGURE 32–8**.

The gears or sprockets are keyed to their shafts so that they can be installed in only one position. The gears and sprockets are then indexed together by marks on the gear teeth or chain links. However, some engines use a tolerance ring that locks the drive sprocket to the camshaft such as the Ford modular V-8s. In these engines, the drive sprocket should *not* be removed from the camshaft unless the specified procedures are followed. When the crankshaft and camshaft timing marks are properly lined up, the cam lobes are indexed to the crankshaft throws of each cylinder so that the valves will open and close correctly in relation to the piston position.

CAMSHAFT CHAIN DRIVES

The crankshaft gear or sprocket that drives the camshaft is usually made of sintered iron. When gears are used on the camshaft, the teeth must be made from a soft material to help reduce noise. Usually, the whole gear is made of aluminum or fiber, especially in older engines. ● **SEE FIGURE 32–9**.

When a chain and sprocket are used, the camshaft sprocket may be made of iron or it may have an aluminum hub with nylon teeth for noise reduction.

Two types of timing chains are used.

1. The **silent chain type** (also known as a **flat-link type,** or **Morse type** for its original manufacturer) operates quietly but tends to stretch with use. The metal links themselves do not "stretch" but, instead, the pin bushings at each joint wear, which causes the chain to become longer. ● **SEE FIGURES 32–10 AND 32–11.**

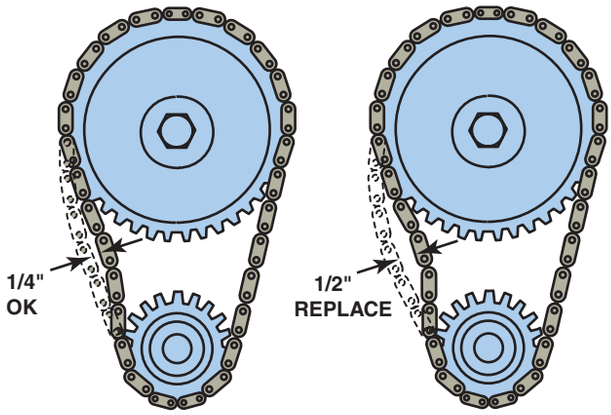


FIGURE 32–11 The industry standard for when to replace a timing chain and gears is when 1/2 in. (13 mm) or more of slack is measured in the chain. However, it is best to replace the timing chain and gear anytime the camshaft is replaced or the engine is disassembled for repair or overhaul.

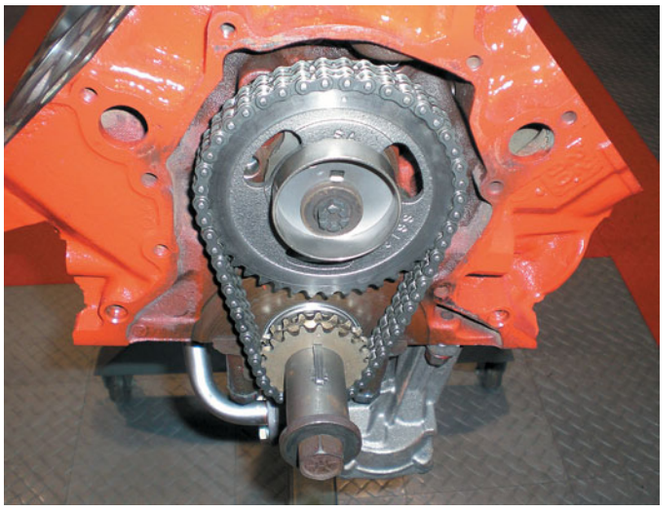


FIGURE 32–12 A replacement high-performance double roller chain. Even though a bit noisier than a flat-link chain, a roller chain does not stretch as much and will therefore be able to maintain accurate valve timing for a long time.

NOTE: When the timing chain stretches, the valve timing will be retarded and the engine will lack low-speed power. In some instances, the chain can wear through the timing chain cover and create an oil leak.

2. The **roller chain type** is noisier but operates with less friction and stretches less than the silent type of chain. If two chains are used side by side, this type of chain is called a **double roller chain.** ● **SEE FIGURE 32–12.**

   Some four-cam engines use a two-stage camshaft drive system:

   - Primary, from crankshaft to camshaft
   - Secondary, from one camshaft to another

   ● **SEE FIGURE 32–13.**

CAMSHAFT BELT DRIVES Many overhead camshaft engines use a timing belt rather than a chain. Cam drive belts are made from rubber and fabric and are often reinforced with fiberglass or Kevlar. The belt sprocket teeth are square-cut or cogged. Drive belts and sprockets reduce weight compared to a chain drive and require no lubrication with reduced noise. However, the belt requires periodic

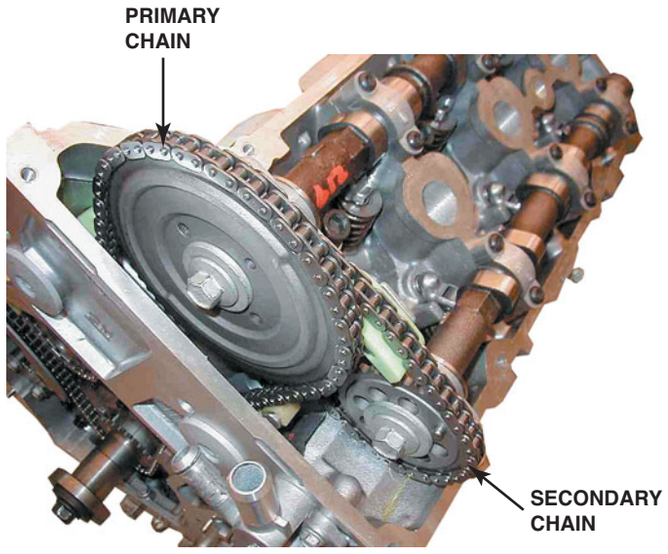


FIGURE 32–13 This dual overhead camshaft (DOHC) engine uses one chain from the crankshaft to the intake cam and a secondary chain to rotate the exhaust camshaft.

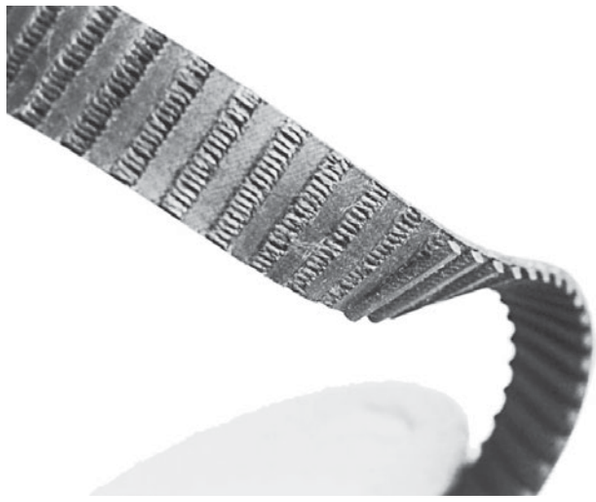


FIGURE 32–14 A timing belt failed when the teeth were sheared off. This belt failed at 88,000 miles because the owner failed to replace it at the recommended interval of 60,000 miles.



FIGURE 32–15 This timing belt broke because an oil leak from one of the camshaft seals caused oil to get into and weaken the belt. Most experts recommend replacing all engine seals in the front of the engine anytime a timing belt is replaced. If the timing belt travels over the water pump, the water pump should also be replaced as a precaution.

replacement, usually every 60,000 miles (100,000 km) or longer in some vehicles. ● **SEE FIGURES 32–14 AND 32–15.**

Unless the engine is freewheeling, the piston can hit the valves if the belt breaks. A **freewheeling engine** is one that causes no internal damage if the camshaft drive belt breaks when the engine is running. An **interference engine,** however, will cause some of the valves that are open to hit the pistons, causing major engine damage. ● **SEE FIGURES 32–16 AND 32–17.**

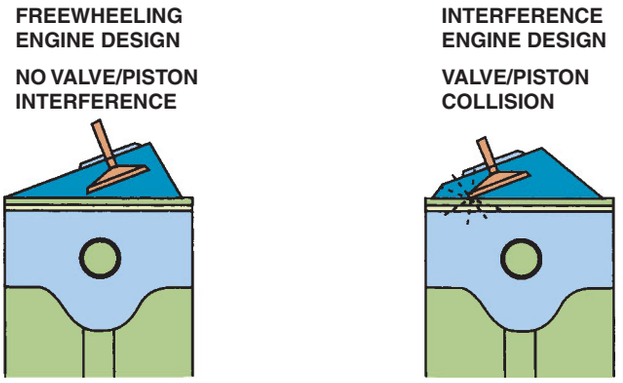


FIGURE 32–16 Many engines are of the interference design. If the timing belt (or chain) breaks, the piston still moves up and down in the cylinder while the valves remain stationary. With a freewheeling design, nothing is damaged, but in an interference engine, the valves are often bent.

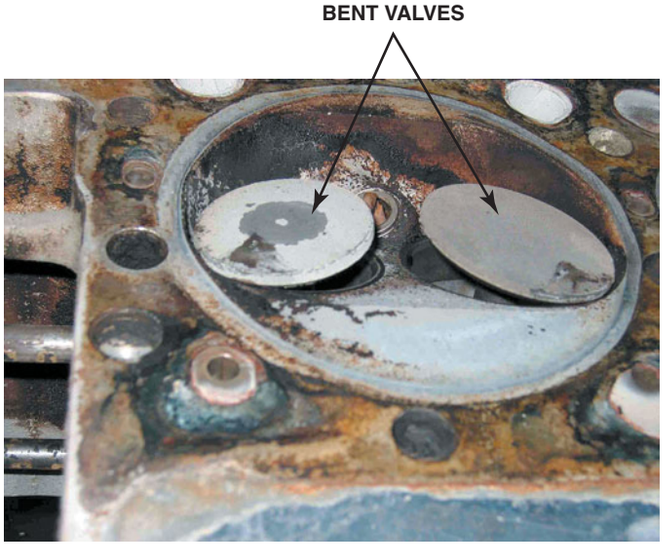


FIGURE 32–17 A head from a Mercedes showing bent valves when the timing chain stretched and skipped over the crankshaft sprocket. When this happened, the piston kept moving and bent the valves.

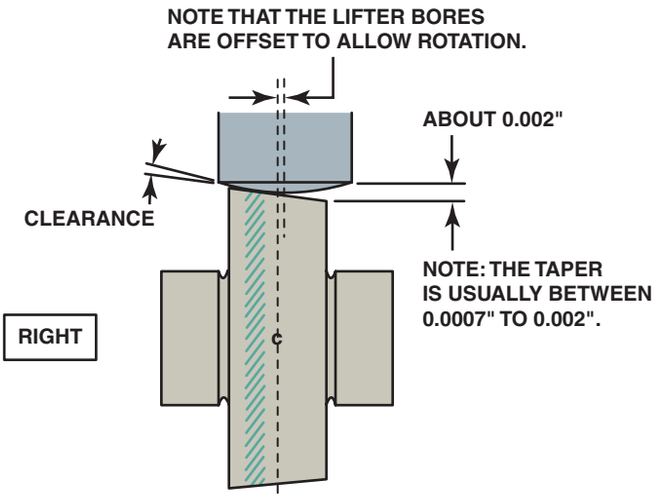


FIGURE 32–18 The slight angle and the curve on the bottom of a flat bottom lifter cause the lifter and the pushrod to rotate during normal operation.

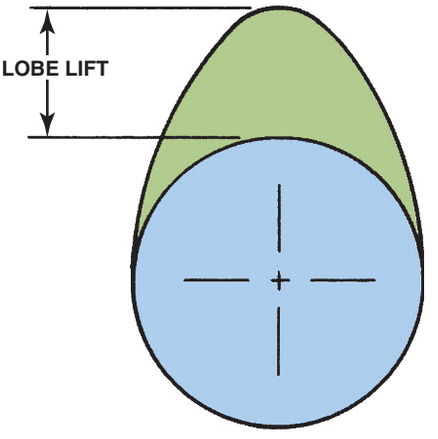


FIGURE 32–19 The lobe lift is the amount the cam lobe lifts the lifter. The blue circle is called the base circle. Because the rocker arm adds to this amount, the entire valve train has to be considered when selecting a camshaft that has the desired lift and duration.

CAMSHAFT MOVEMENT

REASONS CAMSHAFTS MOVE

On engines equipped with flat bottom lifters, as the camshaft lobe pushes the lifter upward against the valve spring force, a backward twisting force is developed on the camshaft. After the lobe goes past its high point, the lifter moves down the backside of the lobe. This makes a forward twisting force. This action produces an alternating torsion force forward, then backward, at each cam lobe. The number of cam lobes on the shaft multiplies this alternating torsion force.

Cam chucking is the movement of the camshaft *lengthwise in the engine during operation.* Each camshaft must have some means to control the shaft end thrust. One method is to use a **thrust plate** between the camshaft drive gear or sprocket and a flange on the camshaft.

A thrust plate is attached to the engine block with cap screws. In a few camshafts, a button, spring, or retainer that contacts the timing cover limits forward motion of the camshaft.

WHY FLAT-BOTTOM LIFTERS ROTATE

Valve trains that use flat bottom lifters use a spherical (curved) lifter face that slides against the cam lobe. This produces a surface on the lifter face that is slightly convex, by about 0.002 in. The lifter also contacts the lobe at a point that is slightly off center. This produces a small turning force on the lifter to cause some lifter rotation for even wear. In operation, there is a wide line of contact between the lifter and the high point of the cam lobe. ● **SEE FIGURE 32–18.**

These are the highest loads that are produced in an engine. This surface is the most critical lubrication point in an engine.

CAMSHAFT LOBE LIFT

The **lobe lift** of the cam is usually expressed in decimal inches and represents the distance that the valve lifter or follower is moved. The amount that the valve is lifted is determined by the lobe lift times the ratio of the rocker arm. ● **SEE FIGURES 32–19 AND 32–20.**

The higher the lift of the camshaft lobe, the greater the amount of air and fuel that can enter the engine. The more air and fuel burned in an engine, the greater the power potential of the engine.

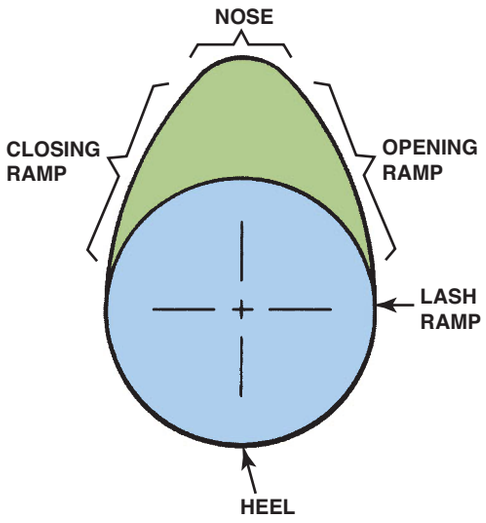


FIGURE 32–20 The ramps on the cam lobe allow the valves to be opened and closed quickly yet under control to avoid damaging valve train components, especially at high engine speeds.

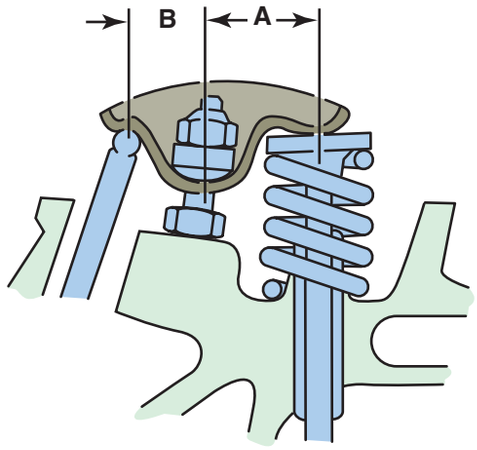


FIGURE 32–21 A 1.5:1 ratio rocker arm means that dimension A is 1.5 times the length of dimension B. Therefore, if the pushrod is moved up 0.4 in. by the camshaft lobe, the valve will be pushed down (opened) 0.4 in. × 1.5, or 0.6 in.

TECH TIP

Best to Warn the Customer

A technician replaced a timing chain and gears on a high mileage Chevrolet V-8. The repair was accomplished correctly, yet after starting, the engine burned an excessive amount of oil. Before the timing chain replacement, oil consumption was minimal. The replacement timing chain restored proper operation of the engine by restoring the proper cam and valve timing which increased engine vacuum. Increased vacuum can draw oil from the crankcase past worn piston rings and through worn valve guides during the intake stroke. Similar increased oil consumption problems occur if a valve job is performed on a high-mileage engine with worn piston rings and/or cylinders.

To satisfy the owner of the vehicle, the technicians had to disassemble and refinish the cylinders and replace the piston rings. Therefore, all technicians should warn customers that increased oil usage might result from almost any engine repair to a high-mileage engine.

The amount of lift of a camshaft is often different for the intake and exhaust valves.

- If the specifications vary, the camshaft is called **asymmetrical.**
- If the lift is the same, the cam is called **symmetrical.**

However, when the amount of lift increases, so do the forces on the camshaft and the rest of the valve train. Generally, a camshaft with a lift of over 0.5 in. (1.3 cm) is unsuitable for street operation except for use in engines that are over 400 $in.^3$ (6 liters).

The lift specifications at the valve face assume the use of the stock rocker arm ratio. If nonstock rocker arms with a higher ratio are installed (for example, 1.6:1 rockers replacing the stock 1.5:1 rocker arms), the lift at the valve is increased. Also, because the rocker arm rotation covers a greater distance at the pivot of the rocker arm, the rocker arm can hit the edge of the valve retainer.

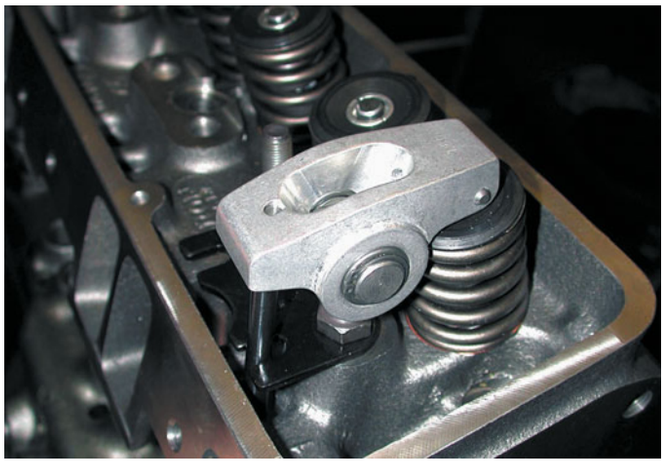


FIGURE 32–22 A high-performance aluminum roller rocker arm. Both the pivot and the tip that contacts the stem of the valve are equipped with rollers to help reduce friction for more power and better fuel economy.

ROCKER ARMS

PURPOSE AND FUNCTION A rocker arm reverses the upward movement of the pushrod to produce a downward movement on the tip of the valve. Engine designers make good use of the rocker arm. It is designed to reduce the travel of the cam follower or lifter and pushrod while maintaining the required valve lift. This is done by using a rocker arm ratio usually of 1.5:1.

For a given amount of lift on the pushrod, the valve will open to 1.5 times the cam lobe lift. This ratio allows the camshaft to be smaller, so the engine can be smaller. ● **SEE FIGURE 32–21.**

CAUTION: Using rocker arms with a higher ratio than stock can also cause the valve spring to compress too much and actually bind. Valve spring bind (coil bind) occurs when the valve spring is compressed to the point where there is no clearance in the spring. (It is completely compressed.) When coil bind occurs in a running engine, bent pushrods, broken rocker arms, or other valve train damage can result. ● **SEE FIGURE 32–22.**

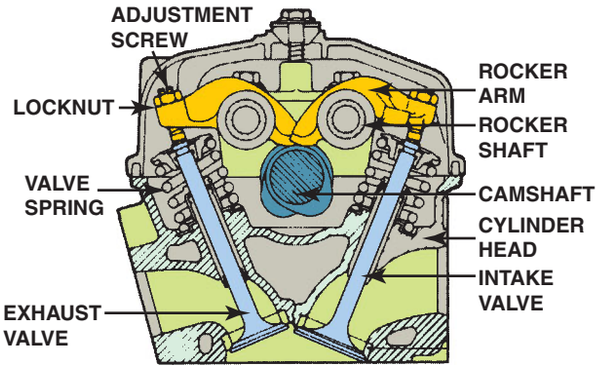


FIGURE 32–23 Some engines today use rocker shafts to support rocker arms such as the V-6 engine with a single overhead camshaft located in the center of the cylinder head.

Rocker arms may be:

- Cast
- Forged
- Stamped steel

Forged rocker arms are the strongest, but they require expensive manufacturing operations. Rocker arms may have bushings or bearings installed to reduce friction and increase durability. Cast rocker arms cost less to make and do not usually use bushings, but they do require several machining operations. They are not as strong as forged rocker arms but are satisfactory for passenger vehicle service. Stamped steel rocker arms are lightweight and cost effective.

SHAFT-MOUNTED ROCKER ARMS On some overhead valve and most single overhead camshaft engines, the rocker arms are mounted on a shaft that runs the full length of the cylinder head. ● **SEE FIGURE 32–23.**

Because the shaft provides a strong and stable platform for the rocker arms, shaft-mounted rocker arms work well, especially at high engine speeds. While most overhead camshaft engines that use rocker arm shafts do use an adjustable rocker arm, most OHV engines using rocker arm shafts have no provision for adjustment. Shaft-mounted rocker arms are lubricated through oil passages that travel from the block through the head and into the shaft, and then to the rocker arms.

STUD-MOUNTED ROCKER ARMS Stud-mounted rockers are only found on overhead valve (OHV) engines and each rocker arm is attached to a stud that is pressed or threaded into the cylinder head. A ball on top of the rocker arm provides the bearing surface as the rocker arm pivots and is held in place and adjusted for valve clearance by a nut. While this design looks less stable than a shaft-mounted rocker, this design has proved to be reliable and is inexpensive to manufacture. The rocker arms receive lubricating oil under pressure through hollow pushrods. ● **SEE FIGURE 32–24.**

Some engines use pushrod guide plates fastened to the head. ● **SEE FIGURE 32–25.**

PEDESTAL-MOUNTED ROCKER ARMS Pedestal-mounted rocker arms are similar to stud-mounted rocker arms but do not use a stud and are used only in overhead valve engines. Two rocker arms are attached to and pivot on a pedestal attached to the cylinder head with one or two bolts. The pedestal is usually made from aluminum and the rocker arms are usually stamped steel, which is lightweight and nonadjustable. ● **SEE FIGURE 32–26.**

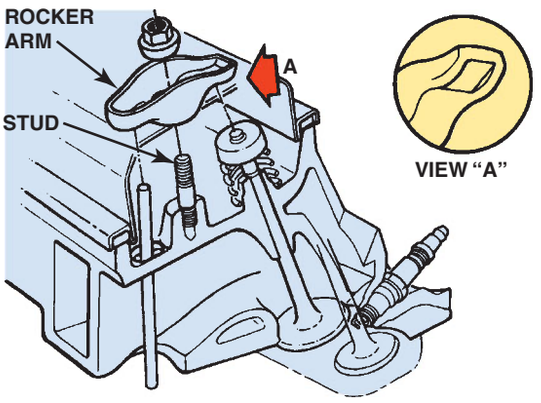


FIGURE 32–24 A typical stud-mounted rocker arm.

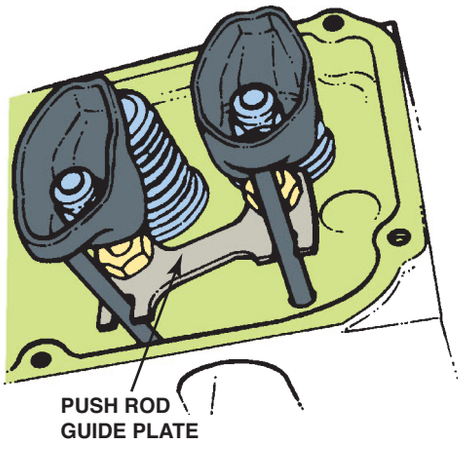


FIGURE 32–25 Pushrod guide plates are bolted to the head and help stabilize the valve train, especially at high engine speeds.

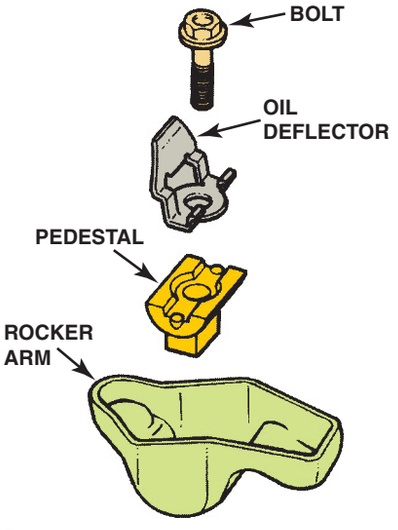


FIGURE 32–26 A pedestal-type rocker arm design that used one bolt for each rocker arm and is nonadjustable. If valve lash needs to be adjusted, different length pushrod(s) must be used.

? FREQUENTLY ASKED QUESTION

Are the Valves Adjustable?

If the stud has the same diameter for its whole length, the rockers *are adjustable* and the nut will be the "interference" type (lock-type nut). If the stud has a shoulder of a different diameter, the rockers are *nonadjustable* and the nut will not have interference threads.

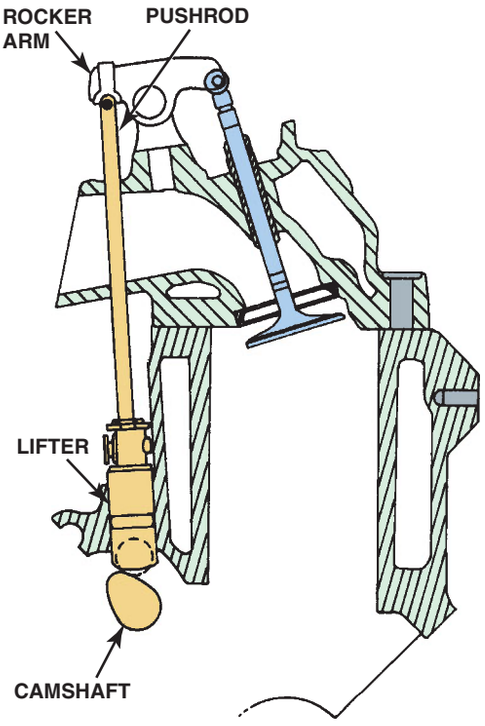


FIGURE 32–27 Overhead valve engines are also known as pushrod engines because of the long pushrod that extends from the lifter to the rocker arm.

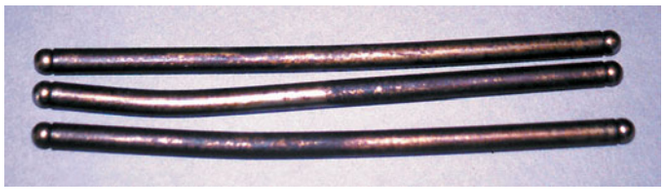


FIGURE 32–28 When the timing chain broke, the valves stopped moving up and down but the pistons kept moving and hit the valves causing the pushrods to bend.

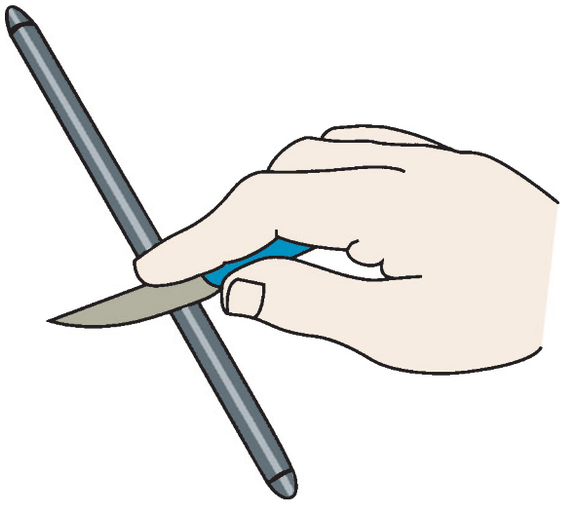


FIGURE 32–29 Hardened pushrods should be used in any engine that uses pushrod guides (plates). To determine if the pushrod is hardened, simply try to scratch the side of the pushrod with a pocketknife.

TECH TIP

Rocker Arm Shafts Can Cause Sticking Valves

As oil oxidizes, it forms a varnish. Varnish buildup is particularly common on hot upper portions of the engine, such as rocker arm shafts. The varnish restricts clean oil from getting into and lubricating the rocker arms. The cam lobe can easily *force* the valves open, but the valve springs often do not exert enough force to fully close the valves. The result is an engine miss, which may be intermittent. Worn valve guides and/or weak valve springs can also cause occasional rough idle, uneven running, or an engine misfire.

TECH TIP

Hollow Pushrod Dirt

Many engine rebuilders and remanufacturers do not reuse old hollow pushrods. Dirt, carbon, and other debris are difficult to thoroughly clean from inside a hollow pushrod. When an engine is run with used pushrods, the trapped particles can be dislodged and ruin new bearings and other new engine parts. Therefore, for best results, consider purchasing new hollow pushrods instead of trying to clean and reuse the originals.

TECH TIP

The Scratch Test

All pushrods used with guide plates *must* be hardened on the sides and on the tips. To easily determine if a pushrod is hardened, simply use a sharp pocketknife to scrape the wall of the pushrod. A heat-treated pushrod will not scratch. ● **SEE FIGURE 32–29**.

PUSHRODS

PURPOSE AND FUNCTION Pushrods transfer the lifting motion of the valve train from the cam lobe and lifters to the rocker arms. ● **SEE FIGURE 32–27**.

TYPES OF PUSHRODS Pushrods are designed to be as light as possible and still maintain their strength. They may be either solid or hollow. If they are to be used as passages for oil to lubricate rocker arms, they *must* be hollow. Pushrods use a convex ball on the lower end that seats in the lifter. The rocker arm end is also a convex ball, unless there is an adjustment screw in the pushrod end of the rocker arm. In this case, the rocker arm end of the pushrod has a concave socket. It mates with the convex ball on the adjustment screw in the rocker arm.

All pushrods should be rolled on a flat surface to check for straightness. ● **SEE FIGURE 32–28**.

The tolerance in the valve train allows for some machining of engine parts without the need to change pushrod length. However, if one or more of the following changes have been made to an engine, a different pushrod length may be necessary.

- Block deck height machined
- Cylinder head deck height machined

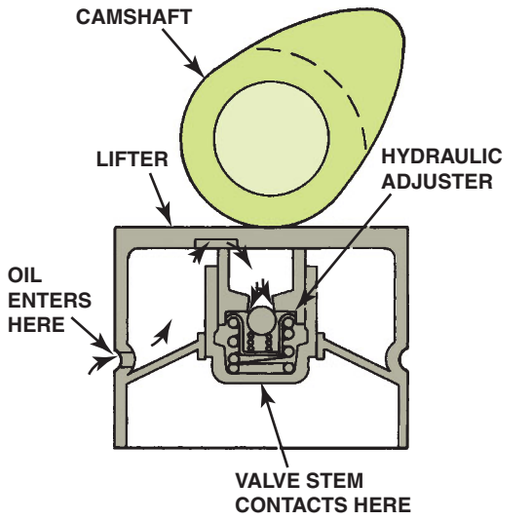


FIGURE 32–30 Hydraulic lifters may be built into bucket-type lifters on some overhead camshaft engines.

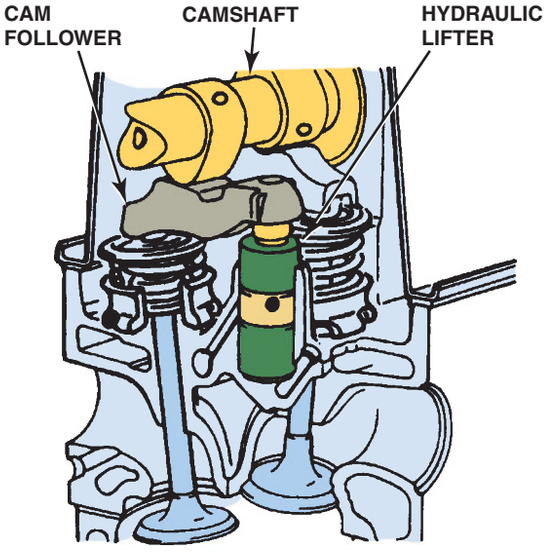


FIGURE 32–31 The use of cam followers allows the use of hydraulic lifters with an overhead camshaft design.

- Camshaft base circle size reduced
- Valve length increased
- Lifter design changed

OVERHEAD CAMSHAFT VALVE TRAINS

TERMINOLOGY Overhead camshaft engines use several different types of valve opening designs.

1. One type opens the valves directly with a **bucket.** ● **SEE FIGURE 32–30**.
2. The second type uses a **cam follower,** also called a **finger follower,** that provides an opening ratio similar to that of a rocker arm. Finger followers open the valves by approximately 1 1/2 times the cam lift. The pivot point of the finger follower may have a mechanical adjustment or it may have an automatic hydraulic adjustment. ● **SEE FIGURE 32–31**.

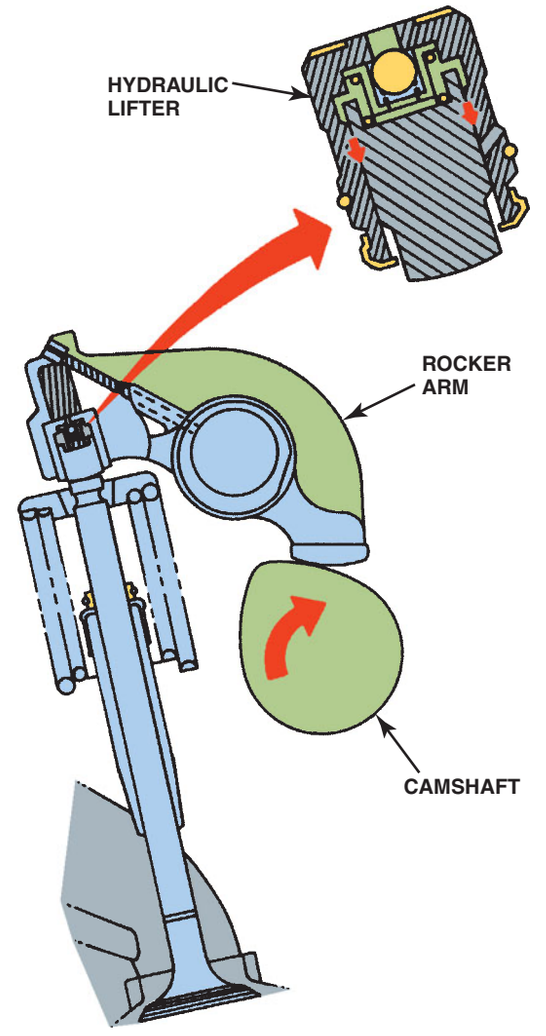


FIGURE 32–32 Hydraulic lash adjusters (HLA) are built into the rocker arm on some OHC engines. Sometimes hydraulic lash adjusters may not bleed down properly if the wrong viscosity (SAE rating) oil is used.

3. A third type moves the rocker arm directly through a hydraulic lifter.
4. In the fourth design, some newer engines have the hydraulic adjustment in the rocker arm and are commonly called **hydraulic lash adjusters (HLA).** ● **SEE FIGURE 32–32**.

CAMSHAFT SPECIFICATIONS

DURATION **Camshaft duration** is the number of degrees of *crankshaft* (not camshaft) rotation for which a valve is lifted off the seat.

The specification for duration can be expressed by several different methods, which must be considered when comparing one cam with another. The three most commonly used methods include:

1. **Duration of valve opening at zero lash (clearance).** If a hydraulic lifter is used, the lash is zero. If a solid lifter is used, this method of expression refers to the duration of the opening of the valve after the specified clearance (lash) between the rocker arm and the valve stem tip has been closed.
2. **Duration at 0.05 in. lifter (tappet) lift.** Because this specification method eliminates all valve lash clearances and compensates for lifter (tappet) styles, it is the preferred method to use when

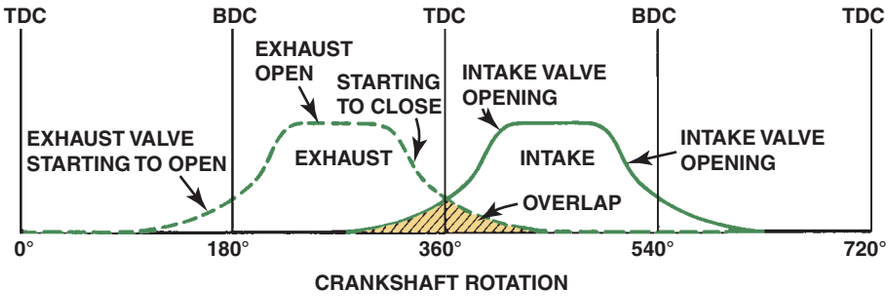


FIGURE 32–33 Graphic representation of a typical camshaft showing the relationship between the intake and exhaust valves. The shaded area represents the overlap period of 100 degrees.

comparing one camshaft with another. Another method used to specify duration of some factory camshafts is to specify crankshaft duration at 0.01 in. lifter lift. The important point to remember is that the technician must be sure to use equivalent specification methods when comparing or selecting camshafts.

NOTE: Fractions of a degree are commonly expressed in units called minutes (′). Sixty (60) minutes equal one degree (1°). For example, 45′ = 3/4 degree, 30′ = 1/2 degree, and 15′ = 1/4 degree.

3. **SAE camshaft specifications.** SAE's recommended practice is to measure all valve events at 0.006 in. (0.15 mm) valve lift. This method differs from the usual method used by vehicle or camshaft manufacturers. Whenever comparing valve timing events, be certain that the exact same methods are used on all camshafts being compared.

VALVE OVERLAP

Another camshaft specification is the number of degrees of overlap. **Valve (camshaft) overlap** is the number of degrees of crankshaft rotation during which both intake and exhaust valves are open. In other words, overlap occurs at the beginning of the intake stroke and at the end of the exhaust stoke. All camshafts provide for some overlap to improve engine performance and efficiency, especially at higher engine speeds.

- A lower amount of overlap results in smoother idle and low-engine speed operation, but it also means that a lower amount of power is available at higher engine speeds.
- A greater valve overlap causes rougher engine idle, with decreased power at low speeds, but it also means that high-speed power is improved.

Example 1: A camshaft with 50 degrees (or less) of overlap may be used in an engine in which low-speed torque and smooth idle qualities are desired. Engines used with overdrive automatic transmissions benefit from the low-speed torque and fuel economy benefits of a small-overlap cam.

Example 2: A camshaft with 100 degrees of overlap is more suitable for use with a manual transmission, with which high-RPM power is desired. An engine equipped with a camshaft with over 100 degrees of overlap tends to idle roughly and exhibit poorer low-engine speed response and lowered fuel economy. ● **SEE FIGURE 32–33**.

CALCULATING VALVE OVERLAP

An engine features a camshaft where the intake valve starts to open at 19 degrees before top dead center (BTDC) and the exhaust valve is open until 22 degrees after top dead center (ATDC).

To determine overlap, total the number of degrees for which the intake valve is open BTDC (19 degrees) and the number of degrees for which the exhaust valve is open ATDC (22 degrees):

Valve overlap = 19 + 22 = 41 degrees

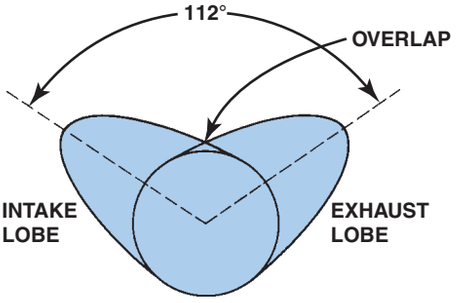


FIGURE 32–34 As the lobe center angle decreases, the overlap increases, with no other changes in the lobe profile lift and duration.

LOBE CENTERS

Another camshaft specification that creates some confusion is the angle of the centerlines of the intake and exhaust lobes. This separation between the centerlines of the intake and exhaust lobes is called:

- **Lobe center**
- **Lobe separation**
- **Lobe displacement angle (LDA)**
- **Lobe spread**

The lob center's measurement is measured in degrees. ● **SEE FIGURE 32–34**.

Two camshafts with identical lift and duration can vary greatly in operation because of variation in the angle between the lobe centerlines.

1. The smaller the angle between the lobe centerlines, the greater the amount of overlap. For example, 108 degrees is a narrower lobe center angle.
2. The larger the angle between the lobe centerlines, the less the amount of overlap. For example, 114 degrees is a wider lobe center angle.

NOTE: Some engines that are equipped with dual overhead camshafts and four valves per cylinder use a different camshaft profile for each of the intake and exhaust valves. For example, one intake valve for each cylinder could have a cam profile designed for maximum low-speed torque. The other intake valve for each cylinder could be designed for higher engine speed power. This results in an engine that is able to produce a high torque over a broad engine speed range.

To find the degree of separation between intake and exhaust lobes of a cam, use the following formula:

$$\frac{\text{(Intake duration + Exhaust duration)}}{4} - \frac{\text{Overlap}}{2} = \text{Number of degrees of separation}$$

● **SEE FIGURE 32–35**.

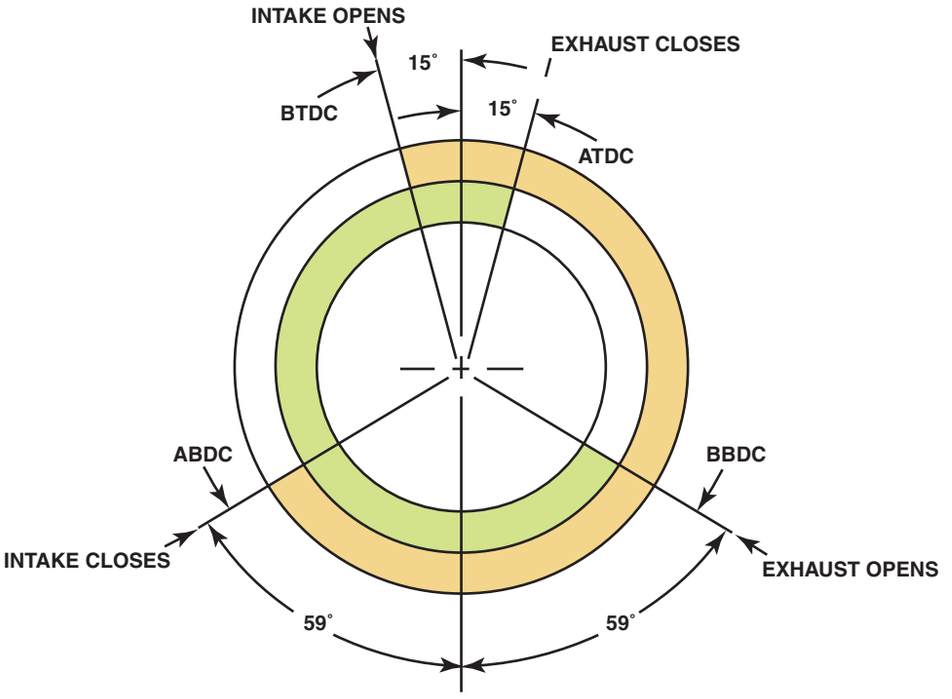


FIGURE 32–35 Typical cam timing diagram.

LOBE SEPARATION ANGLE (LSA)	NARROWER	WIDER
Valve overlap	Greater	Less
Intake valve opening	Sooner	Later
Intake valve closing	Sooner	Later
Exhaust valve opening	Later	Sooner
Exhaust valve closing	Later	Sooner
Idle quality	Worst	Better

CHART 32–1

Changing the lobe separation angle has a major effect on engine operation.

The lobe separation angle can be determined by transferring the intake and exhaust duration and overlap into the formula, as follows:

Intake duration = 15 degrees + 180 degrees + 59 degrees = 254 degrees
Exhaust duration = 59 degrees + 180 degrees + 15 degrees = 254 degrees
Overlap = 15 degrees + 15 degrees = 30 degrees

The lobe separation angle can be calculated by taking the center of the intake lobe use: Intake valve duration plus exhaust valve duration divided by 4 minus the overlap divided by 2.

$$\frac{(254 + 254)}{4} - \frac{30}{2} = \frac{508}{4} - \frac{30}{2} = 127 - 15$$

= 112 degrees (lobe separation angle)

EFFECTS OF LOBE SEPARATION ON VALVE OPERATION

● **SEE CHART 32–1** for what effect a change in lobe separation angle (LSA) has on engine operation.

CAM TIMING SPECIFICATIONS Cam timing specifications are stated in terms of the angle of the crankshaft in relation to top dead center (TDC) or bottom dead center (BDC) when the valves open and close.

- **Intake valve.** The intake valves should open slightly before the piston reaches TDC and starts down on the intake stroke. This ensures that the valve is fully open when the piston travels downward on the intake stroke. The flow through a partially open valve (especially a valve ground at 45 degrees instead of 30 degrees) is greatly reduced as compared with that when the valve is in its fully open position. The intake valve closes after the piston reaches BDC because the air-fuel mixture has inertia, or the tendency of matter to remain in motion. Even after the piston stops traveling downward on the intake stroke and starts upward on the compression stroke, the inertia of the air-fuel mixture can still be used to draw in additional charge. Typical intake valve specifications are to open at 19 degrees before top dead center (BTDC) and close at 46 degrees after bottom dead center (ABDC).
- **Exhaust valve.** The exhaust valve opens while the piston is traveling down on the power stroke, before the piston starts up on the exhaust stroke. Opening the exhaust valve before the piston starts up on the exhaust stroke ensures that the combustion pressure is released and the exhaust valve is mostly open when the piston starts up. The exhaust valve does not close until after the piston has traveled past TDC and is starting down on the intake stroke. Because of inertia of the exhaust, some of the burned gases continue to flow out the exhaust valve after the piston is past TDC. This can leave a partial vacuum in the combustion chamber to start pulling in the fresh charge. This partial vacuum is called **scavenging** and helps bring in a fresh air-fuel charge into the cylinders. Typical exhaust valve specifications are to open at 49 degrees before bottom dead center (BBDC) and close at 22 degrees after top dead center (ATDC).

CAM TIMING CHART During the four strokes of a four-stroke cycle gasoline engine, the crankshaft revolves 720 degrees (it makes two complete revolutions [2 × 360 = 720 degrees]). Camshaft

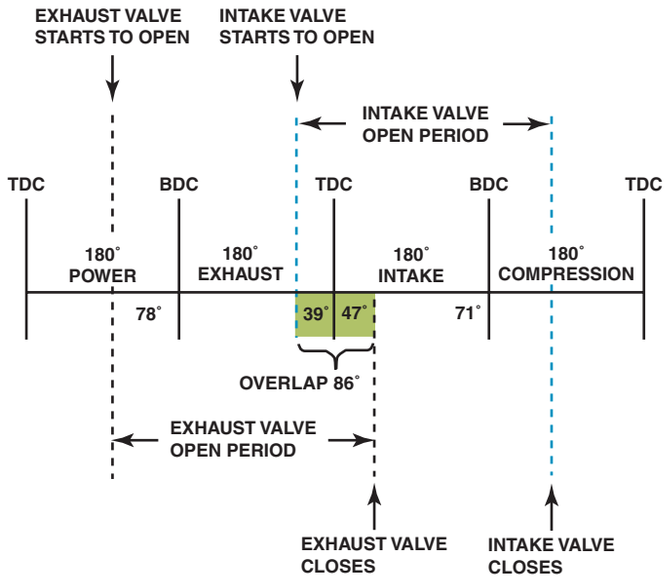


FIGURE 32–36 Typical high-performance camshaft specifications on a straight-line graph. Intake valve duration = 39 + 180 + 71 = 290 degrees. Exhaust valve duration = 7 + 180 + 47 = 234 degrees. Because intake and exhaust valve specifications are different, the camshaft grind is called asymmetrical.

specifications are given in crankshaft degrees. In the example in ● **FIGURE 32–36,** the intake valve starts to open at 39 degrees BTDC, remains open through the entire 180 degrees of the intake stroke, and does not close until 71 degrees ATDC.

Therefore, the duration of the intake valve is 39 degrees + 180 degrees + 71 degrees, or 290 degrees.

The exhaust valve of the example camshaft opens at 78 degrees BBDC and closes at 47 degrees ATDC. When the exhaust valve specifications are added to the intake valve specifications in the diagram, the overlap period is easily observed. The overlap in the example is 39 degrees + 47 degrees, or 86 degrees. The duration of the exhaust valve opening is 78 degrees + 180 degrees + 47 degrees, or 305 degrees. Because the specifications of this camshaft indicate close to and over 300 degrees of duration, this camshaft should only be used where power is more important than fuel economy.

The usual method of drawing a camshaft timing diagram is in a circle illustrating two revolutions (720 degrees) of the crankshaft. ● **SEE FIGURE 32–37** for an example of a typical camshaft timing diagram for a camshaft with the same specifications as the one illustrated in Figure 32–36.

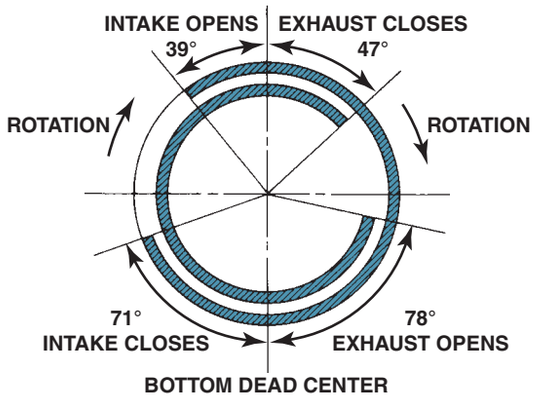


FIGURE 32–37 Typical camshaft valve timing diagram with the same specifications as those shown in Figure 32–36.

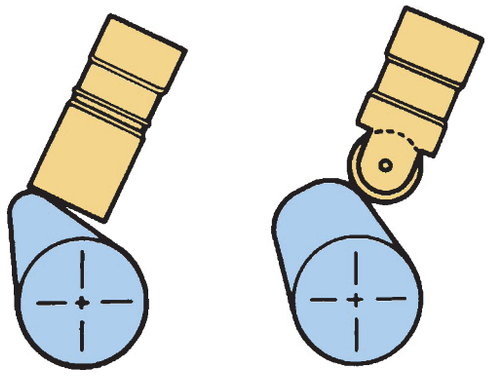


FIGURE 32–38 Older engines used flat-bottom lifters, whereas all engines since the 1990s use roller lifters.

LIFTERS OR TAPPETS

PURPOSE AND FUNCTION Valve lifters or tappets follow the contour or shape of the camshaft lobe. This arrangement changes the rotary cam motion to a reciprocating motion in the valve train. Older-style lifters have a relatively flat surface that slides on the cam.

Most lifters, however, are designed with a roller to follow the cam contour. Roller lifters are used primarily in production engines to reduce valve train friction (by up to 8%). This friction reduction can increase fuel economy and help to offset the greater manufacturing cost. ● **SEE FIGURE 32–38**.

All roller lifters must use a retainer or a guide plate to prevent lifter rotation. The retainer ensures that the roller is kept in line with the cam. ● **SEE FIGURE 32–39**.

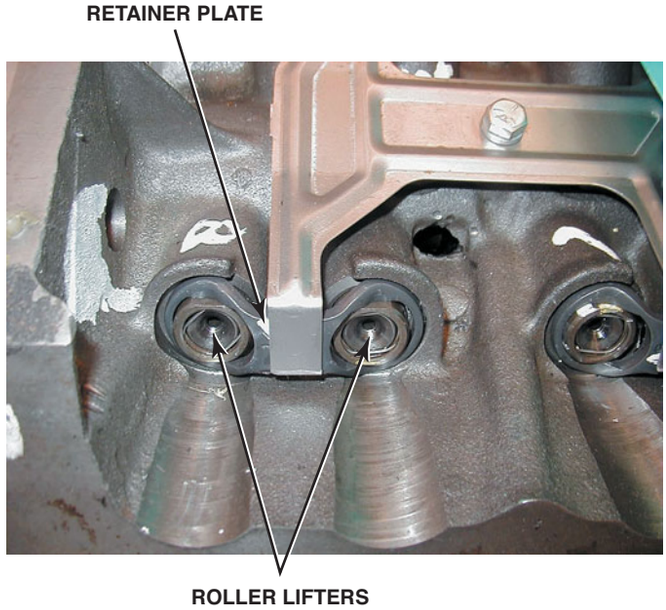


FIGURE 32–39 All roller lifters must use some method to keep the lifter straight and not rotating.

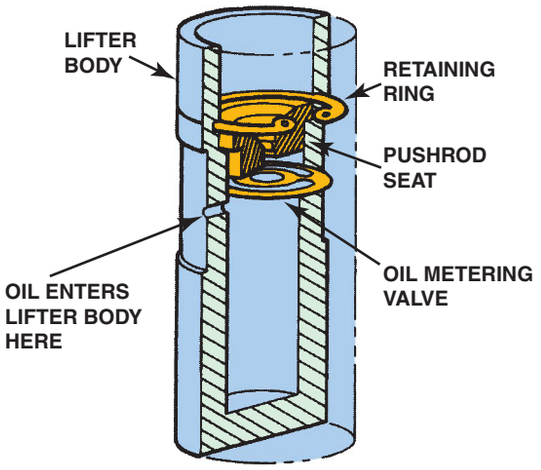


FIGURE 32–40 A cutaway of a flat-bottom solid lifter. Because this type of lifter contains a retaining ring and oil holes, it is sometimes confused with a hydraulic lifter that also contains additional parts. The holes in this lifter are designed to supply oil to the rocker arms through a hollow pushrod.

VALVE LASH Valve train clearance is also called **valve lash,** which is needed to help compensate for thermal expansion and wear. Valve train clearance must not be excessive, or it will cause noise or result in premature failure. Two methods are commonly used to make the necessary valve clearance adjustments.

- One involves a **solid valve lifter,** which can be adjusted mechanically at the rocker arm or by changing shims on certain overhead camshaft engines.
- The other involves a lifter with an automatic hydraulic adjustment built into the lifter body, called a **hydraulic valve lifter.**

SOLID LIFTERS Overhead valve engines with mechanical lifters have an adjustment screw at the pushrod end of the rocker arm or an adjustment nut at the ball pivot. Adjustable pushrods are available for specific applications.

Valve trains using solid lifters must run with some clearance to ensure positive valve closure, regardless of the engine temperature. This clearance is matched by a gradual rise in the cam contour, called a **ramp.** (Hydraulic lifter camshafts do not have this ramp.) The ramp will take up the clearance before the valve begins to open. The camshaft lobe also has a closing ramp to ensure quiet operation.

A lifter is solid in the sense that it transfers motion directly from the cam to the pushrod or valve. Its physical construction is that of a lightweight cylinder, either hollow or with a small-diameter center section and full-diameter ends. In some types that transfer oil through the pushrod, the external appearance is the same as for hydraulic lifters. ● **SEE FIGURE 32–40**.

HYDRAULIC LIFTERS A hydraulic lifter consists primarily of a hollow cylinder body enclosing a closely fit hollow plunger, a check valve, and a pushrod cup. Lifters that feed oil up through the pushrod have a metering disc or restrictor valve located under the pushrod cup. Engine oil under pressure is fed through an engine passage to the exterior lifter body. An undercut portion allows the oil under pressure to surround the lifter body. Oil under pressure goes through holes in the undercut section into the center of the plunger. From there, it goes down through the check valve to a clearance space between the bottom of the plunger and the interior bottom of the lifter body. It fills this space with oil at engine pressure. Slight leakage allowance is designed into the lifter so that the air can bleed out and the lifter can leak down if it should become overfilled.

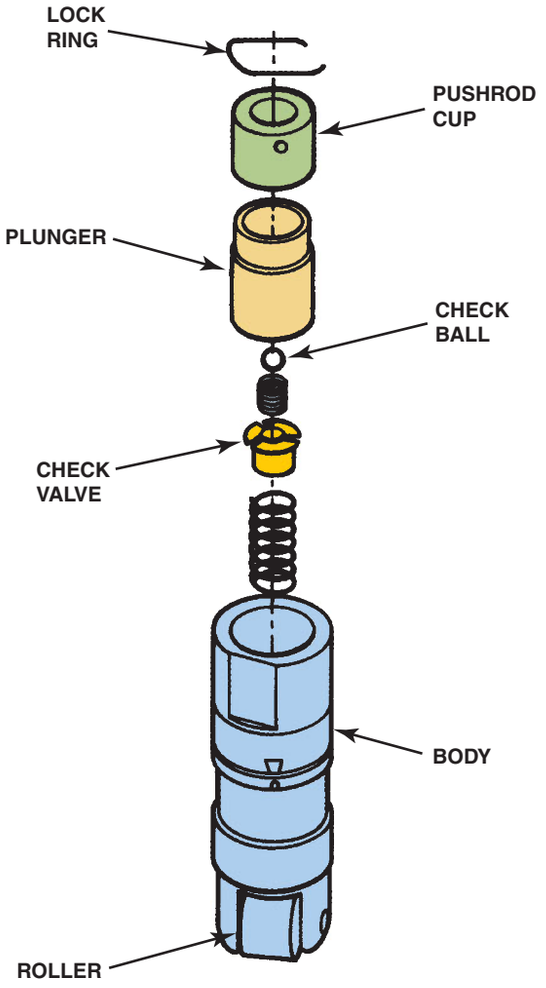


FIGURE 32–41 An exploded view of a hydraulic roller lifter.

The pushrod fits into a cup in the top, open end of the lifter plunger. Holes in the pushrod cup, pushrod end, and hollow pushrod allow oil to transfer from the lifter piston center, past a metering disc or restrictor valve, and up through the pushrod to the rocker arm. Oil leaving the rocker arm lubricates the rocker arm assembly.

As the cam starts to push the lifter against the valve train, the oil below the lifter plunger is squeezed and tries to return to the lifter plunger center. A lifter check valve, either ball or disc type, traps the oil below the lifter plunger. This hydraulically locks the operating length of the lifter. The hydraulic lifter then opens the engine valve as would a solid lifter. When the lifter returns to the base circle of the cam, engine oil pressure again works to replace any oil that may have leaked out of the lifter. ● **SEE FIGURE 32–41**.

The job of the hydraulic lifter is to take up all clearance in the valve train. Occasionally, engines are run at excessive speeds. This tends to throw the valve open, causing **valve float.** During valve float, clearance exists in the valve train. The hydraulic lifter will take up this clearance as it is designed to do. When this occurs, it will keep the valve from closing on the seat, a process called **pump-up.** Pump-up will not occur when the engine is operated in the speed range for which it is designed.

VALVE TRAIN LUBRICATION

The lifters in an overhead valve (OHV) engine are lubricated through oil passages drilled through the block. The engine oil then flows through the lifter, and up through the hollow pushrod where the oil flows to lubricate and cool the rocker arm, valve, and valve spring.

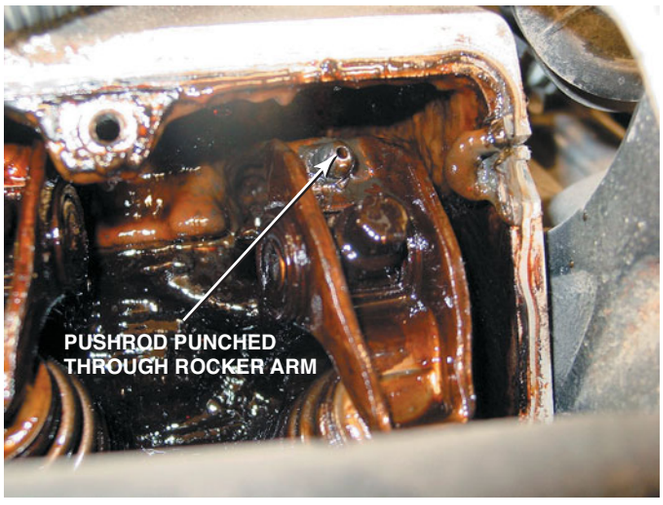


FIGURE 32–42 The cause of a misfire diagnostic trouble code was discovered to be a pushrod that had worn through the rocker arm on a General Motors 3.1 liter V-6 engine.

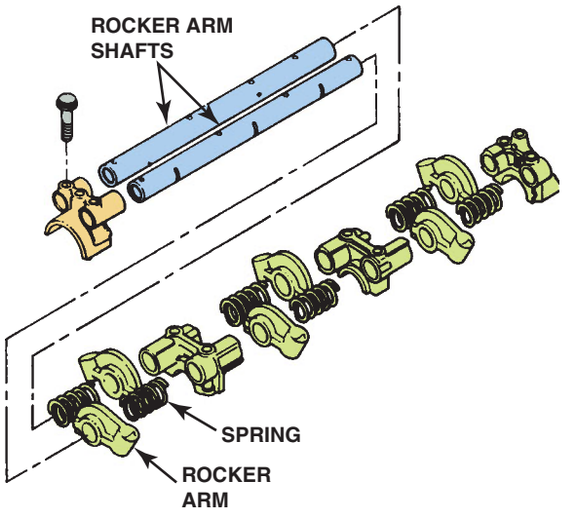


FIGURE 32–43 Shaft-mounted rocker arms are held in position by an assortment of springs, spacers, and washers, which should be removed so that the entire shaft can be inspected for wear.

NOTE: The Chrysler 5.7 liter Hemi engine is opposite because the oil is first sent to the rocker arm through passages in the block and head and then *down* through the hollow pushrod to the lifters. In all other engine designs, the oil flows through the lifter and *up* to the rocker arm through the hollow pushrod.

CAMSHAFT LUBRICATION The camshaft in overhead valve (OHV) engines is lubricated by splash oil thrown up by the movement of the crankshaft counterweights and connecting rods. At low engine speed there is less splash lubrication than occurs at higher engine speeds. This is the major reason why an engine equipped with flat-bottom lifters should be operated at a fast idle of about 2,500 RPM during the first 10 minutes of engine operation. The high idle speed helps ensure that there is enough splash oil to properly lubricate and break in a new camshaft and lifters.

VALVE TRAIN PROBLEM DIAGNOSIS

SYMPTOMS A camshaft with a partially worn lobe is often difficult to diagnose. Sometimes a valve "tick, tick, tick" noise is heard if the cam lobe is worn. The ticking noise can be intermittent, which makes it harder to determine the cause. If the engine has an overhead camshaft (OHC), it is usually relatively easy to remove the cam cover and make a visual inspection of all cam lobes and the rest of the valve train. In an overhead valve (OHV) engine, the camshaft is in the block, where easy visual inspection is not possible. However, it always pays to perform a visual inspection. ● **SEE FIGURE 32–42**.

VALVE NOISE DIAGNOSIS Valve lifters are often noisy, especially at engine start-up. When the engine is off, some valves are open. The valve spring pressure forces the inner plunger to leak down (oil is forced out of the lifter). Therefore, many vehicle manufacturers consider valve ticking at one-half engine speed after start-up to be normal, especially if the engine is quiet after 10 to 30 seconds. Be sure that the engine is equipped with the correct oil filter, and that the filter has an internal check valve. If in doubt, use an original equipment oil filter. If all of the valves are noisy, check the oil level. If low, the oil may have been **aerated** (air mixed with the oil), which would prevent proper operation of the hydraulic lifter. Aeration can be caused by:

- Low oil pressure, which can also cause all valves to be noisy
- The oil level being too high, which can also cause noisy valve lifters (The crankshaft counterweights create foam as they rotate through the oil. This foam can travel through the oiling systems to the lifters. The foam in the lifters prevents normal operation and allows the valves to make noise.)

If the valves are abnormally noisy, remove the valve cover and use a stethoscope to listen or apply pressure to the rocker arms to determine which valves or valve train parts may be causing the noise. Check for all of the following items.

- Valve lash too loose
- Worn camshaft lobe
- Dirty, stuck, or worn lifters
- Worn rocker arm (if the vehicle is so equipped)
- Worn rocker arm shaft (● **SEE FIGURE 32–43**.)
- Worn or bent pushrods (if the vehicle is so equipped)
- Broken or weak valve springs
- Sticking or warped valves

Any of the above can cause the engine to idle roughly, misfire, or even backfire during acceleration.

CAMSHAFT REMOVAL

CAM-IN-BLOCK ENGINES If the engine is of an overhead valve (OHV) design, the camshaft is usually located in the block above the crankshaft. The timing chain and gears (if the vehicle is so equipped) should be removed after the timing chain (gear) cover is removed. Loosen the rocker arms (or rocker arm shaft) and remove the pushrods. Then remove the valve lifters before removing the camshaft from the block.

NOTE: Be sure to keep the pushrods and rocker arms together if they are to be reused.

TECH TIP

The Rotating Pushrod Test

To quickly and easily test whether the camshaft is okay, observe if the pushrods are rotating when the engine is running. This test will work on any overhead valve pushrod engine that uses flat-bottom lifters. Due to the slight angle on the cam lobe and lifter offset, the lifter (and pushrod) should rotate whenever the engine is running. To check, simply remove the rocker arm cover and observe the pushrods when the engine is running. If one or more pushrods are *not* rotating, this camshaft and/or the lifter for that particular valve is worn and needs to be replaced.

REAL WORLD FIX

The Noisy Camshaft

The owner of an overhead cam 4-cylinder engine complained of a noisy engine. After taking the vehicle to several technicians and getting high estimates to replace the camshaft and followers, the owner tried to find a less expensive solution. Finally, another technician replaced the serpentine drive belt on the front of the engine and "cured" the "camshaft" noise for a fraction of the previous estimates.

Remember, accessory drive belts can often make noises similar to valve or bad bearing types of noises. Many engines have been disassembled and/or overhauled because of a noise that was later determined to be from one of the following:

- Loose or defective accessory drive belt(s)
- Loose torque converter-to-flex plate (drive plate) bolts (nuts)
- Defective mechanical fuel pump (if equipped)

MEASURING CAMSHAFTS

TOTAL INDICATOR RUNOUT All camshafts should be checked for straightness by placing them on V-blocks and measuring the cam bearings for runout by using a dial indicator. The maximum **total indicator runout (TIR)** (also called total indicated runout) should be less than 0.002 in. (0.05 mm).

CAM LOBE HEIGHT Sometimes the camshaft lobe height needs to be measured to verify the exact camshaft that is installed in the engine. This can be done by attaching a dial indicator and then slowly rotating the engine while observing the indicator and comparing the measurement to factory specifications. ● **SEE FIGURE 32–44**.

SELECTING A CAMSHAFT

DETERMINING ENGINE USAGE For stock rebuilds, use a replacement camshaft with the same specifications as the engine had from the factory for like-new performance. However, if more power

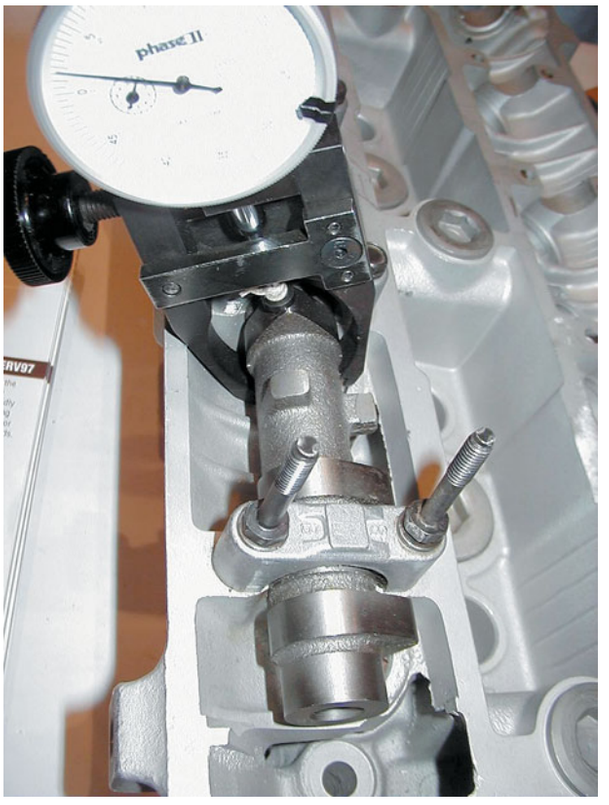


FIGURE 32–44 A dial indicator being used to measure cam lobe height.

TECH TIP

Hot Lifter in 10 Minutes?

A technician working at a shop discovered a noisy (defective) valve lifter on an older Chevrolet small block V-8. Another technician questioned how long it would take to replace the lifter and was told, "Less than an hour"! (The factory flat rate was much longer than one hour.) Ten minutes later the repair technician handed the questioning technician a hot lifter that had been removed from the engine. The lifter was removed using the following steps.

1. The valve cover was removed.
2. The rocker arm and pushrod for the affected valve were removed.
3. The distributor was removed.
4. A strong magnet was fed through the distributor opening into the valley area of the engine. (If the valve lifter is not mushroomed or does not have varnish deposits, the defective lifter can be lifted up and out of the engine; remember, the technician was working on a new vehicle.)
5. A replacement lifter was attached to the magnet and fed down the distributor hole and over the lifter bore.
6. The pushrod was used to help guide the lifter into the lifter bore.

After the lifter preload was adjusted and the valve cover was replaced, the vehicle was returned to the customer in less than one hour.

COMMON USAGE	SEAT DURATION (IN DEGREES)	LIFT (IN INCHES)	DURATION @ 0.05 IN. (IN DEGREES)	CHARACTERISTICS
Street	246 to 254	0.4	192 to 199	Smooth idle; power = idle to 4500 RPM
Street	262	0.432	207	Broad power range, smooth idle; power = idle to 4800 RPM
Street	266	0.441	211	Good idle for 350 cu. in. engines; power = idle to 5200 RPM
Street/drag strip	272	0.454	217	Low idle; power = idle to 5500 RPM
Street/race track	290	0.5	239	Shaky idle; power = idle to 5500 to 6500 RPM

CHART 32–2

A comparison showing the effects of valve timing and lift on engine performance.

DRIVING CONDITION	CHANGE IN CAMSHAFT POSITION	OBJECTIVE	RESULT
Idle	No change	Minimize valve overlap	Stabilize idle speed
Light engine load	Retard valve timing	Decrease valve overlap	Stable engine output
Medium engine load	Advance valve timing	Increase valve overlap	Better fuel economy with lower emissions
Low to medium RPM with heavy load	Advance valve timing	Advance intake valve closing	Improve low to midrange torque
High RPM with heavy load	Retard valve timing	Retard intake valve closing	Improve engine output

CHART 32–3

The purpose for varying the cam timing includes providing for more engine torque and power over a wide engine speed and load range.

is desired, then many engine builders will want to select a different camshaft than the stock version.

A common mistake of beginning engine builders is to install a camshaft with too much duration for the size of the engine. This extended duration of valve opening results in a rough idle and low manifold vacuum, which causes lack of low-speed power.

For example, a hydraulic cam with duration of greater than 225 degrees at 0.05 in. lift for a 350 cu. in. engine will usually not be suitable for street driving. **Seat duration** is the number of degrees of crankshaft rotation that the valve is off the seat. ● **SEE CHART 32–2.**

Check with the camshaft manufacturer for their recommendation for the best camshaft to use. Be prepared to furnish them with the following information.

- Engine make and size
- Weight of the vehicle
- Type of transmission
- Final drive gear ratio
- Intended use of the vehicle

VARIABLE VALVE TIMING

PURPOSE AND FUNCTION Conventional camshafts are permanently synchronized to the crankshaft so that they operate the valves at a specific point in each combustion cycle. In an engine, the intake valve opens slightly before the piston reaches the top of the cylinder and closes about 60 degrees after the piston reaches the bottom of the stroke on every cycle, regardless of the engine speed or load.

On newer engines, the camshaft can have the capability of a variable valve-timing feature that changes the camshaft specifications during different operating modes. For example, many vehicle manufacturers use three basic types of variable valve timing.

1. Exhaust camshaft variable action only on overhead camshaft engines, such as on many inline 4- and 6-cylinder engines
2. Intake and exhaust camshaft variable action on both camshafts used in many engines
3. Changing the relationship of the camshaft to the crankshaft, in overhead valve cam-in-block engines

Variable-cam timing allows the valves to be operated at different points in the combustion cycle, to improve performance. ● **SEE CHART 32–3.**

Variable camshaft timing is used on engines from the following vehicle manufacturers.

- General Motors 4-, 5-, 6-, and 8-cylinder engines
- BMW
- Chrysler
- Ford
- Nissan/Infinity
- Toyota/Lexus

On a system that controls the intake camshaft only, the camshaft timing is advanced at low engine speed, closing the intake valves earlier to improve low RPM torque. At high engine speeds, the camshaft is retarded by using engine oil pressure against a helical gear to rotate the camshaft. When the camshaft is retarded, the intake valve closing is delayed, improving cylinder filling at higher engine speeds. Variable cam timing can be used to control exhaust cam timing only. Engines that use this system, such as the 4.2 liter GM inline 6-cylinder engines, can eliminate the exhaust gas recirculation (EGR) valve because the computer can close the exhaust valve sooner than normal, trapping some exhaust gases in the combustion chamber and therefore eliminating the need for an EGR valve. Some engines use variable camshaft timing on both intake and exhaust cylinder cams.

OPERATION The camshaft position actuator **oil control valve (OCV)** directs oil from the oil feed in the head to the appropriate

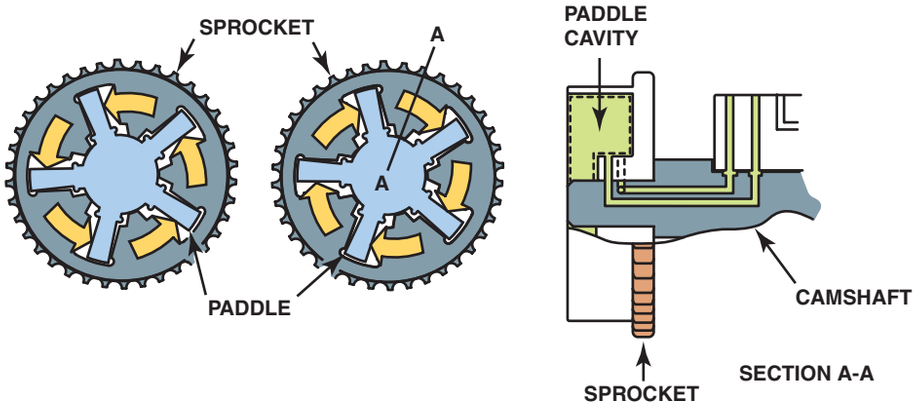


FIGURE 32–45 Camshaft rotation during advance and retard.

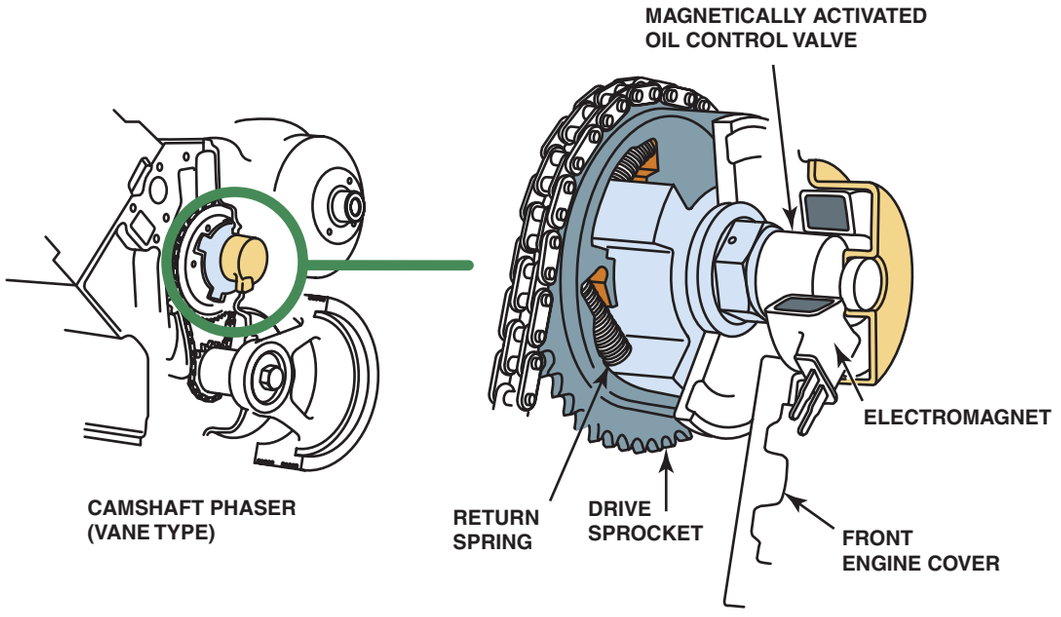


FIGURE 32–46 The camshaft is rotated in relation to the crankshaft by the PCM to provide changes in valve timing.

camshaft position actuator oil passages. There is one OCV for each camshaft position actuator. The OCV is sealed and mounted to the front cover. The ported end of the OCV is inserted into the cylinder head with a sliding fit. A filter screen protects each OCV oil port from any contamination in the oil supply.

The camshaft position actuator is mounted to the front end of the camshaft, and the timing notch in the nose of the camshaft aligns with the dowel pin in the camshaft position actuator to ensure proper cam timing and camshaft position actuator oil hole alignment. ● **SEE FIGURE 32–45**.

OHV VARIABLE TIMING The variable valve timing system uses an electronically controlled, hydraulic gear-driven cam phaser that can alter the relationship of the camshaft from 15 degrees retard to 25 degrees advance (40 degrees overall) relative to the crankshaft. By using **variable valve timing (VVT),** engineers were able to eliminate the EGR valve. The VVT also works in conjunction with an active intake manifold that gives the engine a broader torque curve.

A valve in the intake manifold creates a longer path for intake air at low speeds, improving combustion efficiency and torque output. At higher speed, the valve opens and creates a shorter air path for maximum power production. ● **SEE FIGURE 32–46**.

CAMSHAFT PHASING CHANGED	IMPROVES
Exhaust cam phasing	Reduces exhaust emissions
Exhaust cam phasing	Increases fuel economy (reduced pumping losses)
Intake cam phasing	Increases low-speed torque
Intake cam phasing	Increases high-speed power

CHART 32–4

Changing the exhaust cam timing mainly helps reduce exhaust emissions, whereas changing the intake cam timing mainly helps the engine produce increased power and torque.

Varying the exhaust and/or the intake camshaft position allows for reduced exhaust emissions and improved performance. ● **SEE CHART 32–4**.

By varying the exhaust cam phasing, vehicle manufacturers are able to meet newer NOx reduction standards and eliminate the exhaust gas recirculation (EGR) valve. Also by using exhaust cam phasing, the powertrain control module (PCM) can close the exhaust valves sooner than usual, thereby trapping some exhaust gases in

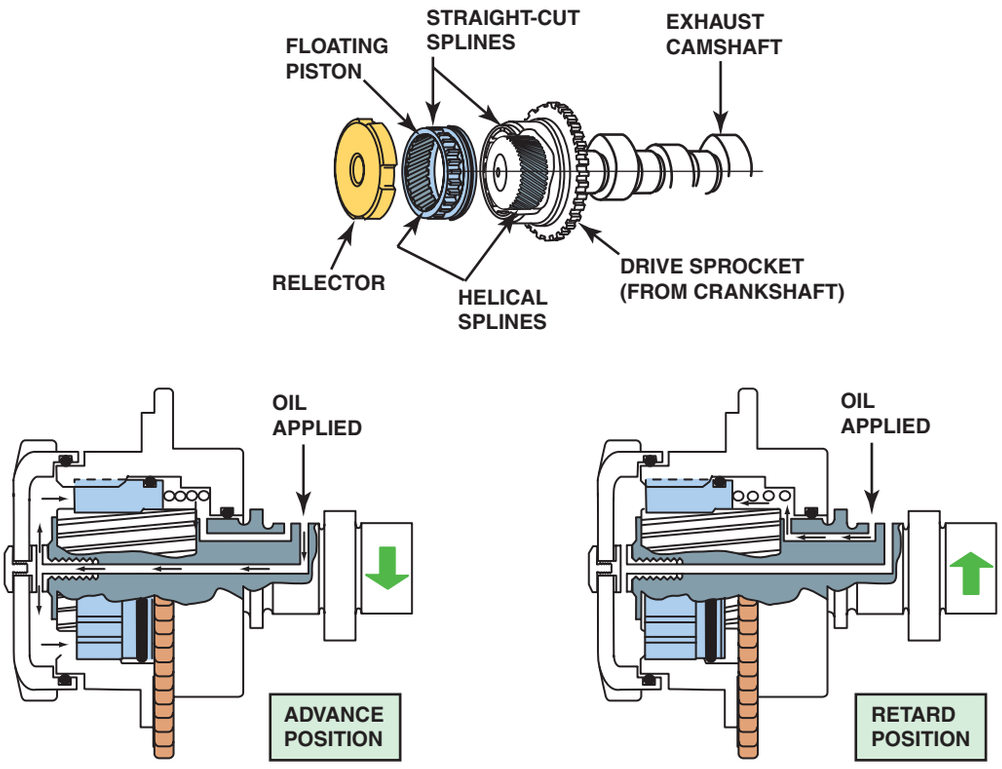


FIGURE 32–47 Spline cam phaser assembly.

the combustion chamber. Manufacturers use one or two actuators that allow the camshaft piston to change by up to 50 degrees in relation to the crankshaft position.

The two types of cam phasing devices commonly used are:

- **Spline phaser.** Used on overhead camshaft (OHC) engines
- **Vane phaser.** Used on overhead camshaft (OHC) and overhead valve (OHV) cam-in-block engines

SPLINE PHASER SYSTEM

The spline phaser system is also called the **valve cam phaser (VCP)** and consists of the following components.

- Engine control module (ECM)
- Four-way pulse-width-modulated (PWM) control valve
- Cam phaser assembly
- Camshaft position (CMP) sensor

● **SEE FIGURE 32–47**.

SPLINE PHASER SYSTEM OPERATION

On most engines, the pulse-width-modulated (PWM) control valve is located on the front of the cylinder head. Oil pressure is regulated by the control valve and then directed to the ports in the cylinder head leading to the camshaft and cam phaser position. The cam phaser is located on the exhaust cams and is part of the exhaust cam sprocket. When the PCM commands an increase in oil pressure, the piston is moved inside the cam phaser and rides along the helical splines, which compresses the coil spring. This movement causes the cam phaser gear and the camshaft to move in an opposite direction, thereby retarding the cam timing. ● **SEE FIGURE 32–48**.

NOTE: A unique cam-within-a-cam is used on 2008 and newer Dodge Viper V-10 OHV engines. This design allows the exhaust lobes to be moved by up to 36 degrees to improve idle quality and reduction of exhaust emissions.

TECH TIP

Check the Screen on the Control Valve If There Are Problems

If a NOx emission failure at a state inspection occurs or a diagnostic trouble code is set related to the cam timing, remove the control valve and check for a clogged oil screen. A lack of regular oil changes can cause the screen to become clogged, thereby preventing proper operation. A rough idle is a common complaint because the spring may not be able to return the camshaft to the idle position after a long highway trip. ● **SEE FIGURE 32–49**.

VANE PHASER SYSTEM ON AN OVERHEAD CAMSHAFT ENGINE

The vane phaser system used on overhead camshaft (OHC) engines uses a camshaft piston (CMP) sensor on each camshaft. Each camshaft has its own actuator and its own *oil control valve* (OCV). Instead of using a piston along a helical spline, the vane phaser uses a rotor with four vanes, which is connected to the end of the camshaft. The rotor is located inside the stator, which is bolted to the cam sprocket. The stator and rotor are not connected. Oil pressure is controlled on both sides of the vanes of the rotor, which creates a hydraulic link between the two parts. The oil control valve varies the balance of pressure on either side of the vanes and thereby controls the position of the camshaft. A return spring is used under the reluctor of the phaser to help return it to the home or zero degrees position. ● **SEE FIGURE 32–50**.

MAGNETICALLY CONTROLLED VANE PHASER

On this type, the PCM controls a magnetically controlled vane phaser by using a 12 volt pulse-width-modulated (PWM) signal to an

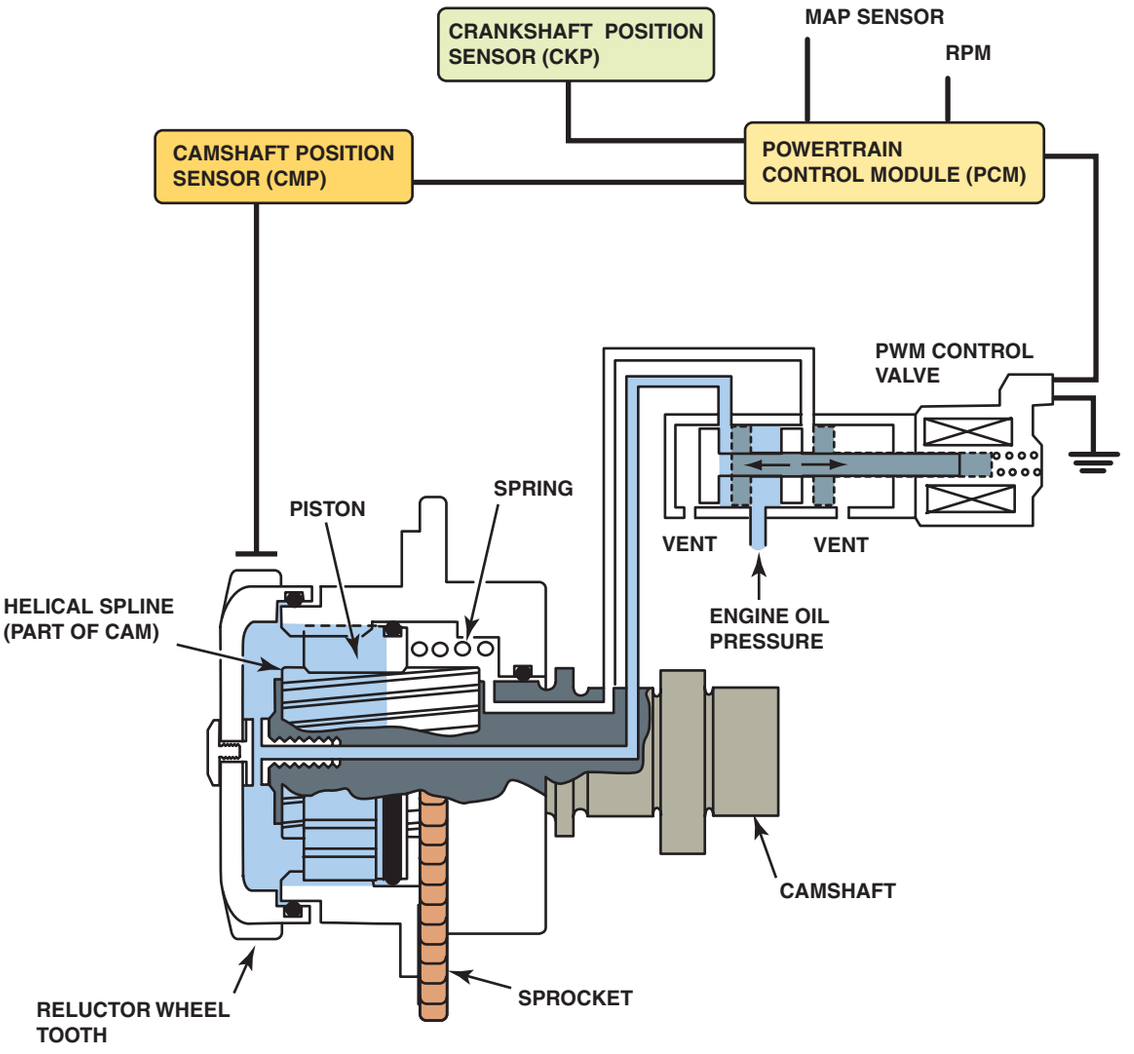


FIGURE 32–48 A spline phaser.

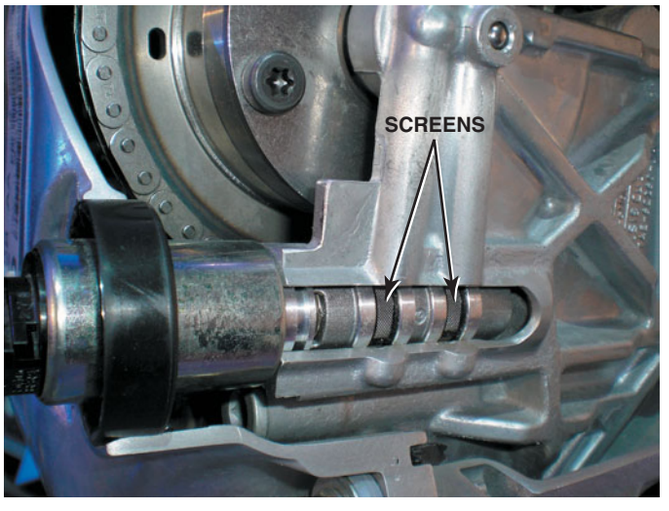


FIGURE 32–49 The screen(s) protect the solenoid valve from dirt and debris that can cause the valve to stick. This fault can set a P0017 diagnostic trouble code (crankshaft position/camshaft position correlation error).

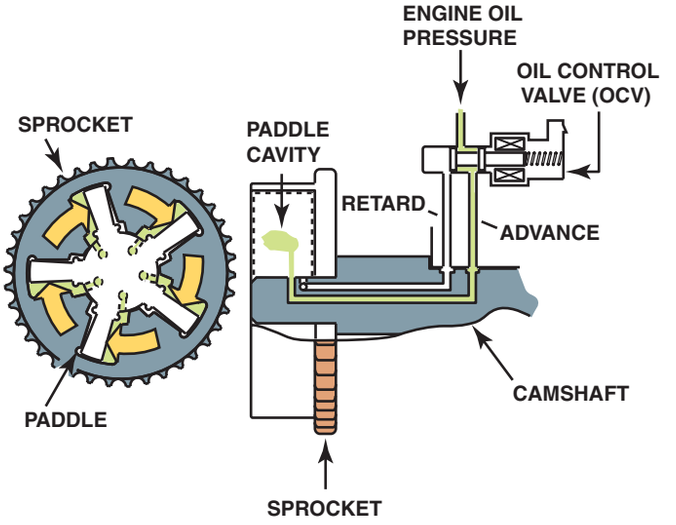


FIGURE 32–50 A vane phaser is used to move the camshaft, using changes in oil pressure from the oil control valve.

electromagnet, which operates the oil control valve (OCV). A magnetically controlled vane phaser is used on many double overhead camshaft engines on both the intake and exhaust camshafts. The OCV directs pressurized engine oil to either advance or retard chambers of the camshaft actuator to change the camshaft position in relation to the crankshaft position. ● **SEE FIGURE 32–51**.

The following occurs when the pulse width is changed.

- **0% pulse width.** The oil is directed to the advance chamber of the exhaust camshaft actuator and the retard chamber of the intake camshaft activator.
- **50% pulse width.** The computer is holding the camshaft steady in the desired position.

- **100% pulse width.** The oil is directed to the retard chamber of the exhaust camshaft actuator and the advance chamber of the intake camshaft actuator.

The cam phasing is continuously variable with a range from 40 degrees for the intake camshaft and 50 degrees for the exhaust camshaft. The ECM uses the following sensors to determine the best position of the camshaft for maximum power and lowest possible exhaust emissions.

- Engine speed (RPM)
- MAP sensor
- Crankshaft position (CKP)
- Camshaft position (CMP)
- Barometric pressure (BARO)

CAM-IN-BLOCK ENGINE CAM PHASER

Overhead valve engines that use a cam-in-block design use a magnetically controlled cam phaser to vary the camshaft in relation to the crankshaft. This type of phaser is not capable of changing the duration of valve opening or valve lift.

Inside the camshaft actuator is a rotor with vanes that are attached to the camshaft. Oil pressure is supplied to the vanes, which causes the camshaft to rotate in relation to the crankshaft. The camshaft actuator solenoid valve directs the flow of oil to either the advance or retard side vanes of the actuator. ● **SEE FIGURE 32–52**.

The ECM sends a pulse-width-modulated (PWM) signal to the camshaft actuator magnet. The movement of the pintle is used to direct oil flow to the actuator. The higher the duty cycle is, the greater the movement in the valve position and change in camshaft timing.

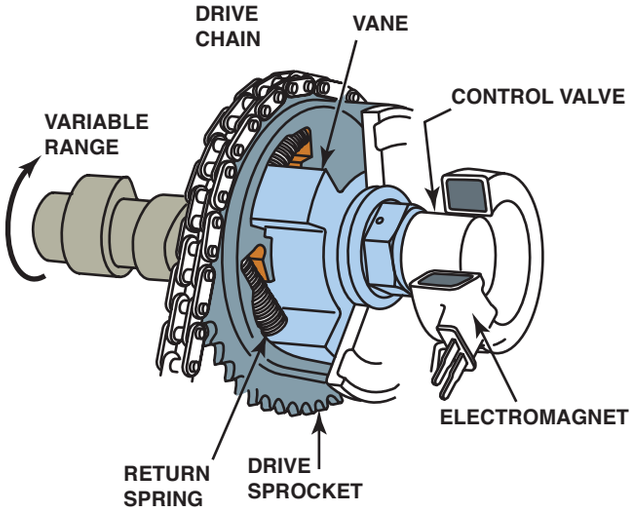


FIGURE 32–51 A magnetically controlled vane phaser.

NOTE: When oil pressure drops to zero when the engine stops, a spring-loaded locking pin is used to keep the camshaft locked to prevent noise at engine start. When the engine starts, oil pressure releases the locking pin.

VARIABLE LIFT AND CYLINDER DEACTIVATION SYSTEMS

VARIABLE VALVE LIFT SYSTEMS

Variable camshafts include the system used by Honda/Acura, called **variable valve timing and lift electronic control (VTEC).** This system uses two different camshafts for low and high RPM. When the engine is operating at idle and speeds below about 4000 RPM, the valves are opened by camshafts that are optimized by maximum torque and fuel economy. When engine speed reaches a predetermined speed, depending on the exact make and model, the computer turns on a solenoid, which opens a spool valve. When the spool valve opens, engine oil pressure pushes against pins that lock the three intake rocker arms together. With the rocker arms lashed, the valves must follow the profile of the high RPM cam lobe in the center. This process of switching from the low-speed camshaft profile to the high-speed profile takes about 100 milliseconds (0.1 sec). ● **SEE FIGURES 32–53 AND 32–54**.

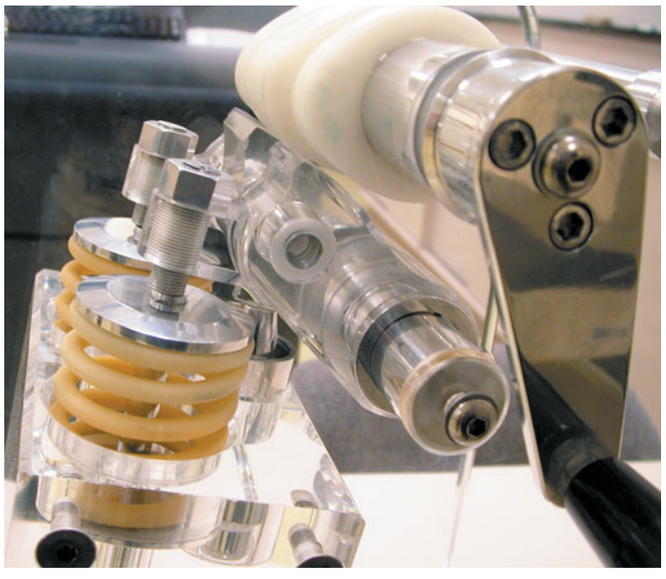


FIGURE 32–53 A plastic mockup of a Honda VTEC system that uses two different camshaft profiles—one for low-speed engine operation and the other for high speed.

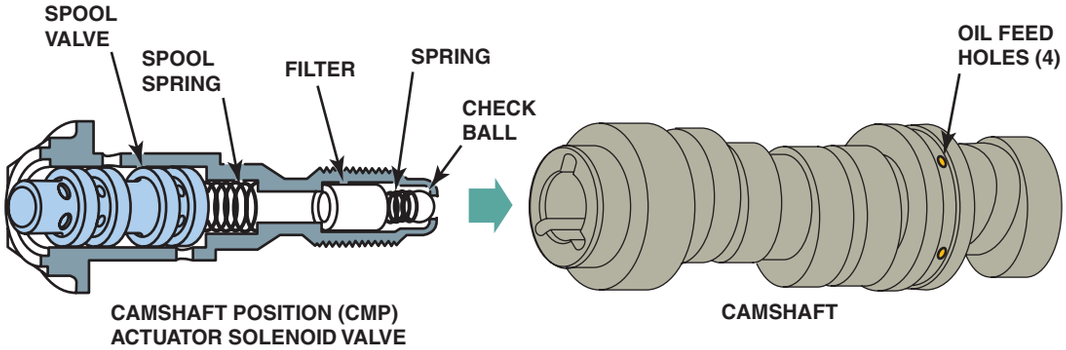


FIGURE 32–52 A camshaft position actuator used in a cam-in-block engine.

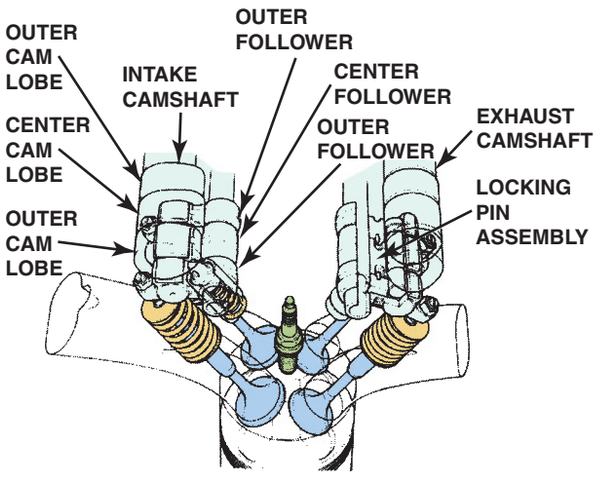


FIGURE 32–54 Engine oil pressure is used to switch cam lobes on a VTEC system.

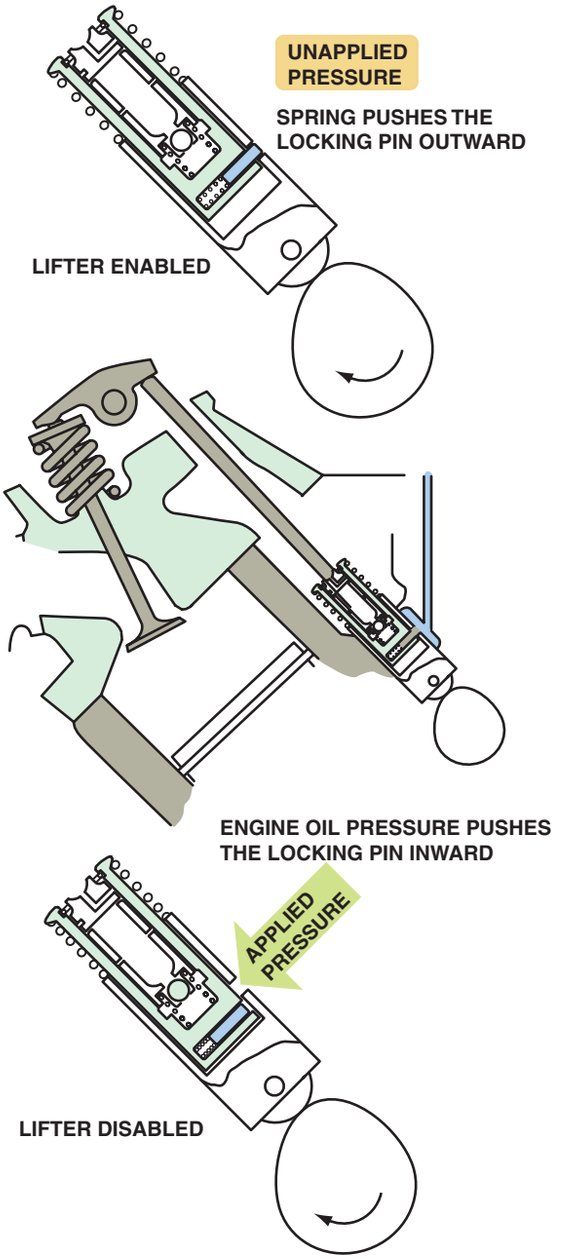


FIGURE 32–55 Oil pressure applied to the locking pin causes the inside of the lifter to freely move inside the outer shell of the lifter, thereby keeping the valve closed.

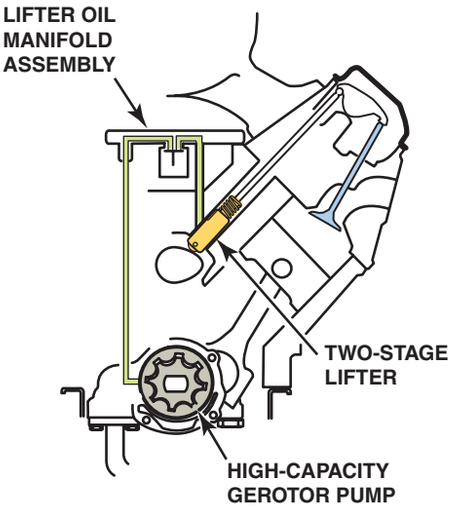


FIGURE 32–56 Active fuel management includes many different components and changes to the oiling system, which makes routine oil changes even more important on engines equipped with this system.

CYLINDER DEACTIVATION SYSTEMS

Some engines are designed to operate on four of eight cylinders, or three of six cylinders, during low load conditions to improve fuel economy.

The powertrain control module (PCM) monitors engine speed, coolant temperature, throttle position, and load, and determines when to deactivate cylinders. The key to this process is the use of two-stage hydraulic valve lifters. In normal operation, the inner and outer lifter sleeves are held together by a pin and operate as an assembly. When the computer determines that the cylinder can be deactivated, oil pressure is delivered to a passage, which depresses the pin and allows the outer portion of the lifter to follow the contour of the cam while the inner portion remains stationary, keeping the valve closed. The electronic operation is achieved through the use of the lifter oil manifold containing solenoids to control the oil flow, which is used to activate or deactivate the cylinders. General Motors once called this system "displacement on demand (DOD)," but now calls it "active fuel management." Chrysler calls this a "multiple displacement system (MDS)." ● **SEE FIGURES 32–55 AND 32–56**.

REVIEW QUESTIONS

1. Explain why the lift and duration and lobe displacement angle (LDA) dimension of the camshaft determine the power characteristics of the engine.
2. List the terms that mean the same as lobe displacement angle (LDA).
3. Describe the operation of a hydraulic lifter.
4. Describe how variable valve timing works.

CHAPTER QUIZ

1. The camshaft makes _____ for every revolution of the crankshaft.
   a. One-quarter revolution **c.** One revolution
   b. One-half revolution **d.** Two revolutions
2. Flat-bottom valve lifters rotate during operation because of the _____ of the camshaft.
   a. Taper of the lobe **c.** Chain tensioner
   b. Thrust plate **d.** Bearings
3. If lift and duration remain constant and the lobe center angle decreases, then _____.
   a. The valve overlap decreases
   b. The effective lift increases
   c. The effective duration increases
   d. The valve overlap increases
4. Which timing chain type is also called a "silent chain"?
   a. Roller **c.** Flat link
   b. Morse **d.** Both b and c
5. Two technicians are discussing variable valve timing. Technician A says that changing the exhaust valve timing helps reduce exhaust emissions. Technician B says that changing the intake valve timing helps increase low-speed torque. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. Many technicians always use new pushrods because _____.
   a. They are less expensive to buy than clean
   b. All of the dirt cannot be cleaned out from the hollow center
   c. They wear at both ends
   d. They shrink in length if removed from an engine
7. A DOHC V-6 has how many camshafts?
   a. 4 **c.** 2
   b. 3 **d.** 1
8. The intake valve opens at 39 degrees BTDC and closes at 71 degrees ABDC. The exhaust valve opens at 78 degrees BBDC and closes at 47 degrees ATDC. Which answer is correct?
   a. Intake valve duration is 110 degrees.
   b. Exhaust valve duration is 125 degrees.
   c. Overlap is 86 degrees.
   d. Both a and b
9. Hydraulic valve lifters can make a ticking noise when the engine is running if _____.
   a. The valve lash is too close
   b. The valve lash is too loose
   c. The lobe centerline is over 110 degrees
   d. Both a and c
10. Hydraulic lifters or hydraulic lash adjusters (HLA) may not bleed down properly and cause an engine miss if _____.
    a. The engine oil is 1 quart low
    b. The wrong API-rated engine oil is used
    c. The wrong SAE-rated engine oil is used
    d. Both a and b

chapter 33

PISTONS, RINGS, AND CONNECTING RODS

OBJECTIVES: **After studying Chapter 33, the reader should be able to:** • Prepare for Engine Repair (A1) ASE certification test content area "C" (Engine Block Diagnosis and Repair). • Describe the purpose and function of pistons, rings, and connecting rods. • Explain how pistons and rods are constructed and what to look for during an inspection. • Discuss connecting rod reconditioning procedures. • Explain how piston rings operate and how to install them on a piston.

KEY TERMS: Back clearance 343 • Balancing bosses (pads) 346 • Barrel face ring 344 • Bleed hole 346 • Blowby 343 • Cam ground 339 • Compression rings 343 • Connecting rod bearing journal 337 • Crankpin 337 • Crank throw 337 • Double knock 341 • Ductile iron 344 • Freewheeling 339 • Full floating 341 • Grooves 337 • Heat dams 339 • Hypereutectic 338 • Interference fit 342 • Lands 337 • Lock rings 342 • Major thrust surface 340 • Oil control ring 343 • Piston 337 • Piston pin 337 • Piston ring expander 350 • Piston rings 337 • Positive twist ring 344 • Reverse twist ring 344 • Ring gap 343 • Scraper ring 344 • Side clearance 343 • Skirt 337 • Slipper skirt 339 • Spit hole 346 • Struts 340 • Taper face ring 344 • Wrist pin 337



FIGURE 33–1 The piston seals the bottom of the combustion chamber and is attached to a connecting rod.

PISTONS

PURPOSE AND FUNCTION

All engine power is developed by burning fuel mixed with air in the combustion chamber. Heat from the combustion causes the burned gas to increase in pressure. The force of this pressure is converted into useful work through the piston, connecting rod, and crankshaft. Therefore, the piston serves three purposes.

1. **Transfers force.** The piston transfers the force of combustion to the crankshaft through the connecting rod.
2. **Seals the combustion chamber.** The piston and piston rings seal the compressed air during the compression stroke and the combustion gases on the power stroke.
3. **Conducts heat.** The piston transfers heat from the combustion chamber to the cylinder walls through the piston rings and to the engine oil through the piston.

PARTS INVOLVED

The **piston** forms a movable bottom to the combustion chamber. ● **SEE FIGURE 33–1.**

The piston is attached to the connecting rod with a **piston pin,** also called **a wrist pin.** The piston pin is allowed to have a rocking movement because of a swivel joint at the piston end of the connecting rod. The crankshaft changes the up-and-down (reciprocating) motion of the pistons into rotary motion. The connecting rod is connected to a part of the crankshaft called a **crank throw, crankpin,** or **connecting rod bearing journal.**

Piston rings seal the small space between the piston and cylinder wall, keeping the pressure above the piston. When the pressure builds up in the combustion chamber, it pushes on the piston. The piston, in turn, pushes on the piston pin and upper end of the connecting rod. The lower end of the connecting rod pushes on the crank throw. This provides the force to turn the crankshaft. As the crankshaft turns, it develops inertia. *Inertia is the force that causes the crankshaft to continue rotating.* This action will bring the piston back to its original position, where it will be ready for the next power stroke. While the engine is running, the combustion cycle keeps repeating as the piston reciprocates (moves up and down) and the crankshaft rotates.

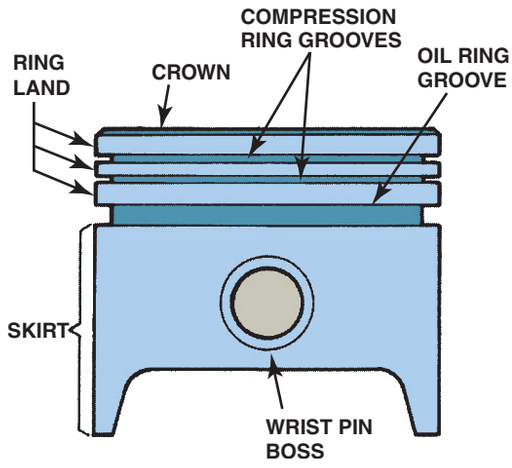


FIGURE 33–2 All pistons share the same parts in common.

PISTON OPERATION

When the engine is running, the piston starts at the top of the cylinder. As it moves downward, it accelerates until it reaches a maximum velocity slightly before it is halfway down. The piston comes to a stop at the bottom of the cylinder at 180 degrees of crankshaft rotation. During the next 180 degrees of crankshaft rotation, the piston moves upward. It accelerates to reach a maximum velocity slightly above the halfway point and then comes to a stop at the top of the stroke. Thus, the piston starts, accelerates, and stops twice in each crankshaft revolution.

NOTE: A typical piston in an engine operating at 4000 RPM accelerates from 0 to 60 mph (97 km/h) in about 0.004 second (4 ms) as it travels about halfway down the cylinder.

This reciprocating action of the piston produces large *inertia forces.* Inertia is the force that causes a part that is stopped to stay stopped or a part that is in motion to stay in motion. The lighter the piston can be made, the less inertia force that is developed. Less inertia will allow higher engine operating speeds. For this reason, pistons are made to be as light as possible while still having the strength that is needed.

The piston operates with its top or head exposed to the hot combustion gases, whereas the skirt contacts the relatively cool cylinder wall. This results in a temperature difference of about 275°F (147°C) between the top and bottom of the piston.

PISTON CONSTRUCTION

PISTON RING GROOVES

Piston ring **grooves** are located between the piston head and skirt. The width of the grooves, the width of the **lands** between the ring grooves, and the number of rings are major factors in determining minimum piston height. The outside diameter of the lands is about 0.02 to 0.04 in. (0.5 to 1 mm) smaller than the **skirt** diameter. ● **SEE FIGURE 33–2.**

● **SEE FIGURE 33–3** for an example of how to measure the diameter of a piston.

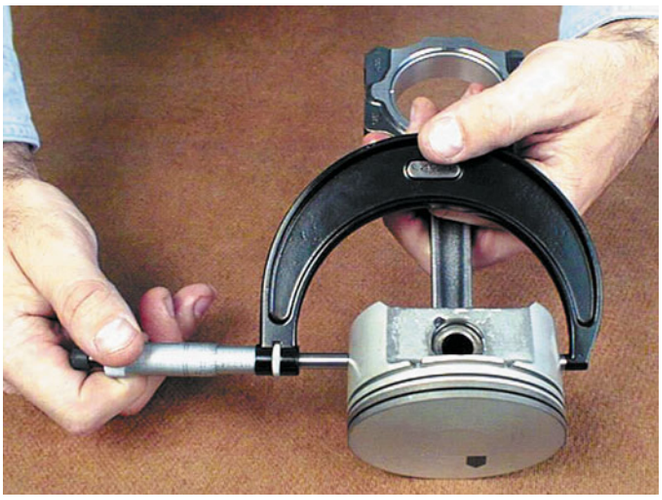


FIGURE 33–3 A piston diameter is measured across the thrust surfaces.



FIGURE 33–4 A cast piston showing the sprues which were used to fill the mold with molten aluminum alloy.

TECH TIP

Piston Weight Is Important!

All pistons in an engine should weigh the same to help ensure a balanced engine. Piston weight becomes a factor when changing pistons. Most aluminum pistons range in weight from 10 to 30 ounces (280 to 850 grams) (1 oz = 28.35 g). *A typical paper clip weighs 1 g.* If the cylinder has been bored, larger replacement pistons are obviously required. If the replacement pistons weigh more, this puts additional inertia loads on the rod bearings. Therefore, to help prevent rod bearing failure on an overhauled engine, the replacement pistons should not weigh more than the original pistons.

CAUTION: Some less expensive replacement cast pistons or high-performance forged pistons are much heavier than the stock pistons, even in the stock bore size. This means that the crankshaft may need heavy metal added to the counterweights of the crankshaft for the engine to be balanced.

For the same reason, if one piston is being replaced, all pistons should be replaced or at least checked and corrected to ensure the same weight.

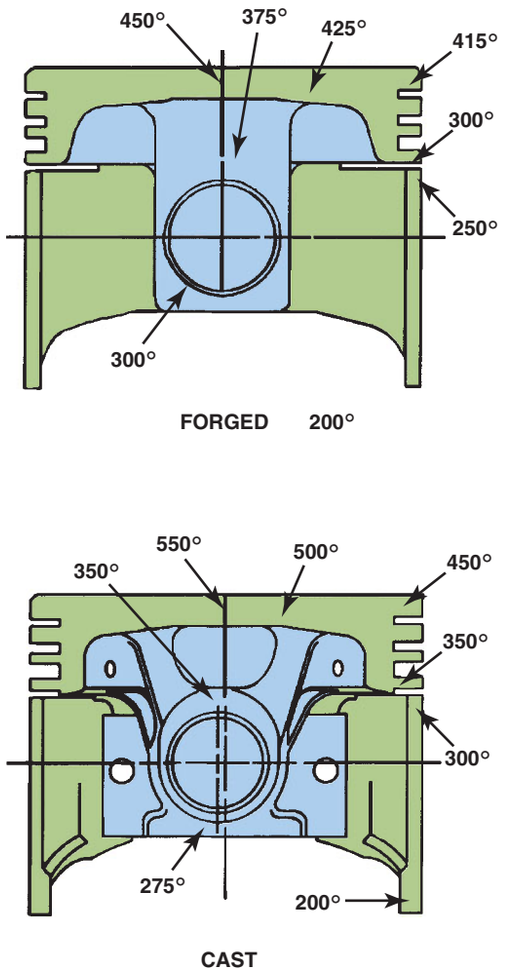


FIGURE 33–5 The top of the piston temperature can be 100°F (38°C) lower on a forged piston compared to a cast piston.

CAST PISTONS Cast aluminum pistons usually are made using *gravity die casting*. In this process, molten aluminum alloy and about 10% silicon are poured into a mold. The silicon is used to increase the strength and help control the expansion of the piston when it gets hot. Other metals used in the aluminum alloy include copper, nickel, manganese, and magnesium. ● **SEE FIGURE 33–4.**

HYPEREUTECTIC PISTONS A standard cast aluminum piston contains about 9% to 12% silicon and is called a *eutectic* piston. To add strength, the silicon content is increased to about 16%, and the resulting piston is called a **hypereutectic** piston. Other advantages of a hypereutectic piston are its 25% weight reduction and lower expansion rate. The disadvantage of hypereutectic pistons is their higher cost, because they are more difficult to cast and machine.

Hypereutectic pistons are commonly used in the aftermarket and as original equipment in many turbocharged and supercharged engines.

FORGED PISTONS High-performance engines need pistons with added strength. Forged pistons have a dense grain structure and are very strong. Forged pistons are often used in turbocharged or supercharged engines. Because forged pistons are less porous than cast pistons, they conduct heat more quickly. Forged pistons generally run about 20% cooler than cast pistons. ● **SEE FIGURE 33–5.**

PISTON HEAD DESIGNS Because the piston head forms a portion of the combustion chamber, its shape is vital to the combustion process. Many newer engines have *flat-top* pistons. Some of these flat-top pistons come so close to the cylinder head that *recesses* are cut in the piston top for valve clearance. Pistons used in high-powered engines may have raised domes or *pop-ups* on the



FIGURE 33–6 Valve reliefs are used to provide valve clearance.

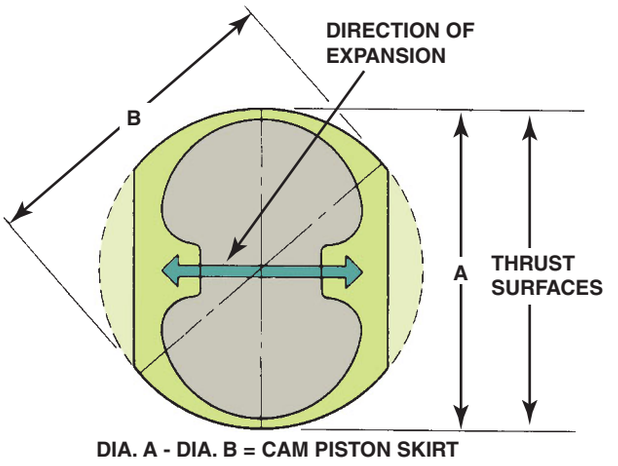


FIGURE 33–7 Piston cam shape. The largest diameter is across the thrust surfaces and perpendicular to the piston pin (labeled A).

piston heads. These are used to increase the compression ratio. Pistons used in other engines may be provided with a depression or a *dish*. The varying depths of the dish provide different compression ratios required by different engine models.

NOTE: Newer engines do not use valve reliefs because this requires that the thickness of the top of the piston be increased to provide the necessary strength. The thicker the top of the piston, the farther down from the top the top piston ring sits. To reduce unburned hydrocarbon (HC) exhaust emissions, engineers attempt to place the top piston ring as close to the top of the piston as possible to prevent the unburned fuel from being trapped (and not burned) between the top of the piston and the top of the top piston ring.

Recesses machined or cast into the tops of the pistons for valve clearance are commonly called:

- Eyebrows
- Valve reliefs
- Valve pockets

The depth of the eyebrows has a major effect on the compression ratio and is necessary to provide clearance for the valves if the timing belt or chain of an overhead camshaft engine should break. Without the eyebrows, the pistons could hit the valves near TDC if the valves are not operating (closing) because of nonrotation of the camshaft. If an engine is designed not to have the pistons hitting the valves, if the timing belt or chain breaks, the engine is called **freewheeling.** ● **SEE FIGURE 33–6.**

SLIPPER SKIRT PISTONS

A **slipper skirt** design piston is shorter on the two sides that are not thrust surfaces. Advantages of using a slipper skirt design include:

- Lighter weight
- Allows for a shorter overall engine height, because the crankshaft counterweights can be closer to the piston when they are at the bottom of the stroke

Most engines today use a slipper skirt piston design.

CAM GROUND PISTONS

Aluminum pistons expand when they get hot. A method of expansion control was devised using a **cam ground** piston skirt. With this design, the piston thrust surfaces closely fit the cylinder, and the piston pin boss diameter is fitted loosely. As the cam ground piston is heated, it expands along the piston pin so that it becomes nearly round at its normal operating temperatures. A cam ground piston skirt is illustrated in ● **FIGURE 33–7.**

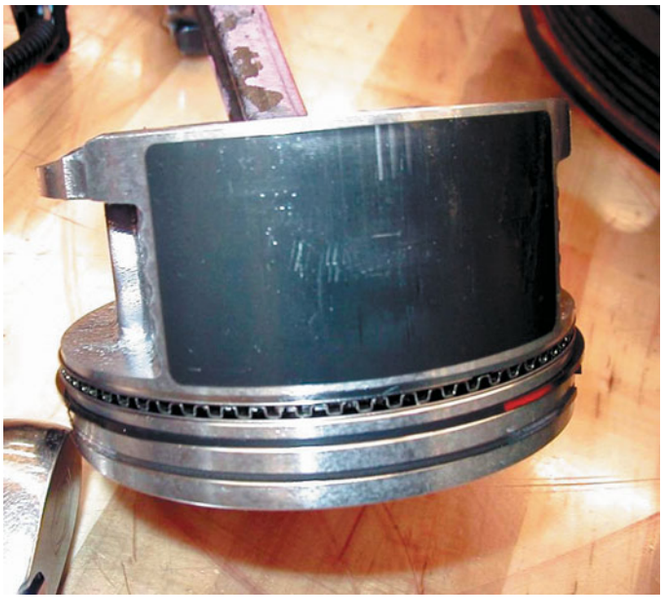


FIGURE 33–8 A moly graphite coating on this piston from a General Motors 3800 V-6 engine helps to prevent piston scuffing.

PISTON FINISH

The finish on piston skirts varies with the manufacturer, but all are designed to help reduce scuffing. Scuffing is a condition where the metal of the piston actually contacts the cylinder wall. When the piston stops at the top of the cylinder, welds or transfer of metal from one part to the other can take place. Scuffing can be reduced by coating the piston skirts with tin 0.0005 in. (0.0125 mm) thick or a moly graphite coating. ● **SEE FIGURE 33–8.**

PISTON HEAD SIZE

The top or head of the piston is smaller in diameter than the rest of the piston. The top of the piston is exposed to the most heat and therefore tends to expand more than the rest of the piston. ● **SEE FIGURE 33–9.**

Most pistons have horizontal separation slots that act as **heat dams.** These slots reduce heat transfer from the hot piston head to the lower skirt. This, in turn, keeps the skirt temperature lower to reduce skirt expansion. Because the slot is placed in the oil ring groove, it can be used for oil drainback and expansion control.

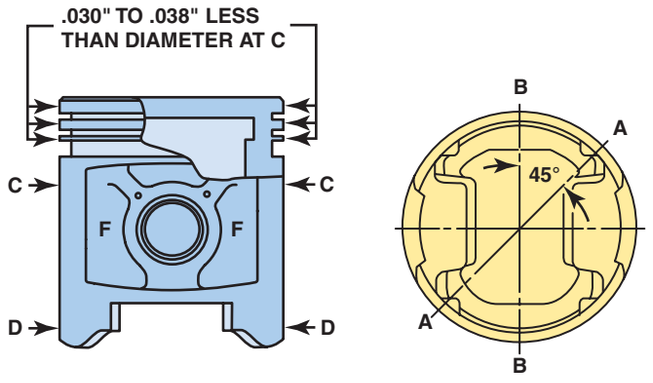


FIGURE 33–9 The head of the piston is smaller in diameter than the skirt of the piston to allow it to expand when the engine is running.

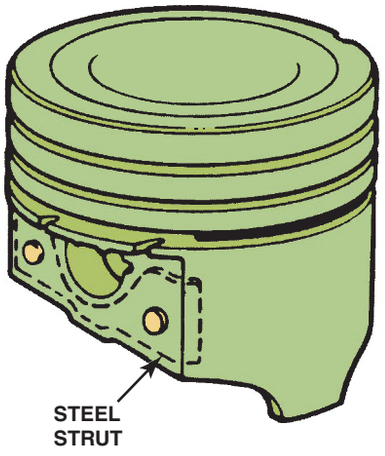


FIGURE 33–10 Steel struts cast inside the piston help control expansion and add strength to the piston pin area.

PISTON STRUT INSERTS

A major development in expansion control occurred when the piston aluminum was cast around two stiff steel **struts.**

- The struts add strength to the piston in the piston pin area where additional strength is needed.
- The struts help control thermal expansion.
- Pistons with steel strut inserts allow good piston-to-cylinder wall clearance at normal temperatures. At the same time, they allow the cold operating clearance to be as small as 0.0005 in. (one-half thousandth of an inch) (0.0127 mm). This small clearance will prevent cold piston slap and noise. A typical piston expansion control strut is visible in ● **FIGURE 33–10.**

PISTON PINS

TERMINOLOGY

Piston pins are used to attach the piston to the connecting rod. Piston pins are also known as *wrist pins* or *gudgeon pins,* a British term. The piston pin transfers the force produced by combustion chamber pressures and piston inertia to the connecting rod. The piston pin is made from high-quality steel in the shape of a tube to make it both strong and light. Sometimes, the interior hole of the piston pin is tapered, so it is large at the ends and small in the middle of the pin. This gives the pin strength that is proportional to the location of the load placed on it. A double-taper hole such as this is more expensive to manufacture, so it is used only where its weight advantage merits the extra cost. ● **SEE FIGURE 33–11.**

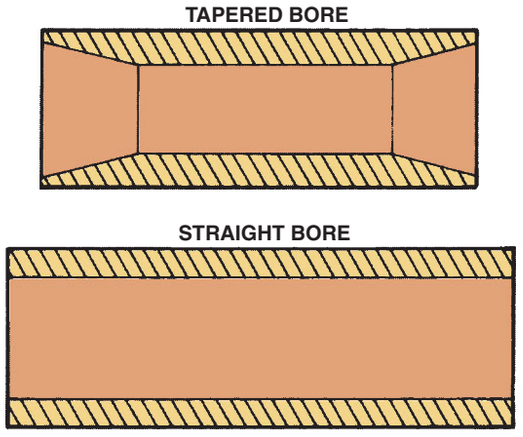


FIGURE 33–11 Most piston pins are hollow to reduce weight and have a straight bore. Some pins have a tapered bore to reinforce the pin.

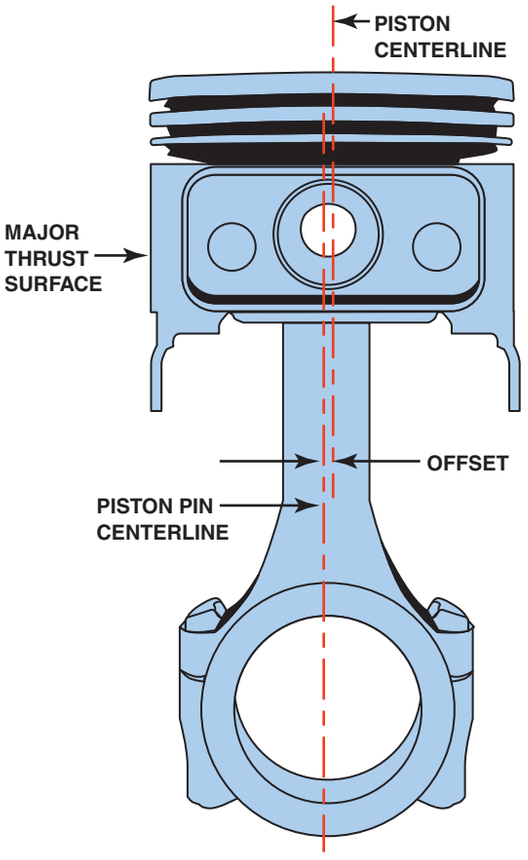


FIGURE 33–12 Piston pin offset toward the major thrust surface.

PISTON PIN OFFSET

Some piston pin holes are not centered in the piston. They are located toward the **major thrust surface,** approximately 0.062 in. (1.57 mm) from the piston centerline, as shown in ● **FIGURE 33–12.**

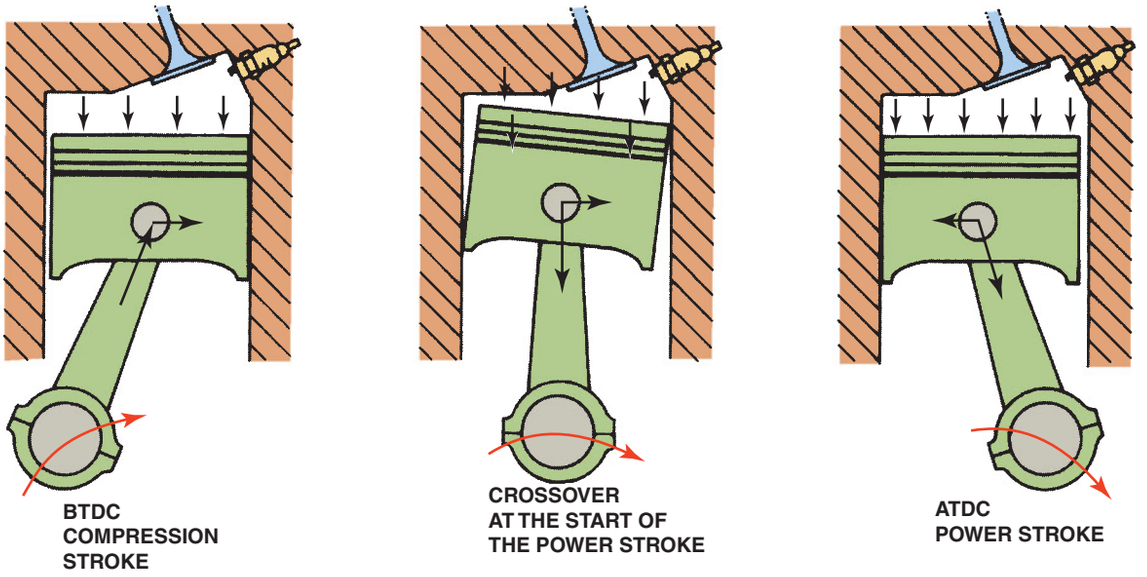


FIGURE 33–13 Engine rotation and rod angle during the power stroke cause the piston to press harder against one side of the cylinder, called the major thrust surface.

? FREQUENTLY ASKED QUESTION

Which Side Is the Major Thrust Side?

The thrust side is the side the rod points to when the piston is on the power stroke. Any V-block engine (V-6 or V-8) that rotates clockwise is viewed from the front of the engine. The left bank piston thrust side faces the inside (center) of the engine. The right bank piston thrust side faces the outside of the block. This rule, called the *left-hand rule,* states the following:

- Stand at the rear of the engine and point toward the front of the engine.
- Raise your thumb straight up, indicating the top of the engine.
- Point your other fingers toward the right. This represents the major thrust side of the piston.

Always assemble the connecting rods onto the rods so that the notch or "F" on the piston is pointing toward the front of the engine and the oil squirt hole on the connecting rod is pointing toward the major thrust side with your left hand.

Pin offset is designed to reduce piston slap and the noise that can result as the large end of the connecting rod crosses over top dead center.

- **Minor thrust.** The minor thrust side of the piston head has a greater area than the major side. This is caused by the pin offset. As the piston moves up in the cylinder on the compression stroke, it rides against the minor thrust surface. When compression pressure becomes high enough, the greater head area on the minor side causes the piston to cock slightly in the cylinder. This keeps the *top* of the minor thrust surface on the cylinder. It forces the *bottom* of the major thrust surface to contact the cylinder wall. As the piston approaches top center, both thrust surfaces are in contact with the cylinder wall.
- **Major thrust.** When the crankshaft crosses over top center, the force on the connecting rod moves the entire piston toward the major thrust surface. The lower portion of the major thrust surface has already been in contact with the cylinder wall. The rest of the piston skirt slips into full contact just after the crossover point, thereby controlling piston slap. This action is illustrated in ● **FIGURE 33–13.**

Off-setting the piston toward the minor thrust surface would provide a better mechanical advantage. It also would cause less piston-to-cylinder friction, and increase piston noise. For these reasons, the offset is often placed toward the minor thrust surface in racing engines. Noise and durability are not as important in racing engines as maximum performance.

NOTE: Not all piston pins are offset. In fact, many engines operate without the offset to help reduce friction and improve power and fuel economy.

PISTON PIN FIT The finish and size of piston pins are closely controlled. Piston pins have a smooth, mirrorlike finish. Their size is held to tens of thousandths of an inch so that exact fits can be maintained. If the piston pin is loose in the piston or in the connecting rod, it will make a sound while the engine is running. This is often described as a **double knock.** The noise is created when the piston stops at top dead center and occurs again as it starts to move downward, creating a doubleknock or rattling sound. If the piston pin is too tight in the piston, it will restrict piston expansion along the pin diameter and lead to piston scuffing. Normal piston pin clearances range from 0.0005 to 0.0007 in. (0.0126 to 0.018 mm).

PISTON PIN RETAINING METHODS

FULL FLOATING **Full-floating** piston pins are free to "float" in the connecting rod and the piston. Often, a bronze bushing is installed in the small end of the connecting rod to support the piston pin. Full-floating pins require a retaining device to keep the piston pin from moving endwise and scrape against the cylinder wall. Most

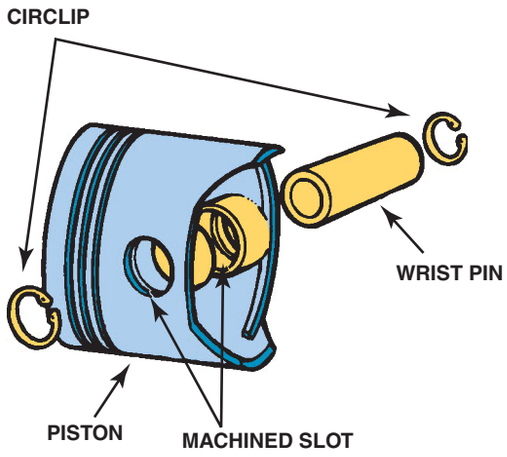


FIGURE 33–14 Circlips hold full-floating piston pins in place.



FIGURE 33–15 A typical interference fit piston pin.

full-floating piston pins use some type of **lock ring** to retain the piston pin. There are two common types of lock rings.

- One is an internal snap ring that fits into a groove in the piston pin bore. These internal snap rings or "circle clips" are commonly called "circlips".
- The other is a "spiral lock" ring, which is a wound flat ring with two or three layers made from hardened steel. The spiral lock is inserted into a groove cut into the piston pin bore by starting with the bottom layer and twisting the spiral ring into place until all layers are in the groove.

Full-floating piston pins are most often used in high-performance modified engines and in diesel engines. ● **SEE FIGURE 33–14.**

Some engines use aluminum or plastic plugs in both ends of the piston pin. These plugs touch the cylinder wall without scoring, to hold the piston pin centered in the piston.

INTERFERENCE FIT Another method of retaining the piston pin in the connecting rod is to make the connecting rod hole slightly smaller than the piston pin. The pin is installed by heating the rod to expand the hole or by pressing the pin into the rod. This retaining method will securely hold the pin. ● **SEE FIGURE 33–15.**

This press or shrink fit is called an **interference fit.** Care must be taken to have the correct hole sizes, and the pin must be centered in the connecting rod. Because the interference fit method is the least expensive to use, it is found in the majority of engines.

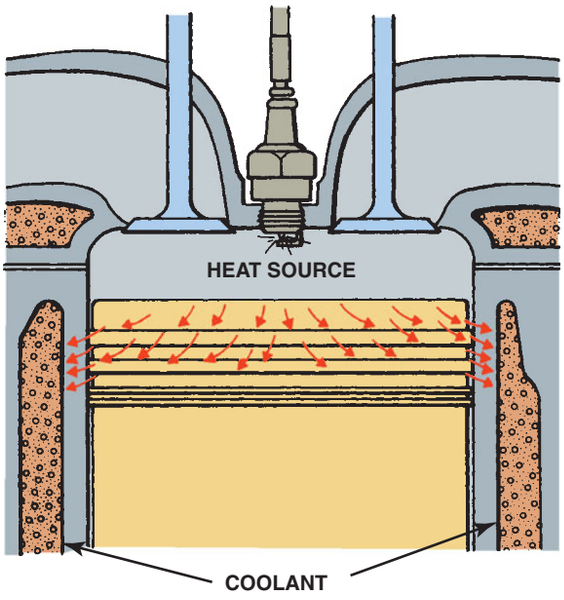


FIGURE 33–16 The rings conduct heat from the piston to the cylinder wall.

REAL WORLD FIX

Big Problem, No Noise

Sometimes the piston pin can "walk" off the center of the piston and score the cylinder wall. This scoring is often not noticed because this type of wear does not create noise. Because the piston pin is below the piston rings, little combustion pressure is lost past the rings until the groove worn by the piston pin has worn the piston rings.

Troubleshooting the exact cause of the increased oil consumption is difficult because the damage done to the oil control rings by the groove usually affects only one cylinder.

Often, compression tests indicate good compression because of the cylinder seals, especially at the top. More than one technician has been surprised to see the cylinder gouged by a piston pin when the cylinder head has been removed for service. In such a case, the cost of the engine repair immediately increases far beyond that of normal cylinder head service.

PISTON RINGS

PURPOSE AND FUNCTION Piston rings serve several major functions in engines.

- They form a sliding combustion chamber seal that prevents the high-pressure combustion gases from leaking past the piston.
- They keep engine oil from getting into the combustion chamber.
- The rings transfer some of the piston heat to the cylinder wall, where it is removed from the engine through the cooling system. ● **SEE FIGURE 33–16.**

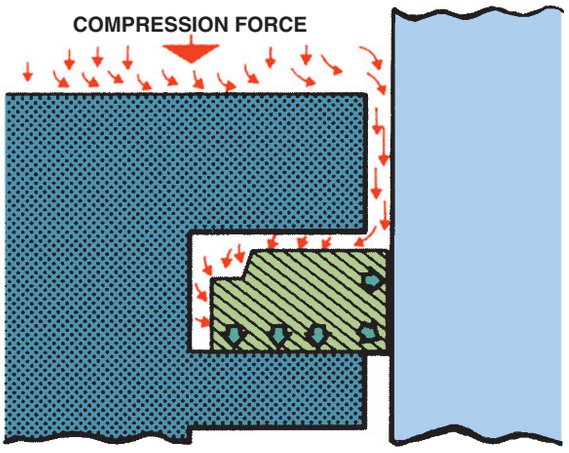


FIGURE 33–17 Combustion chamber pressure forces the ring against the cylinder wall and the bottom of the ring groove to effectively seal the cylinder.

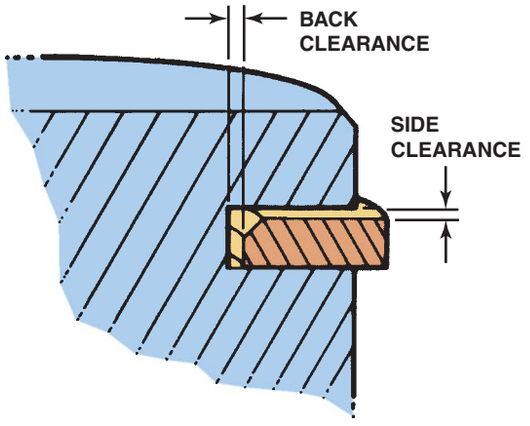


FIGURE 33–18 The side and back clearances must be correct for the compression rings to seal properly.

CLASSIFICATIONS

Piston rings are classified into two types.

1. Two **compression rings,** located toward the top of the piston
2. One **oil control ring,** located below the compression rings

NOTE: Some engines, such as Honda high-fuel economy engines, use pistons with only two rings: one compression ring and one oil control ring.

COMPRESSION RINGS

A compression ring is designed to form a seal between the moving piston and the cylinder wall. This is necessary to get maximum power from the combustion pressure. At the same time, the compression ring must keep friction at a minimum. This is made possible by providing only enough static or built-in mechanical tension to hold the ring in contact with the cylinder wall during the intake stroke. Combustion chamber pressure during the compression, power, and exhaust strokes is applied to the top and back of the ring. This pressure will add extra force on the ring that is required to seal the combustion chamber during these strokes. ● **FIGURE 33–17** illustrates how the combustion chamber pressure adds force to the ring.

The space in the ring groove above the ring is called the **side clearance** and the space behind the ring is called the **back clearance.** ● **SEE FIGURE 33–18.**

OIL CONTROL RINGS

The scraping action of the oil control ring allows oil to return through the expander and openings in the piston.

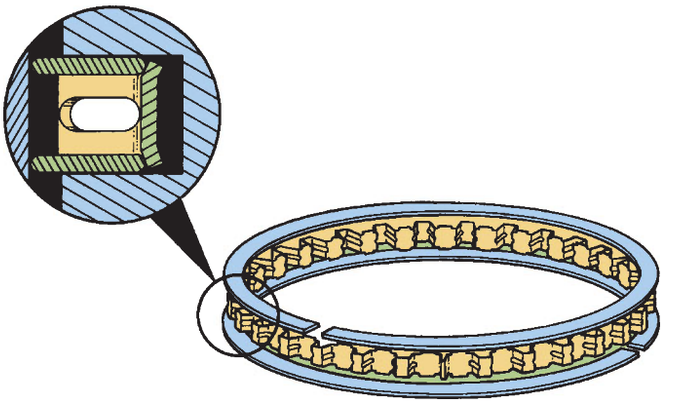


FIGURE 33–19 This typical three-piece oil control ring uses a hump-type stainless steel spacer-expander. The expander separates the two steel rails and presses them against the cylinder wall.

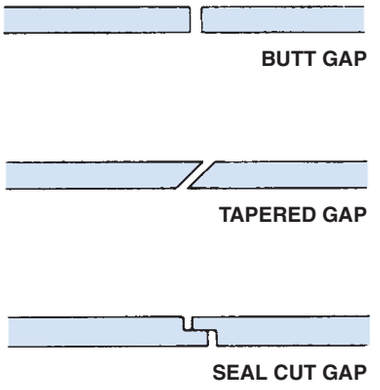


FIGURE 33–20 Typical piston ring gaps.

Steel spring expanders were placed in the ring groove behind the ring to improve static radial tension. They forced the ring to conform to the cylinder wall. Many expander designs are used. On the three-piece ring, a spacer expander lies between the top and bottom rails. The spacer expander keeps the rails separated and pushes them out against the cylinder wall. ● **SEE FIGURE 33–19.**

RING GAP

The piston **ring gap** will allow some leakage past the top compression ring. This leakage is useful in providing pressure on the second ring to develop a dynamic sealing force. The amount of piston ring gap is critical.

- **Too much gap.** A ring gap that is too great will allow excessive **blowby.** Blowby is the leakage of combustion gases past the rings. Blowby will blow oil from the cylinder wall. This oil loss is followed by piston ring scuffing.
- **Too little gap.** A ring gap that is too little will allow the piston ring ends to touch together when the engine is hot. Ring end touching increases the mechanical force against the cylinder wall, causing excessive wear and possible engine failure.

A butt-type piston ring gap is the most common type used in automotive engines. Some low-speed industrial engines and some diesel engines use a more expensive tapered or seal-cut ring gap. These gaps are necessary to reduce losses of the high-pressure combustion gases. At low speeds, the gases have more time to leak through the gap. Typical ring gaps are illustrated in ● **FIGURE 33–20.**

PISTON RING SHAPES

As engine speeds have increased, inertia forces on the piston rings have also increased. As a result, engine manufacturers have found it desirable to reduce inertia forces on the rings by reducing their weight. This has been done by

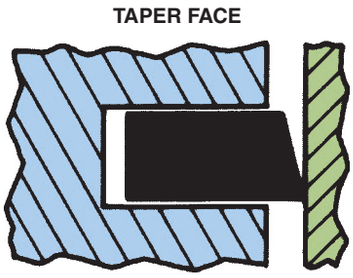


FIGURE 33–21 The taper face ring provides oil control by scraping the cylinder wall. This style of ring must be installed right side up or the ring will not seal and oil will be drawn into the combustion chamber.

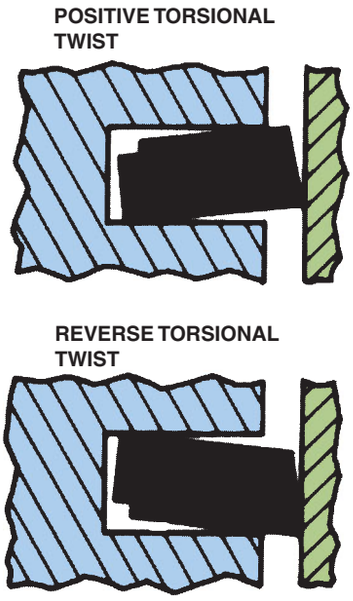


FIGURE 33–22 Torsional twist rings provide better compression sealing and oil control than regular taper rings.

reducing the thickness of the piston ring from 1/4 in. (6 mm) to as little as 1/16 in. (1.6 mm). There are several types of piston rings.

- **Taper face ring** will contact the cylinder wall at the lower edge of the piston ring. ● **SEE FIGURE 33–21.**

  When either a chamfer or counterbore relief is made on the *upper inside* corner of the piston ring, the ring cross section is unbalanced, causing the ring to twist in the groove in a positive direction.
- **Positive twist ring** will give the same wall contact as the taper face ring. It will also provide a line contact seal on the bottom side of the groove. Sometimes, twist and a taper face are used on the same compression ring.

  Some second rings are notched on the *outer lower* corner. This, too, provides a positive ring twist. The sharp, lower outer corner becomes a scraper that helps in oil control, but this type of ring has less compression control than the preceding types.
- **Reverse twist ring** is produced by chamfering the ring's *lower inner* corner. This seals the lower outer section of the ring and piston ring groove, thus improving oil control. Reverse twist rings require a greater taper face or barrel face to maintain the desired ring face-to-cylinder wall contact. ● **SEE FIGURE 33–22.**

  Another style of positive twist ring has a counterbore at the lower outside edge. ● **SEE FIGURE 33–23.**

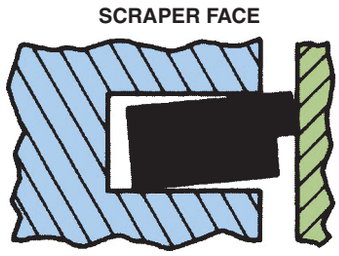


FIGURE 33–23 Scraper-type rings provide improved oil control.

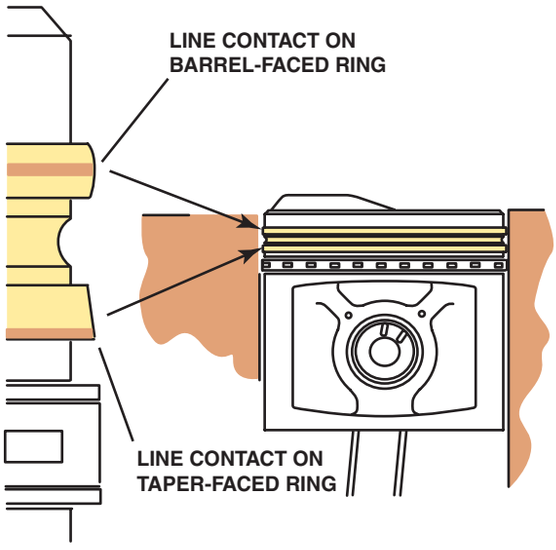


FIGURE 33–24 The upper barrel face ring has a line showing contact with the cylinder wall. The second taper face ring shows contact along the lower edge of the ring.

- **Scraper ring** does a good job of oil control and is usually recommended for use at the second compression ring.
- **Barrel face ring** can replace the outer ring taper on some rings. The barrel is 0.0003 in. per 0.1 in. (0.0076 mm per 0.254 mm) of piston ring width. Barrel faces are found on rectangular rings and on torsionally twisted rings. ● **SEE FIGURE 33–24.**

PISTON RING CONSTRUCTION

PISTON RING MATERIALS The first piston rings were made with a simple rectangular cross section, modified with tapers, chamfers, counterbores, slots, rails, and expanders. Piston ring materials can include:

- Plain cast iron
- Pearlitic cast iron
- Nodular cast iron
- Steel
- **Ductile iron** (This is also used as a piston ring material in some automotive engines, which is very flexible and can be twisted without breaking.)

CHROMIUM PISTON RINGS A chromium facing on cast iron rings greatly increases piston ring life, especially where abrasive materials are present in the air. During manufacture, the chromium-plated

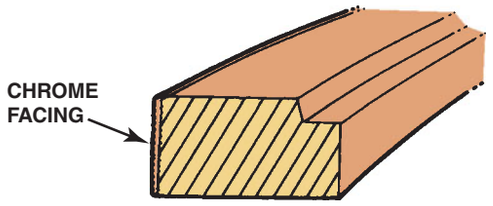


FIGURE 33–25 The chrome facing on this compression ring is about 0.004 in. (0.10 mm) thick.

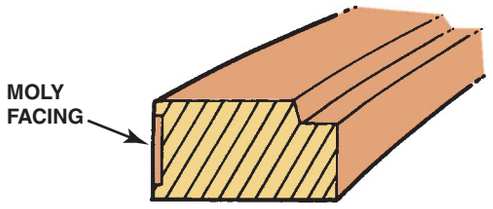


FIGURE 33–26 The moly facing on this compression ring is about 0.005 in. (0.13 mm) thick.

ring is slightly chamfered at the outer corners. About 0.004 in. (0.01 mm) of chrome is then plated on the ring face. Chromium-faced rings are then prelapped or honed before they are packaged and shipped to the customer. The finished chromium facing is shown in a sectional view in ● **FIGURE 33–25.**

MOLYBDENUM PISTON RINGS Early in the 1960s, molybdenum piston ring faces were introduced. These rings proved to have good service life, especially under scuffing conditions. The plasma method is a spray method used to deposit molybdenum on cast iron to produce a long-wearing and low-friction piston ring. The plasma method involves an electric arc plasma (ionized gas) that generates an extremely high temperature to melt the molybdenum and spray-deposit a molten powder of it onto a piston ring. Therefore, plasma rings are molybdenum (moly) rings that have the moly coating applied by the plasma method. Most molybdenum face piston rings have a groove that is 0.004 to 0.008 in. (0.1 to 0.2 mm) deep cut into the ring face. This groove is filled with molybdenum, using a metallic (or plasma) spray method, so that there is a cast iron edge above and below the molybdenum. This edge may be chamfered in some applications. A sectional view of a molybdenum face ring is shown in ● **FIGURE 33–26.**

Molybdenum face piston rings will survive under high-temperature and scuffing conditions better than chromium face rings. Under abrasive wear conditions, chromium face rings will have a better service life. There is little measurable difference between these two facing materials with respect to blowby, oil control, break-in, and horsepower. Piston rings with either of these two types of facings are far better than plain cast iron rings with phosphorus coatings. A molybdenum face ring, when used, will be found in the top groove, and a plain cast iron or chromium face ring will be found in the second groove.

MOLY-CHROME-CARBIDE RINGS Rings with moly-chrome-carbide coating are also used in some original equipment (OE) and replacement applications. The coating has properties that include the hardness of the chrome and carbide combined with the heat resistance of molybdenum.

CERAMIC-COATED RINGS The ceramic-coated ring surface is created by applying a ceramic coating to the ring using a process called *physical vapor deposition (PVD).* Ceramic-coated rings are

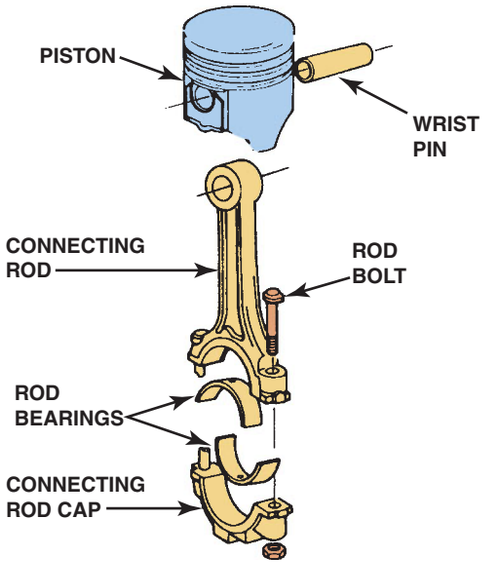


FIGURE 33–27 The connecting rod is the most highly stressed part of any engine because combustion pressure tries to compress it and piston inertia tries to pull it apart.



FIGURE 33–28 The I-beam shape (top rod) is the most common, but the H-beam shape is common in high-performance and racing engine applications.

also being used where additional heat resistance is needed, such as in some heavy-duty, turbocharged, or supercharged engines. For example, the General Motors Duramax 6.6 liter diesel engine uses ceramic-coated rings.

CONNECTING RODS

PURPOSE AND FUNCTION The connecting rod transfers the force and reciprocating motion of the piston to the crankshaft. The small end of the connecting rod reciprocates with the piston. The large end rotates with the crankpin. ● **SEE FIGURE 33–27.**

These dynamic motions make it desirable to keep the connecting rod as light as possible while still having a rigid beam section. ● **SEE FIGURE 33–28.**

Connecting rods are manufactured by casting, forging, and powdered (sintered) metal processes.

CONNECTING ROD DESIGN The big end of the connecting rod must be a perfect circle. Once a rod and cap are initially machined, they must remain a "matched set," due to the precise machining required to obtain a perfect circle. Therefore, the rod caps must not be interchanged. Assembly bolt holes are closely

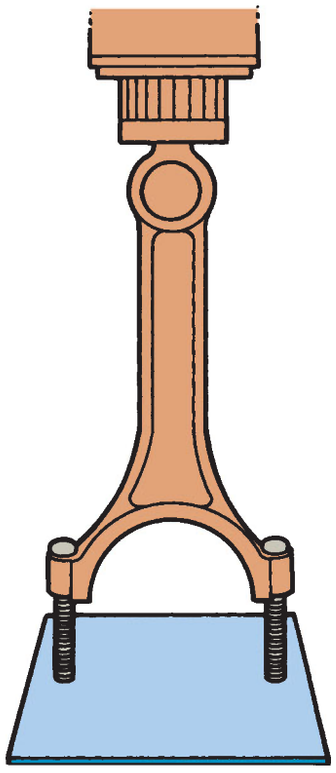


FIGURE 33–29 Rod bolts are quickly removed using a press.

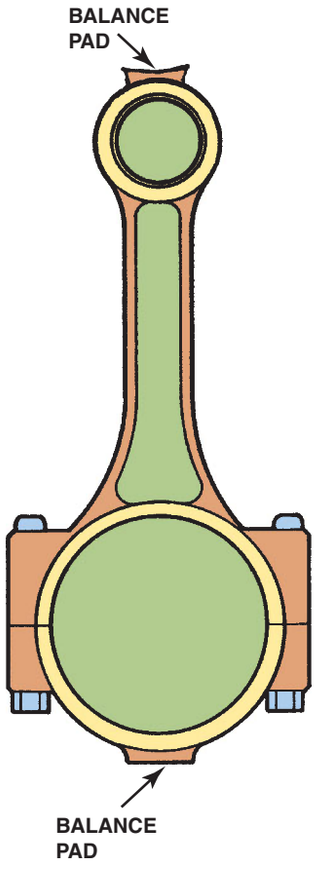


FIGURE 33–30 Some rods have balancing pads on each end of the connecting rod.

reamed in both the cap and connecting rod to ensure alignment. The connecting rod bolts have *piloting surfaces* that closely fit these reamed holes. The fit of the connecting rod bolts is so tight that a press must be used to remove the bolts when they are to be replaced, as shown in ● **FIGURE 33–29.**

In some engines, offset connecting rods provide the most economical distribution of main bearing space and crankshaft cheek clearance.

Many connecting rods are made with **balancing bosses (pads)** so that their weight can be adjusted to specifications. Some have balancing bosses only on the rod cap. Others also have a balancing boss at the small end. Some manufacturers put balancing bosses on the side of the rod, near the center of gravity of the connecting rod. Typical balancing bosses can be seen in ● **FIGURE 33–30.**

Balancing is done on automatic balancing machines as the final machining operation before the rod is installed in an engine.

Some connecting rods have a **spit hole** that bleeds some of the oil from the connecting rod journal. ● **SEE FIGURES 33–31 AND 33–32.**

On inline engines, oil is thrown up from the spit hole into the cylinder in which the rod is located. On V-type engines, it is often thrown into a cylinder in the opposite bank. The oil that is spit from the rod is aimed so that it will splash into the interior of the piston to help lubricate the piston pin. A hole similar to the spit holes may be used, called a **bleed hole,** to control the oil flow through the bearing.

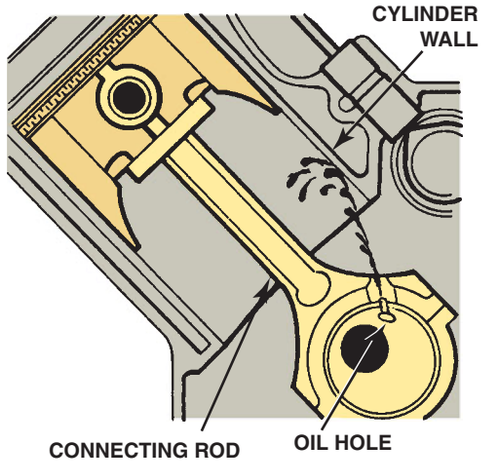


FIGURE 33–31 Some connecting rods have spit holes to help lubricate the cylinder wall or piston pin.

CAST CONNECTING RODS Casting materials and processes have been improved so that they are used in most vehicle engines with high production standards. Cast connecting rods can be identified by their *narrow parting line.* A typical rough connecting rod casting is shown in ● **FIGURE 33–33.**

FORGED CONNECTING RODS Forged connecting rods have been used for years. They are generally used in heavy-duty and high-performance engines. Generally, the forging method produces lighter weight and stronger but more expensive connecting rods. Forged connecting rods can be identified by their *wide parting line.* Many high-performance connecting rods use a bronze bushing in the small end as shown in ● **FIGURE 33–34.**

POWDERED METAL CONNECTING RODS Most new production engines, including the General Motors Northstar, the Ford 4.6, 5.0, and 6.6 liter OHC V-8s, and the Chrysler Hemi, use powdered metal (PM) connecting rods.

Powdered metal connecting rods have many advantages over convention cast or forged rods including precise weight control. Each rod is created using a measured amount of material so that rod

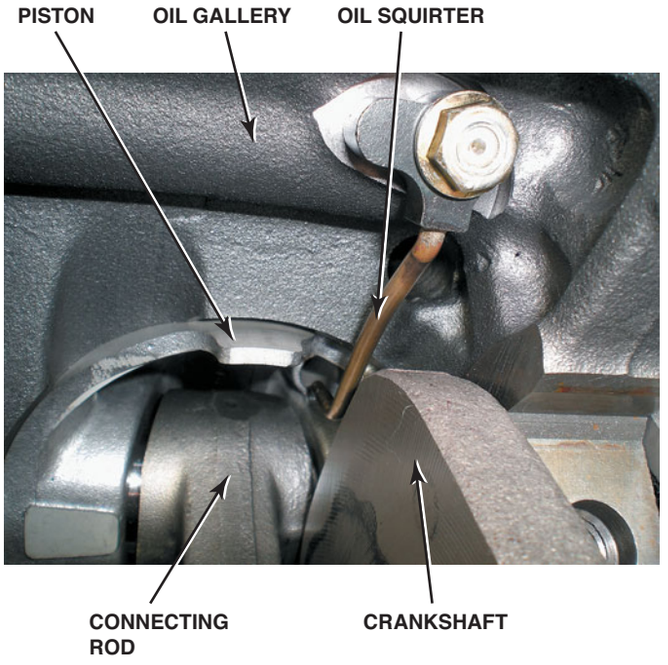


FIGURE 33–32 Some engines, such as this Ford diesel, are equipped with oil squirters that spray or stream oil toward the underneath side of the piston head to cool the piston.

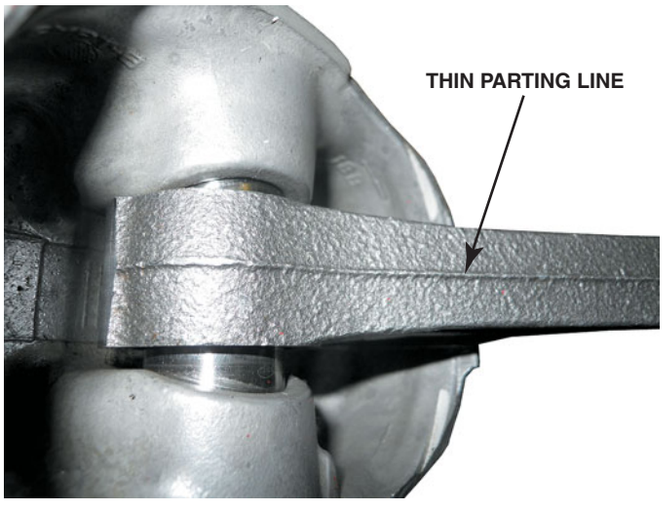


FIGURE 33–33 A cast connecting rod is found on many stock engines and can be identified by the thin parting line.

balancing, and therefore engine balancing, is now achieved without extra weighting and machining operations.

- Powdered metal connecting rods start as powdered metal, which includes iron, copper, carbon, and other alloying agents.
- This powder is then placed in a die and compacted (forged) under a pressure of 30 to 50 tons per square inch.
- After the part is shaped in the die, it is taken through a sintering operation where the part is heated, without melting, to about 2,000°F. During the sintering process, the ingredients are transformed into metallurgical bonds, giving the part strength.
- Machining is very limited and includes boring the small and big end and drilling the holes for the rod bearing cap retaining bolts.
- The big end is then fractured using a large press. The uneven parting line helps ensure a perfect match when the pieces are assembled. ● **SEE FIGURE 33–35.**

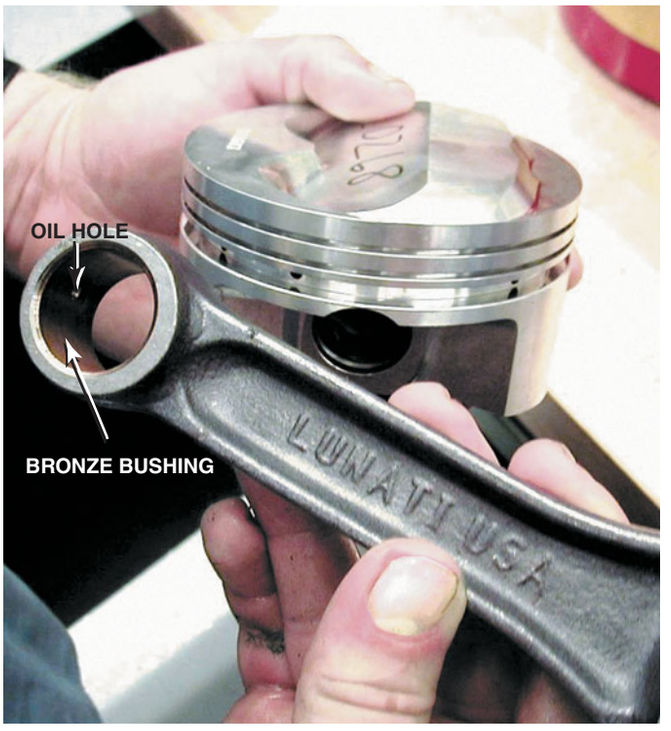


FIGURE 33–34 This high-performance connecting rod uses a bronze bushing in the small end of the rod and oil hole to allow oil to reach the full-floating piston pin.

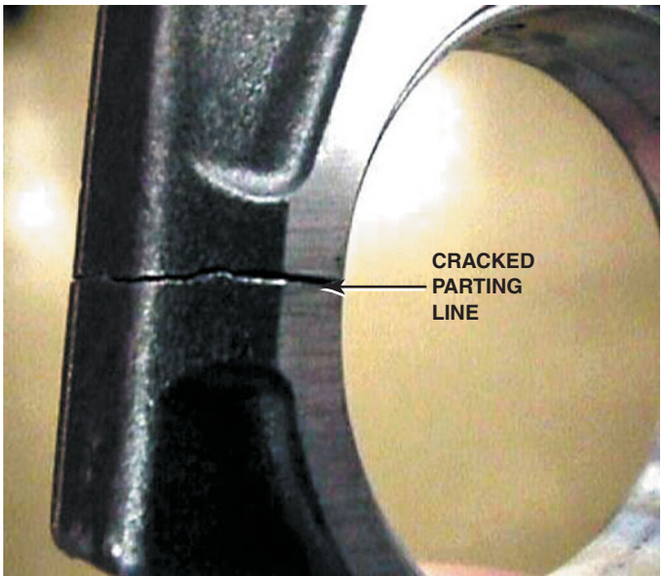


FIGURE 33–35 Powdered metal connecting rods feature a fractured parting line at the big end of the rod.

CONNECTING ROD SERVICE

REMOVING PISTONS FROM RODS The pistons are removed from the rods using a special fixture shown in ● **FIGURE 33–36.**

INSPECTION Before connecting rod reconditioning, the rod should be checked for twist. ● **SEE FIGURE 33–37.**

In other words, the hole at the small end and the hole at the big end of the connecting rod should be parallel. No more than a 0.002 in. (0.05 mm) twist is acceptable. ● **SEE FIGURE 33–38** for the fixture used to check connecting rods for twist.

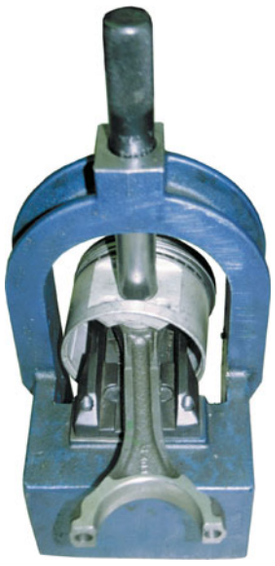


FIGURE 33–36 A press used to remove the connecting rod from the piston.

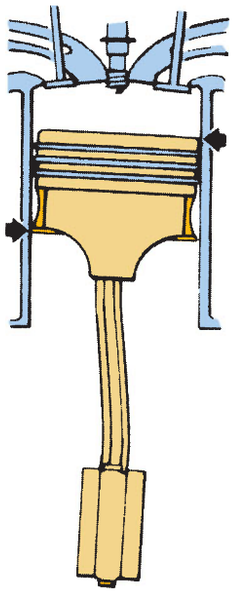


FIGURE 33–37 If the rod is twisted, it will cause diagonal-type wear on the piston skirt.

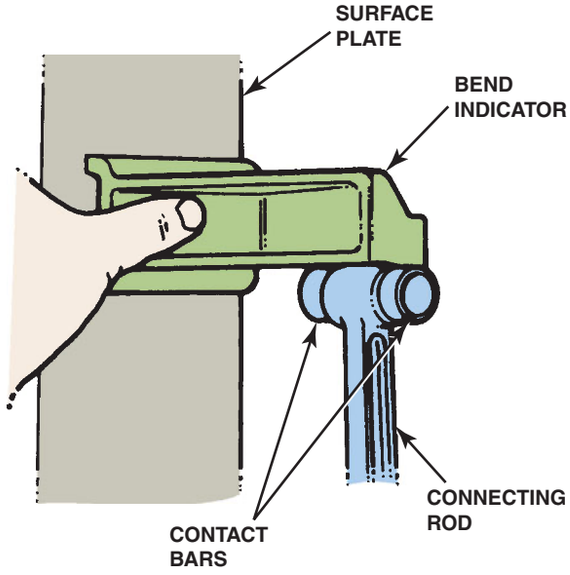


FIGURE 33–38 A rod alignment fixture is used to check a connecting rod for bends or twists.

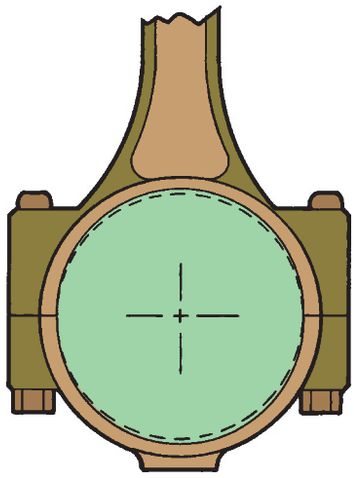


FIGURE 33–39 Rod bearing bores normally stretch from top to bottom, with most wear concentrated on the rod cap.

If measured rod twist is excessive, some specialty shops can remove the twist by bending the rod cold. Both cast and forged rods can be straightened. However, many engine builders replace the connecting rod if it is twisted.

RECONDITIONING PROCEDURE

As an engine operates, the forces go through the large end of the connecting rod. This causes the crankshaft end opening of the rod (eye) to gradually deform. ● **SEE FIGURE 33–39.**

The large eye of the connecting rod is resized during precision engine service.

STEP 1 The parting surfaces of the rod and cap are smoothed to remove all high spots before resizing. A couple of thousandths of an inch of metal is removed from the rod cap parting surface. This is done using the same grinder that is used to remove a slight amount of metal from the parting surface of main bearing caps. The amount removed from the rod and rod cap only reduces the bore size 0.003 to 0.006 in. (0.08 to 0.15 mm).

NOTE: Powdered metal connecting rods cannot be reconditioned using this method. Most manufacturers recommend replacing worn powdered metal connecting rods.

STEP 2 The cap is installed on the rod, and the nuts or cap screws are properly torqued. The hole is then bored or honed to be perfectly round and of the size and finish required to give the correct connecting rod bearing crush. ● **FIGURE 33–40** shows the setup for resizing the rod on a typical hone used in engine reconditioning.

Even though material is being removed at the big end of the rod, the compression ratio is changed very little. The inside of the bore at the big end should have a 60 to 90 microinch finish for proper bearing contact and heat transfer.

PISTON AND ROD ASSEMBLY

INTERFERENCE FIT RODS

To assemble the piston and rod, the piston pin is put in one side of the piston. The small end of the connecting rod should be checked for proper size.

The small eye of the connecting rod is heated before the pin is installed. ● **SEE FIGURE 33–41.**



FIGURE 33–40 To help ensure that the big ends are honed straight, many experts recommend placing two rods together when performing the honing operation.

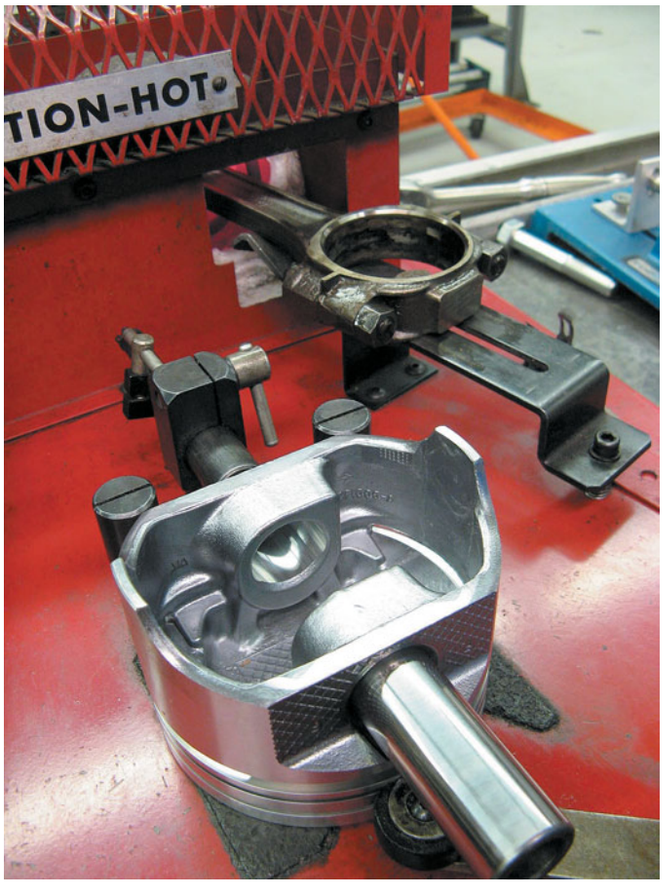


FIGURE 33–41 The small end of the rod is being heated in an electric heater and the piston is positioned properly so the piston pin can be installed as soon as the rod is removed from the heater.

This causes the rod eye to expand so that the pin can be pushed into place with little force. The pin must be rapidly pushed into the correct center position. There is only one chance to get it in the right place because the rod will quickly seize on the pin as the rod eye is cooled by the pin.

FULL-FLOATING RODS Full-floating piston pins operate in a bushing in the small eye of the connecting rod. The bushing can be replaced. The bushing and the piston are honed to the same diameter. This allows the piston pin to slide freely through both. The full-floating piston pin is held in place with a lock ring at each end of the piston pin. The lock ring expands into a small groove in the pin hole of the piston.



FIGURE 33–42 The side clearance of the piston ring is checked with a feeler gauge.

NOTE: The original lock rings should always be replaced with new rings.

PISTON RING SERVICE

STEPS Each piston ring, one at a time, should be placed backward in the groove in which it is to be run.

STEP 1 **Check side clearance.** As the piston goes rapidly up and down in the cylinder, it tosses the rings to the top and to the bottom of the ring grooves.

The pounding of each ring in its groove gradually increases the piston ring side clearance. Material is worn from both the ring and the groove. Replace the piston if the ring groove is larger than factory specifications. The side clearance in the groove should be checked with a feeler gauge, as shown in ● **FIGURE 33–42**.

STEP 2 **Check ring gap.** After the block and cylinder bores have been reconditioned, invert the piston and push each ring into the lower quarter of the cylinder; then measure the ring gap. ● **SEE FIGURE 33–43**.

The usual ring gap should be approximately 0.004 in. for each inch of bore diameter (0.004 mm for each centimeter of bore diameter). The second ring also needs to have a similar or even larger end gap.

- If excessive ring gap is present, the blowby gases can enter the crankcase. Replace the ring(s) if the gap is too large.
- If the gap is too narrow, use a file or hand-operated piston ring grinder to achieve the necessary ring gap. ● **SEE FIGURE 33–44**.

STEP 3 **Installing the oil control ring.** The oil rings are installed first. The expander-spacer of the oil ring is placed in the lower ring groove. One oil ring rail is carefully placed above the expander-spacer by winding it into the groove. The other rail is placed below the expander-spacer. The ring should be rotated in the groove to ensure that the expander-spacer ends have not overlapped. If they have, the ring must be removed and reassembled correctly.

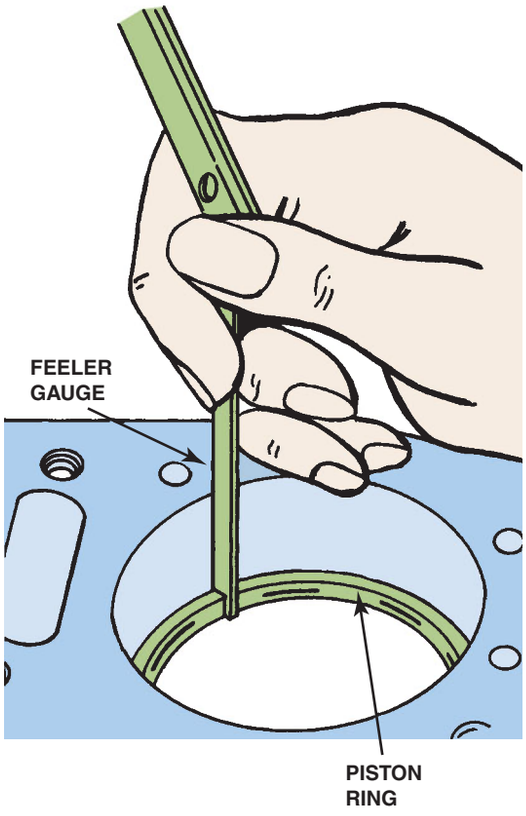


FIGURE 33–43 The ring gap is measured using a feeler gauge.

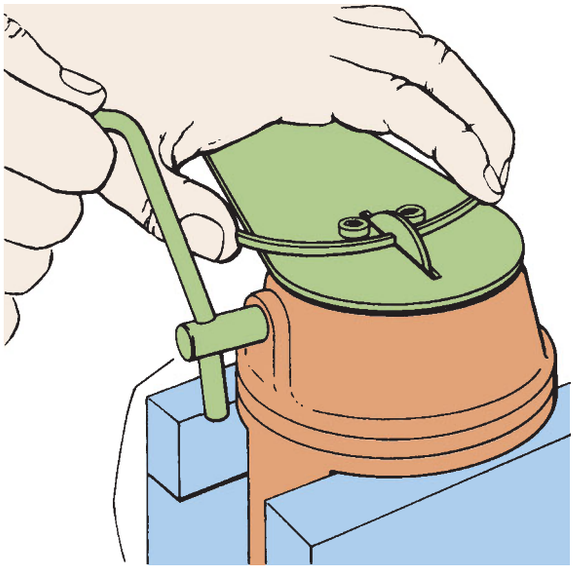


FIGURE 33–44 A hand-operated piston ring end gap grinder being used to increase the end gap of a piston ring so that it is within factory specifications.



FIGURE 33–45 A typical ring expander being used to install a piston ring on a piston.

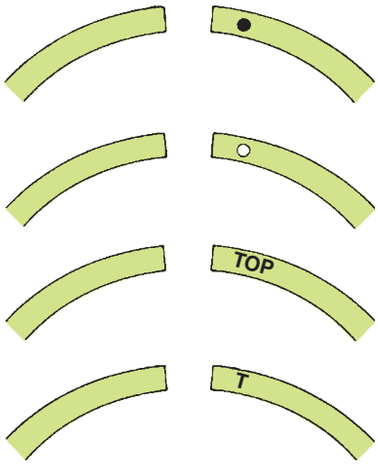


FIGURE 33–46 Identification marks used to indicate the side of the piston ring to be placed toward the head of the piston.

STEP 4 **Installing the compression rings.** Installing the compression rings requires the use of a **piston ring expander** tool that will only open the ring gap enough to slip the ring on the piston. ● **SEE FIGURE 33–45.**

Be careful to install the ring with the correct side up. The top of the compression ring is marked with one of the following:

- One dot
- The letter *T*
- The word *top*

● **SEE FIGURE 33–46.**

STEP 5 **Double-check everything.** After the rings are installed they should be rotated in the groove to ensure that they move freely, and checked to ensure that they will go fully into the groove so that the ring face is flush with the surface of the piston ring lands. Usually, the rings are placed on all pistons before any pistons are installed in the cylinders.

REVIEW QUESTIONS

1. List the methods used to control piston heat expansion.
2. Why are some piston skirts tin plated?
3. How does piston pin offset control piston slap?
4. Why are forged pistons recommended for use in high-performance engines?
5. What causes the piston ring groove clearance to widen in service?
6. List the steps needed to recondition connecting rods.
7. How is the piston pin installed in the piston and rod assembly?

CHAPTER QUIZ

1. A hypereutectic piston _____.
   a. Uses about 16% silicon **c.** Is a forged piston
   b. Is a cast piston **d.** Both a and b
2. Many aluminum piston skirts are plated with _____.
   a. Tin or moly graphite **c.** Antimony
   b. Lead **d.** Terneplate
3. A hypereutectic piston has a higher _____.
   a. Weight than an aluminum piston
   b. Silicon content
   c. Tin content
   d. Nickel content
4. The purpose of casting steel struts into an aluminum piston is to _____.
   a. Provide increased strength
   b. Provide increased weight at the top part of the piston where it is needed for stability
   c. Control thermal expansion
   d. Both a and c
5. Full-floating piston pins are retained by _____.
   a. Lock rings
   b. A drilled hole with roll pin
   c. An interference fit between rod and piston pin
   d. An interference fit between piston and piston pin
6. The space behind the ring is called _____.
   a. Side clearance **c.** Back clearance
   b. Forward clearance **d.** Piston ring clearance
7. A misaligned connecting rod causes what type of engine wear?
   a. Cylinder taper
   b. Barrel shape cylinders
   c. Ridge wear
   d. Diagonal wear on the piston skirt
8. Side clearance is a measure taken between the _____ and the _____.
   a. Piston (side skirt); cylinder wall
   b. Piston pin; piston pin retainer (clip)
   c. Piston ring; piston ring groove
   d. Compression ring; oil control ring
9. Piston ring gap should only be measured after _____.
   a. All cylinder work has been performed
   b. Installing the piston in the cylinder
   c. Installing the rings on the piston
   d. Both a and c
10. Which type of connecting rod needs to be heated to install the piston pin?
    a. Forged **c.** Floating
    b. Interference fit **d.** PM rods

chapter 34

ENGINE BLOCKS

OBJECTIVES: **After studying Chapter 34, the reader should be able to:** • Prepare for ASE Engine Repair (A1) certification test content area "C" (Engine Block Diagnosis and Repair). • Describe the types of engine blocks and how they are manufactured. • Measure cylinder bores. • Discuss the machining operations required on most engine blocks. • List the steps necessary to prepare an engine block for assembly.

KEY TERMS: Bedplate 353 • Block deck 353 • Bores 352 • Compacted graphite iron (CGI) 353 • Cooling jacket 354 • Core plugs 352 • Crosshatch finish 361 • Decking the block 357 • Dry cylinder sleeve 353 • Fiber-reinforced matrix (FRM) 354 • Freeze plugs 352 • Frost plugs 352 • Girdle 355 • Grit size 361 • Monoblock 352 • Oil gallery 354 • Oil gallery plugs 354 • Plateau honing 360 • Saddles 356 • Siamese cylinder bores 354 • Sleeving 359 • Wet cylinder sleeve 353

ENGINE BLOCKS

CONSTRUCTION The engine block, which is the supporting structure for the entire engine, is made from one of the following:

- Gray cast iron
- Cast aluminum
- Die-cast aluminum alloy

Cast iron contains about 3% carbon (graphite), which makes it gray in color. Steel is iron with most of the carbon removed. The carbon in cast iron makes it hard but brittle. Cast iron is used to make engine blocks and cylinder heads for the following reasons.

- The carbon in the cast iron allows for easy machining, often without coolant.
- The graphite in the cast iron also has lubricating properties.
- Cast iron is strong for its weight and usually is magnetic.

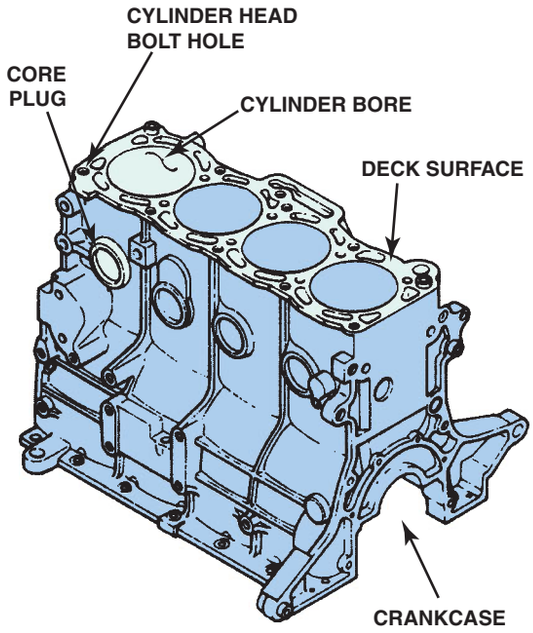


FIGURE 34–1 The cylinder block usually extends from the oil pan rails at the bottom to the deck surface at the top.

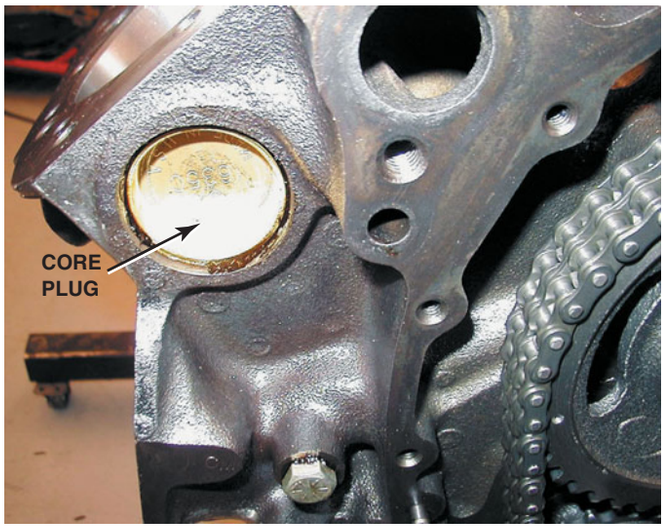


FIGURE 34–2 An expansion (core) plug is used to block the opening in the cylinder head or block the holes where the core sand was removed after the part was cast.

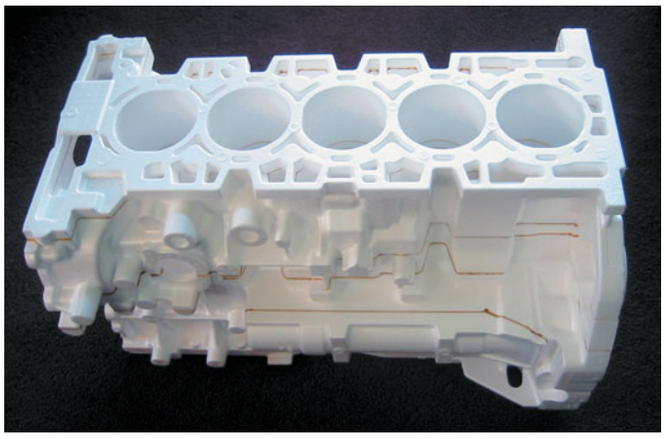


FIGURE 34–3 A Styrofoam casting mold used to make the five cylinder engine blocks for the Chevrolet Colorado and the Hummer H3. The brown lines are glue used to hold the various parts together. Sand is packed around the mold and molten aluminum is poured into the sand which instantly vaporizes the Styrofoam. The aluminum then flows and fills the area of the mold.

The liquid cast iron is poured into a mold made from either sand or Styrofoam. All other engine parts are mounted on or in the block. This large casting supports the crankshaft and camshaft (on OHV engines) and holds all the parts in alignment. Newer blocks use thinner walls to reduce weight. Blocks are often of the **monoblock** design, which means that the cylinder, water jacket, main bearing supports (saddles), and oil passages are all cast as one structure for strength and quietness. Large-diameter holes in the block casting form the cylinders to guide the pistons. The cylinder holes are called **bores** because they are made by a machining process called boring. ● **SEE FIGURE 34–1.**

Combustion pressure loads are carried from the head to the crankshaft bearings through the block structure. The block has webs, walls, and drilled passages to contain the coolant and lubricating oil and to keep them separated from each other.

Mounting pads or lugs on the block transfer the engine torque reaction to the vehicle frame through attached engine mounts. A large mounting surface at the rear of the engine block is used for fastening a bell housing or transmission.

The cylinder head(s) and other components attach to the block. The joints between the components are sealed using gaskets or sealants. Gaskets or sealants are used in the joints to take up differences that are created by machining irregularities and that result from different pressures and temperatures.

BLOCK MANUFACTURING Cast-iron cylinder block sand casting technology continues to be improved. The trend is to make blocks with larger cores, using fewer individual pieces. Oil-sand cores are forms that shape the internal openings and passages in the engine block. Before casting, the cores are supported within a core box. The core box also has a liner to shape the outside of the block. Special alloy cast iron is poured into the box. It flows between the cores and the core box liner. As the cast iron cools, the core breaks up. When the cast iron has hardened, it is removed from the core box, and the pieces of sand core are removed through the openings in the block by vigorously shaking the casting. These openings in the block are plugged with **core plugs.** Core plugs are also called **freeze plugs** or **frost plugs.** Although the name seems to mean that the plugs would be pushed outward if the coolant in the passages were to freeze, they seldom work this way. ● **SEE FIGURE 34–2.**

One way to keep the engine weight as low as possible is to make the block with minimum wall thickness. The cast iron used with thin-wall casting techniques has higher nickel content and is harder than the cast iron previously used. Engine designers have used foundry techniques to make engines lightweight by making the cast-iron block walls and bulkheads only as heavy as necessary to support their required loads.

ALUMINUM BLOCKS Aluminum is used for some cylinder blocks and is nonmagnetic and lightweight. Styrofoam is often used as a core when casting an aluminum block. The Styrofoam vaporizes as soon as the molten aluminum comes in contact with the foam leaving behind a cavity where the aluminum flows. ● **SEE FIGURE 34–3.**

Aluminum block engines usually require cast-iron cylinder walls for proper wear and longevity. Aluminum blocks may have one of several different types of cylinder walls.

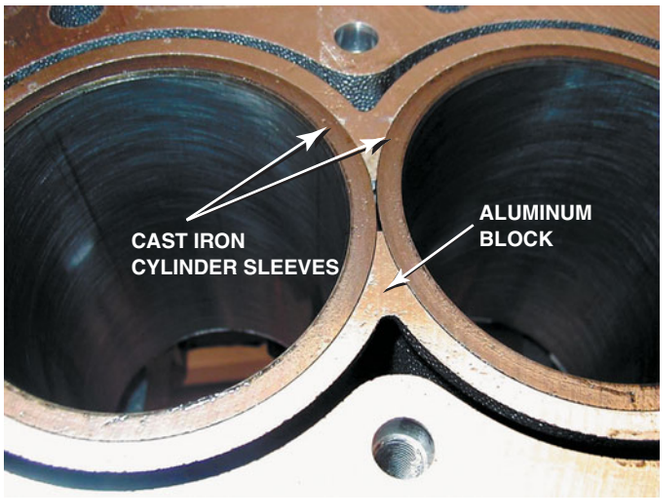


FIGURE 34–4 Cast-iron dry sleeves are used in aluminum blocks to provide a hard surface for the rings.

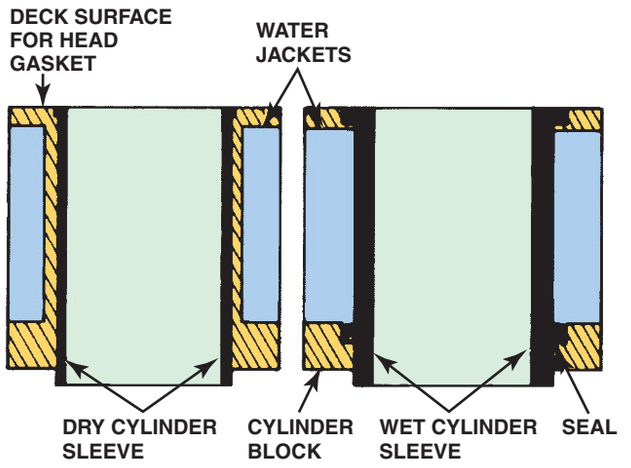


FIGURE 34–5 A dry sleeve is supported by the surrounding cylinder block. A wet sleeve must be thicker to be able to withstand combustion pressures without total support from the block.

FREQUENTLY ASKED QUESTION

What Is Compacted Graphite Iron?

Compacted graphite iron (CGI) has increased the strength, ductility, toughness, and stiffness compared to gray iron. If no magnesium is added, the iron will form gray iron when cooled, with the graphite present in flake form. If a very small amount of magnesium is added, more and more of the sulfur and oxygen form in the molten solution, and the shape of the graphite begins to change to compacted graphite forms. Compacted graphite iron is used for bedplates and many diesel engine blocks. It has higher strength, stiffness, and toughness than gray iron. The enhanced strength has been shown to permit reduced weight while still reducing noise vibration and harshness. Compacted graphite iron is commonly used in the blocks of diesel and some high-performance engines.

- Most cast-aluminum blocks have cast-iron cylinder sleeves (liners) such as Saturn, Northstar, and Ford modular V-8s and V-6s. The cast-iron cylinder sleeves are either cast into the aluminum block during manufacturing or pressed into the aluminum block. These sleeves are not in contact with the coolant passages and are called **dry cylinder sleeves.** ● **SEE FIGURE 34–4.**
- Another aluminum block design has the block die cast from silicon-aluminum alloy with no cylinder liners. Pistons with zinc-copper-hard iron coatings are used in these aluminum bores (in some Porsche engines).
- Some engines have die-cast aluminum blocks with replaceable cast-iron cylinder sleeves. The sleeves are sealed at the block deck and at their base. Coolant flows around the cylinder sleeve, so this type of sleeve is called a **wet cylinder sleeve** (in Cadillac 4.1, 4.5, and 4.9 liter V-8 engines). ● **SEE FIGURE 34–5.**

Cast-iron main bearing caps are used with aluminum blocks to give the required strength.

BEDPLATE DESIGN BLOCKS A **bedplate** is a structural member that attaches to the bottom of the block and supports the crankshaft. The oil pan is mounted under the bedplate which in most cases is also part of the structure and support for the block assembly. ● **SEE FIGURE 34–6.**

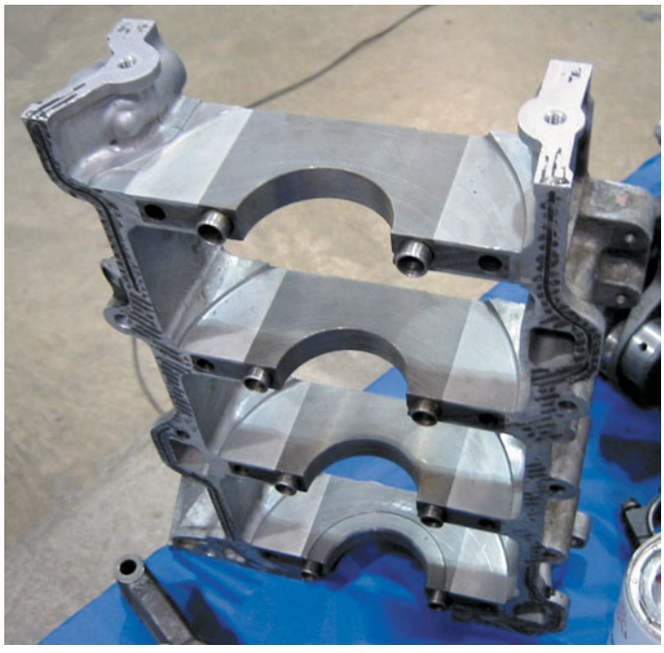


FIGURE 34–6 A bedplate is a structural part of the engine which is attached between the block and the oil pan and supports the crankshaft.

CASTING NUMBERS Whenever an engine part such as a block is cast, a number is put into the mold to identify the casting. These casting numbers can be used to check dimensions, such as the cubic inch displacement, and other information, such as year of manufacture. Sometimes changes are made to the mold, yet the casting number is not changed. Most often the casting number is the best piece of identifying information that the service technician can use. ● **SEE FIGURE 34–7.**

BLOCK DECK The cylinder head is fastened to the top surface of the block. This surface is called the **block deck.** The deck has a smooth surface to seal *against* the head gasket. Bolt holes are positioned around the cylinders to form an even holding pattern. Four, five, or six head bolts are used around each cylinder in automobile engines. These bolt holes go into reinforced areas within the block that carry the combustion pressure load to the main bearing bulkheads.

Additional holes in the block are used to transfer coolant and oil, as seen in ● **FIGURE 34–8.**

COOLING PASSAGES Cylinders are surrounded by cooling passages. These coolant passages around the cylinders are often called the **cooling jacket.** In most cylinder designs, the cooling passages extend nearly to the bottom of the cylinder. In some engine blocks where the block ends at the centerline of the crankshaft, the cooling passages are limited to the upper portion of the cylinder.

? FREQUENTLY ASKED QUESTION

What Are FRM-Lined Cylinders?

Fiber-reinforced matrix (FRM) is used to strengthen cylinder walls in some Honda/Acura engines. FRM is a ceramic material similar to that used to construct the insulators of spark plugs. The lightweight material has excellent wear resistance and good heat transfer properties, making it ideal for use as a cylinder material. FRM inserts are placed in the mold and the engine block is cast over them. The inserts are rough and can easily adhere to the engine block. The inserts are then bored and honed to form the finished cylinders. FRM blocks were first used in a production engine on the Honda S2000 and are also used on the turbocharged Acura RDX sport utility vehicle.

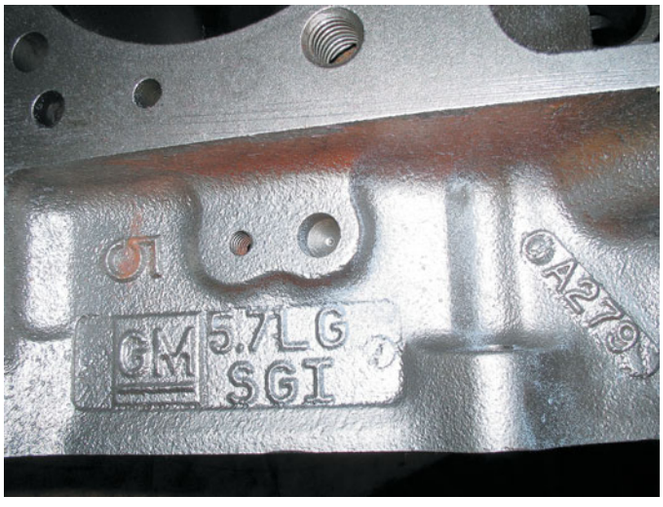


FIGURE 34–7 Casting numbers identify the block.

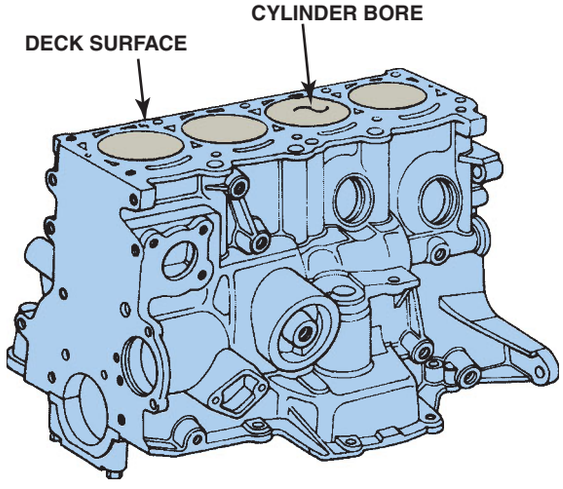


FIGURE 34–8 The deck is the machined top surface of the block.

Some engines are built with **Siamese cylinder bores** where the cylinder walls are cast together without a water jacket (passage) between the cylinders. While this design improves the strength of the block and adds stability to the cylinder bores, it can reduce the cooling around the cylinders. ● **FIGURE 34–9** is a typical V-8 engine cutaway that shows the coolant jackets and some of the lubrication holes.

LUBRICATING PASSAGES An engine block has many oil holes that carry lubricating oil to the required locations. During manufacture, all oil holes, called the **oil gallery,** are drilled from outside the block. When a curved passage is needed, intersecting straight drilled holes are used. In some engines, plugs are placed in the oil holes to direct oil to another point before it comes back to the original hole, on the opposite side of the plug. After oil holes are drilled, the unneeded open ends may be capped by pipe plugs, steel balls, or cup-type soft plugs, often called **oil gallery plugs.** These end plugs in the oil passages can be a source of oil leakage in operating engines. ● **SEE FIGURE 34–10.**

TECH TIP

What Does LHD Mean?

The abbreviation LHD means *left-hand dipstick,* which is commonly used by rebuilders and remanufacturers in their literature in describing Chevrolet small block V-8 engines. Before about 1980, most small block Chevrolet V-8s used an oil dipstick pad on the left side (driver's side) of the engine block. Starting in about 1980, when oxygen sensors were first used on this engine, the dipstick was relocated to the right side of the block.

Therefore, to be assured of ordering or delivering the correct engine, knowing the dipstick location is critical. An LHD block cannot be used with the exhaust manifold setup that includes the oxygen sensor without major refitting or the installing of a different style of oil pan that includes a provision for an oil dipstick. Engine blocks with the dipstick pad cast on the right side are, therefore, coded as right-hand dipstick (RHD) engines.

NOTE: Some blocks cast around the year 1980 are cast with both right- and left-hand oil dipstick pads, but only one is drilled for the dipstick tube. ● **SEE FIGURE 34–11.**

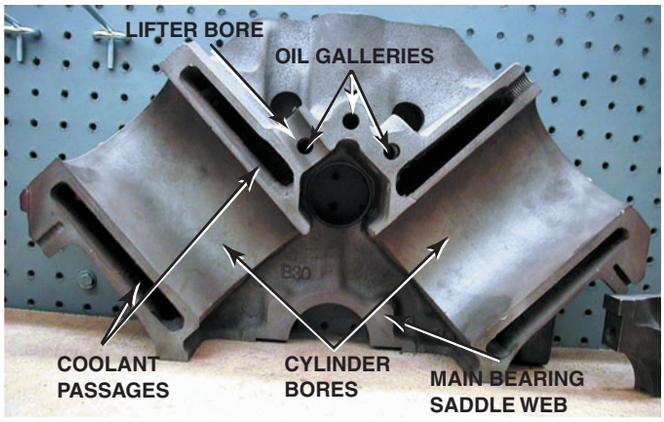


FIGURE 34–9 Cutaway of a Chevrolet V-8 block showing all of the internal passages.

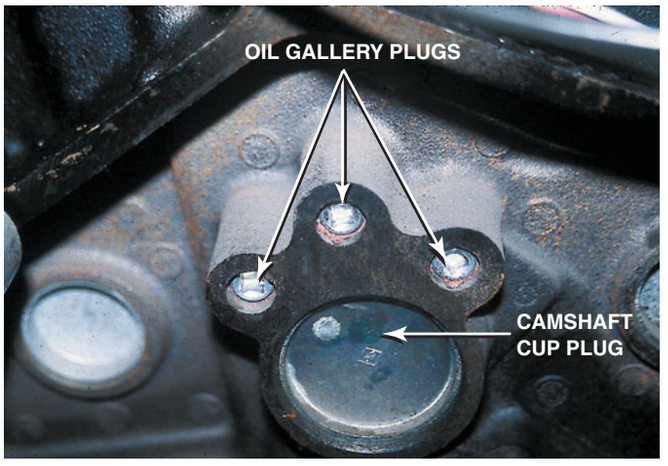


FIGURE 34–10 Typical oil gallery plugs on the rear of a Chevrolet small block V-8 engine.

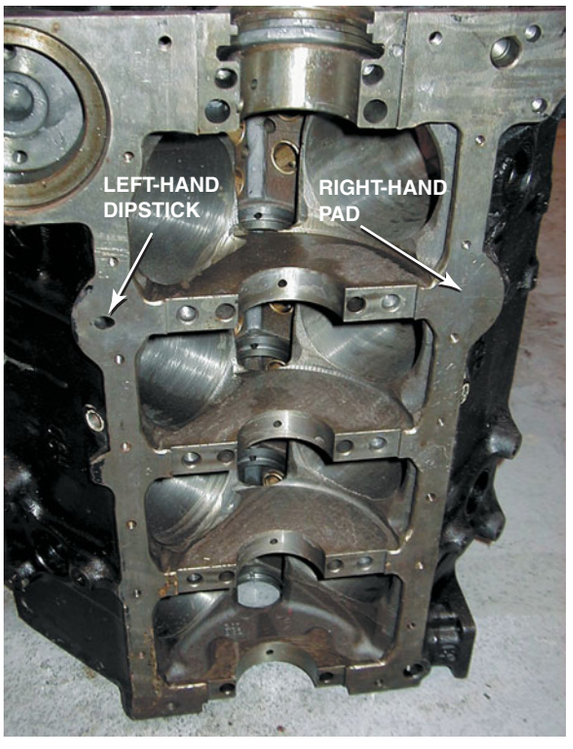


FIGURE 34–11 Small block Chevrolet block. Note the left-hand dipstick hole and a pad cast for a right-hand dipstick.

MAIN BEARING CAPS

The main bearing caps are cast or manufactured from sintered or billeted materials, separately from the block.

- They are machined and then installed on the block for a final bore finishing operation.
- With caps installed, the main bearing bores and cam bearing bores (on OHV engines) are machined to the correct size and alignment. On some engines, these bores are honed to a very fine finish and exact size.
- Main bearing caps are not interchangeable or reversible, because they are individually finished in place.
- Main bearing caps may have cast numbers indicating their position on the block. If not, they should be marked with numbers and arrows pointing toward the front of the engine.

Standard production engines usually use two bolts to hold the main bearing cap in place. ● **SEE FIGURE 34–12.**

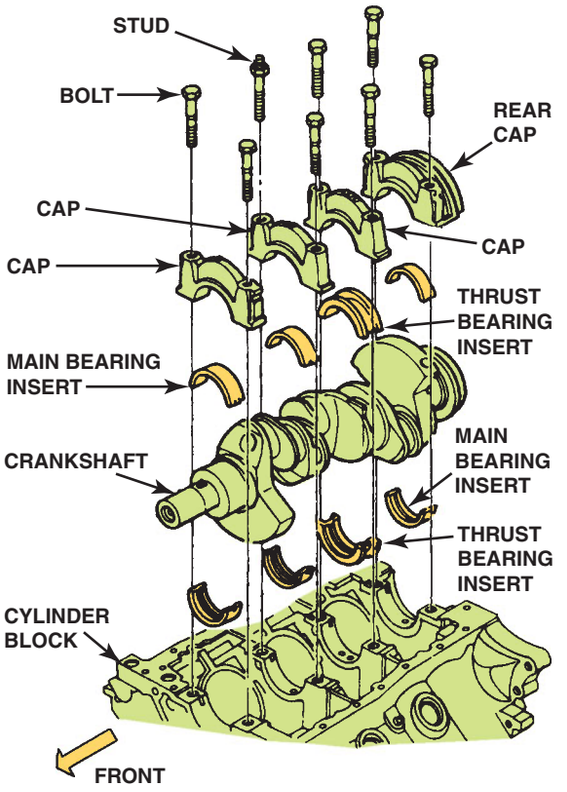


FIGURE 34–12 Two-bolt main bearing caps provide adequate bottom end strength for most engines.

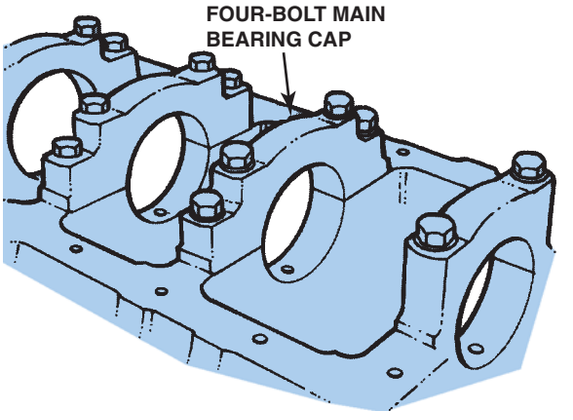


FIGURE 34–13 High-performance and truck engines often use four-bolt main bearing caps for greater durability.

Heavy-duty and high-performance engines often use additional main bearing support bolts. A four-bolt, and even six-bolt, main cap can be of a cross-bolted design in a deep skirt block or of a parallel design in a shallow skirt block. ● **SEE FIGURES 34–13 AND 34–14.**

Expansion force of the combustion chamber gases will try to push the head off the top and the crankshaft off the bottom of the block. The engine is held together with the head bolts and main bearing cap bolts screwed into bolt bosses and ribs in the block. The extra bolts on the main bearing cap help to support the crankshaft when there are high combustion pressures and mechanical loads, especially during high engine speed operation. Many engines use a **girdle** which ties all of the main bearing caps together to add strength to the lower part of the block. ● **SEE FIGURE 34–15.**

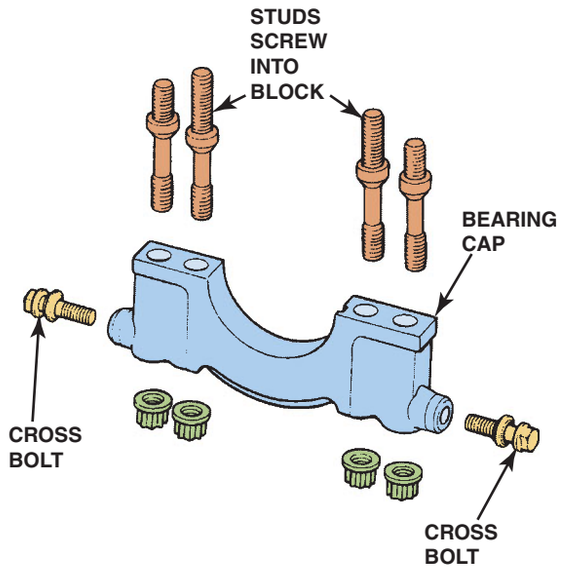


FIGURE 34–14 Some engines add to the strength of a four-bolt main bearing cap by also using cross bolts through the bolt on the sides of the main bearing caps.

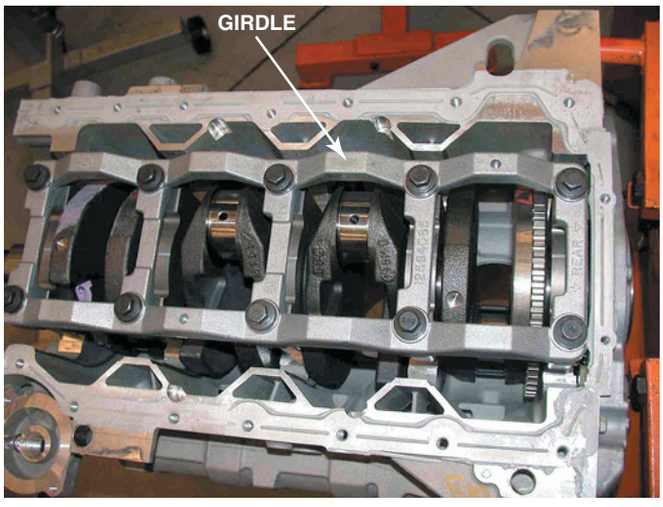


FIGURE 34–15 A girdle is used to tie all of the main bearing caps together.

ENGINE BLOCK SERVICE

PROCEDURES The engine block is the foundation of the engine. All parts of the block must be of the correct size and they must be aligned. The parts must also have the proper finishes if the engine is to function dependably for a normal service life. Engine blueprinting is the reconditioning of all the critical surfaces and dimensions so that the block is actually like new.

After a thorough cleaning, the block should be inspected for cracks or other flaws before machine work begins. After the block has been cleaned and the cracked checked, the block should be prepared in the following sequence.

OPERATION 1 Main bearing housing bore alignment, often called "align boring" (or honing)

OPERATION 2 Machining of the block deck surface parallel to the crankshaft

OPERATION 3 Cylinder boring and honing

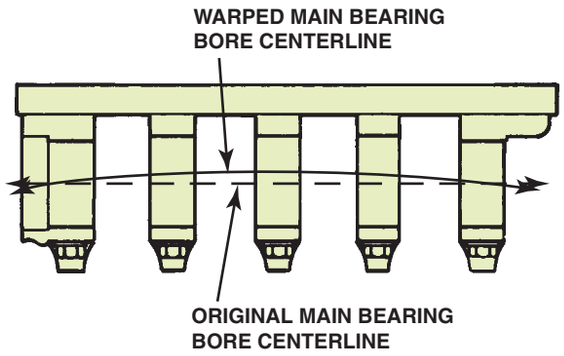


FIGURE 34–16 The main bearing bores of a warped block usually bend into a bowed shape. The greatest distortion is in the center bores.

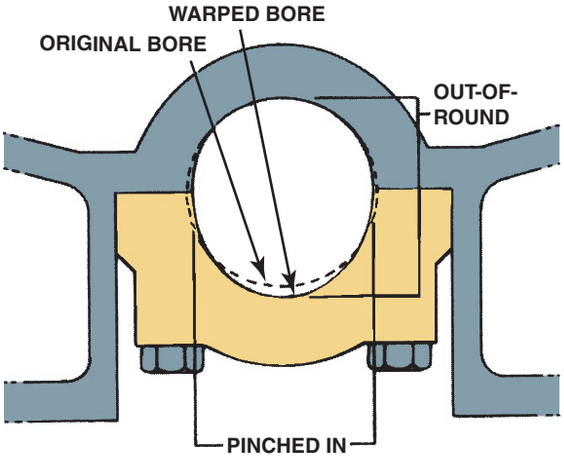


FIGURE 34–17 When the main bearing caps bow downward, they also pinch in at the parting line.

MAIN BEARING HOUSING BORE ALIGNMENT The main bearing journals of a straight crankshaft are in alignment. If the main bearing housing bores in the block are not in alignment, the crankshaft will bend as it rotates. This condition increases rotational friction of the crankshaft and will lead to premature bearing failure or a broken crankshaft. The original stress in the block casting is gradually relieved as the block is used. Some slight warpage may occur as the stress is relieved. In addition, the continued pounding caused by combustion will usually cause some stretch in the main bearing caps. ● **SEE FIGURE 34–16.**

The main bearing bores gradually bow upward and elongate vertically. This means that the bearing bore becomes smaller at the centerline as the block distorts, pinching the bore inward at the sides. ● **SEE FIGURE 34–17.**

The procedure includes the following steps.

STEP 1 The first step in determining the condition of the main bearing bores is to determine if the bore alignment in the block is straight. These bores are called the **saddles.** A precision ground straightedge and a feeler gauge are used to determine the amount of warpage. The amount of variation along the entire length of the block should not exceed 0.0015 in. (0.038 mm).

CAUTION: When performing this measurement, be sure that the block is resting on a flat surface. If the engine is mounted to an engine stand, the weight of the block on the unsupported end can cause an error in the measurement of the main bearing bores and saddle alignment.

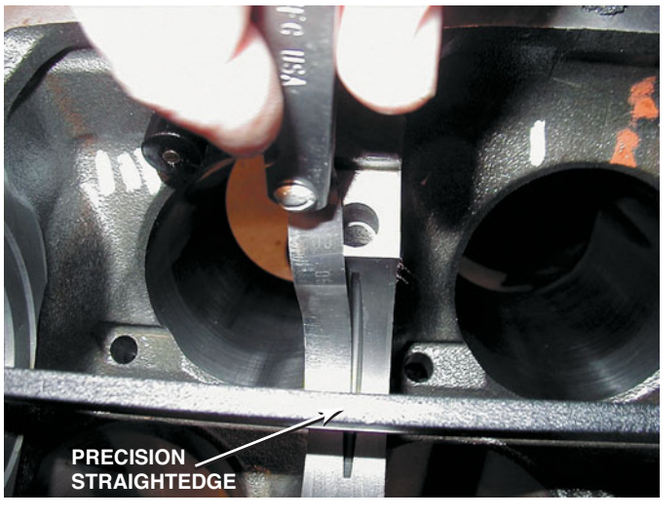


FIGURE 34–18 The main bearing bore alignment can be checked using a precision straightedge and a feeler gauge.

FREQUENTLY ASKED QUESTION

What Is a Seasoned Engine?

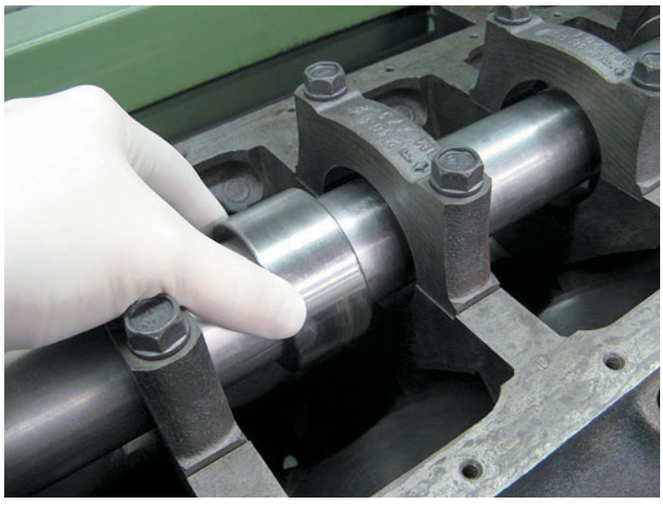
A new engine is machined and assembled within a few hours after the heads and block are cast from melted iron. Newly cast parts have internal stresses within the metal. The stress results from the different thickness of the metal sections in the head. Forces from combustion in the engine, plus continued heating and cooling, gradually relieve these stresses. By the time the engine has accumulated 20,000 to 30,000 miles (32,000 to 48,000 km), the stresses have been completely relieved. This is why some engine rebuilders prefer to work with used heads and blocks that are stress relieved. Used engines are often called "seasoned" because of the reduced stress and movement these components have as compared with new parts.

STEP 2 If the block saddles exceed one-and-a-half thousandth of an inch distortion, then align honing is required to restore the block. If the block saddles are straight, the bores should be measured to be sure that the bearing caps are not distorted. ● **SEE FIGURE 34–18.**

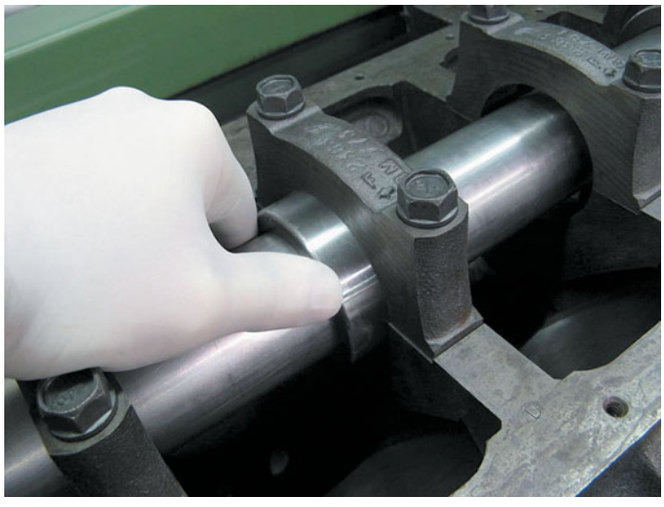
STEP 3 The bearing caps should be installed and the retaining bolts tightened to the specified torque before measuring the main bearing bores. Using a telescoping gauge, measure each bore in at least two directions. Check the service information for the specified main bearing bore diameter. The bearing bore should not vary by more than one-half of a thousandth of an inch or 0.0005 in. (0.0127 mm). A dial bore gauge is often used to measure the main bearing bore. Set up the dial bore gauge in the fixture with the necessary extensions to achieve the nominal main bearing bore diameter.

Check the service information for the specified main bearing bore diameter and determine the exact middle of the range.

ARBOR CHECK METHOD The arbor is installed, then all main caps are tightened to specifications. After tightening, the arbor is checked to make sure it rotates freely, indicating a true centerline. However, because of all the different diameters required, it is an expensive method. ● **SEE FIGURE 34–19.**



(a)

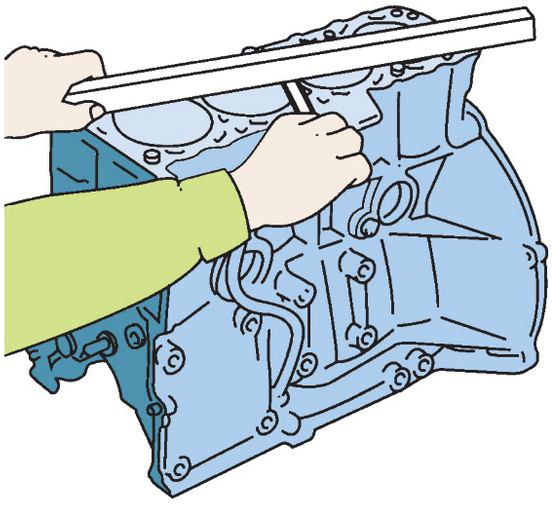


(b)

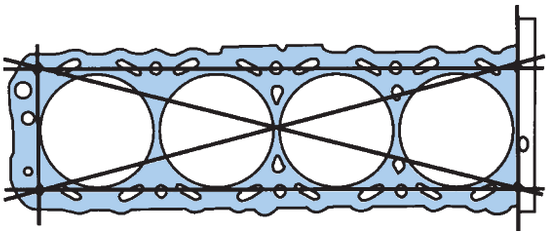
FIGURE 34–19 (a) A precision arbor can be used to check the main bearing bore alignment. (b) If the sleeve can be inserted into all of the main bearing bores, then they are aligned.

MACHINING THE DECK SURFACE OF THE BLOCK An engine should have the same combustion chamber size in each cylinder. For this to occur, each piston must come up an equal distance from the block deck. The connecting rods are attached to the rod bearing journals of the crankshaft. Pistons are attached to the connecting rods. As the crankshaft rotates, the pistons come to the top of the stroke. When all parts are sized equally, all the pistons will come up to the same level. This can only happen if the block deck is parallel to the main bearing bores. Therefore, the flatness of the block deck should be checked. ● **SEE FIGURE 34–20.**

The block deck must be resurfaced in a surfacing machine that can control the amount of metal removed when it is necessary to match the size of the combustion chambers. This procedure is called **decking the block.** The block is set up on a bar located in the main bearing saddles, or set up on the oil pan rails of the block. The bar is parallel to the direction of cutting head movement. The block is leveled sideways, and then the deck is resurfaced in the same manner as the head is resurfaced. ● **FIGURE 34–21** shows a block deck being resurfaced by grinding.



(a)



(b)

FIGURE 34–20 (a) Checking the flatness of the block deck surface using a straightedge and a feeler gauge. (b) To be sure that the top of the block is flat, check the block in six locations as shown.



FIGURE 34–21 Grinding the deck surface of the block.

DECK SURFACE FINISH

The surface finish of the block deck should be:

- 60 to 100 Ra (65 to 110 RMS) for cast iron
- 50 to 60 Ra (55 to 65 RMS) for aluminum block decks to be assured of a proper head gasket surface

The surface finish is determined by the type of grinding stone used, as well as the speed and coolant used in the finishing operation. The higher the surface finish number is, the rougher the surface.

CYLINDER BORING

Cylinders should be measured across the engine (perpendicular to the crankshaft), where the greatest wear occurs. In other words, measure the bores at 90 degrees to the piston pin. Most wear will be found just below the ridge, and the least amount of wear will occur below the lowest ring travel. ● **SEE FIGURE 34–22.**

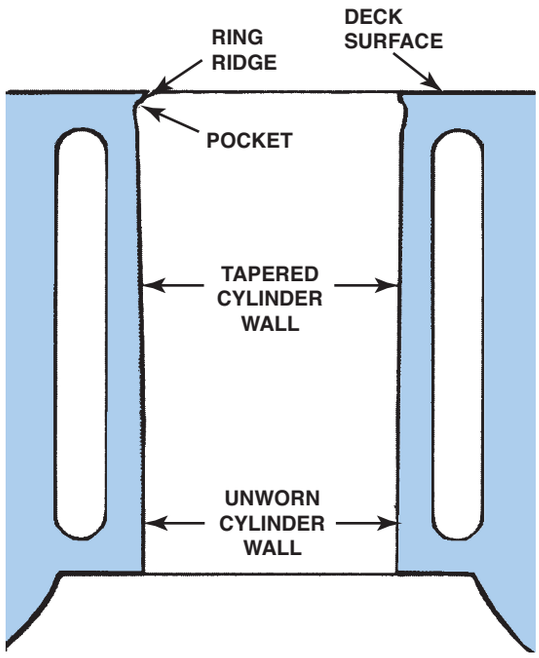


FIGURE 34–22 Cylinders wear in a taper, with most of the wear occurring at the top of the cylinder where the greatest amount of heat and pressure are created. The ridge is formed because the very top part of the cylinder is not contacted by the rings.

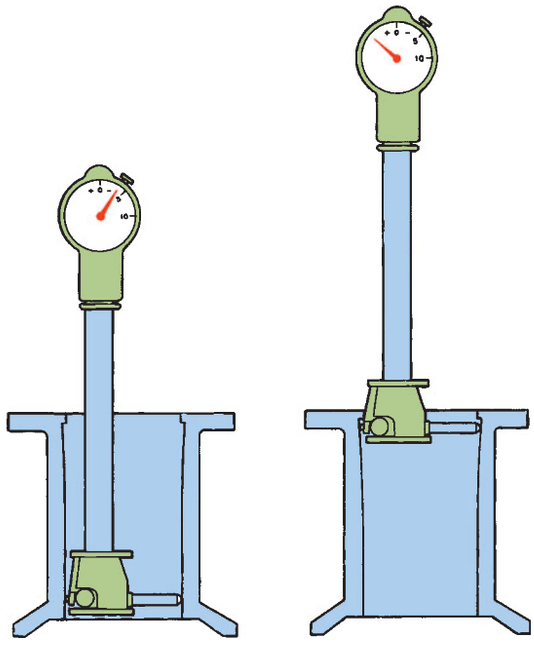


FIGURE 34–23 Using a dial bore gauge to measure the bore diameter at the top just below the ridge (maximum wear section) and at the bottom below the ring travel (minimum wear section). The difference between these two measurements is the amount of cylinder taper. Take the measurements in line with the crankshaft and then repeat the measurements at right angles to the centerline of the block in each cylinder to determine out-of-round.

The cylinder should be checked for out-of-round and taper. ● **SEE FIGURE 34–23.**

Most cylinders are serviceable if they:

- Are a maximum of 0.003 in. (0.076 mm) out-of-round
- Have no more than a 0.005 in. (0.127 mm) taper
- Have no deep scratches in the cylinder wall

NOTE: Always check the specifications for the engine being serviced. For example, the General Motors 4.8, 5.3, 5.7, 6, and 6.2 liter LS series V-8s have a maximum out-of-round of only 0.0003 in. (3/10 of one-thousandths of an inch). This specification is about one-third of the normal dimension of about 0.001 in.

The most effective way to correct excessive cylinder out-of-round, taper, or scoring is to rebore the cylinder. The rebored cylinder requires the use of a new, oversize piston.

The maximum bore oversize is determined by two factors.

1. Cylinder wall thickness—at least 0.17 in. for street engines and 0.2 in. for high-performance or racing applications
2. Size of the available oversize pistons

If in doubt as to the amount of overbore that is possible without causing structural weakness, an ultrasonic test should be performed on the block to determine the thickness of the cylinder walls. An ultrasonic tester can measure the thickness of the cylinder walls and is used to determine if a cylinder can be bored oversize and, if so, by how much. All cylinders should be tested. Variation in cylinder wall thickness occurs because of core shifting (moving) during the casting of the block. For best results, cylinders should be rebored to the smallest size possible.

HINT: The pistons that will be used should always be in hand before the cylinders are rebored. The cylinders are then bored and honed to match the exact size of the pistons.

The cylinder must be perpendicular to the crankshaft for normal bearing and piston life. If the block deck has been aligned with the crankshaft, it can be used to align the cylinders. Portable cylinder boring bars are clamped to the block deck. Heavy-duty production boring machines support the block on the main bearing bores.

Main bearing caps should be torqued in place when cylinders are being rebored. In precision boring, a torque plate is also bolted on in place of the cylinder head while boring cylinders. In this way, distortion is kept to a minimum. The general procedure used for reboring cylinders includes the following steps.

STEP 1 Set the boring bar up so that it is perpendicular to the crankshaft. It must be located over the center of the cylinder.

STEP 2 The cylinder center is found by installing centering pins in the bar.

STEP 3 The bar is lowered so that the centering pins are located near the bottom of the cylinder, where the least wear has occurred. This locates the boring bar over the original cylinder center. Once the boring bar is centered, the boring machine is clamped in place to hold it securely. This will allow the cylinder to be rebored on the original centerline, regardless of the amount of cylinder wear.

STEP 4 A sharp, properly ground cutting tool is installed and adjusted to the desired dimension. Rough cuts remove a great deal of metal on each pass of the cutting tool. The rough cut is followed by a fine cut that produces a much smoother and more accurate finish. Different-shaped tool bits are used for rough and finish boring.

STEP 5 The last cut is made to produce a diameter that is at least 0.002 in. (0.05 mm) smaller than the required diameter. ● **SEE FIGURE 34–24.**

SLEEVING THE CYLINDER

Sometimes, cylinders have a gouge so deep that it will not clean up when the cylinder is rebored to the maximum size. This could happen if the piston pin moved endways and rubbed on the cylinder wall. Cylinder blocks with deep gouges may be able to be salvaged by **sleeving** the cylinder. The cylinder wall thickness has to be checked to see if sleeving is possible. Sleeving a cylinder is done by boring the cylinder to a dimension that is greatly oversize to almost match the outside diameter of the cylinder sleeve. The sleeve is pressed into the rebored block and then the center of the sleeve is bored to the diameter required by the piston. The cylinder can be sized to use a standard-size piston when it is sleeved. ● **SEE FIGURE 34–25.**

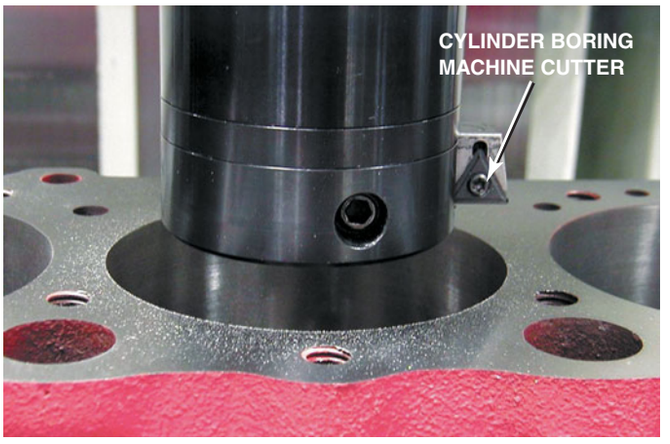


FIGURE 34–24 A cylinder boring machine is used to enlarge cylinder bore diameter so a replacement oversize piston can be used to restore a worn engine to useful service or to increase the displacement of the engine in an attempt to increase power output.

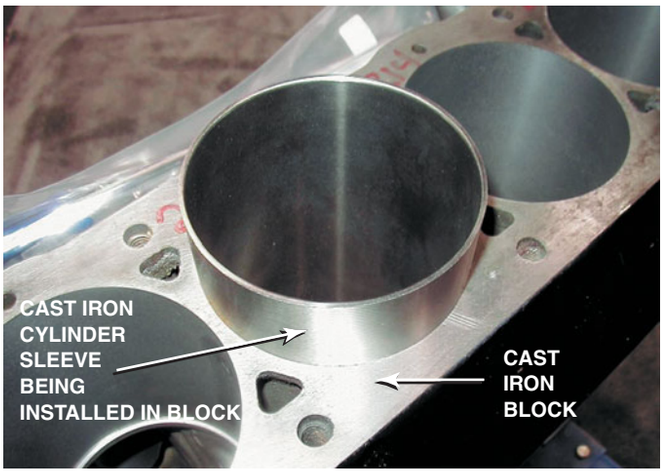


FIGURE 34–25 A dry cylinder sleeve can also be installed in a cast-iron block to repair a worn or cracked cylinder.

CYLINDER HONING

It is important to have the proper surface finish on the cylinder wall for the rings to seat against. Honing includes two basic operations depending on the application.

1. When installing new piston rings on a cylinder that is not being bored, some ring manufacturers recommend breaking the hard surface glaze on the cylinder wall with a hone before installing new piston rings. This process is often called “deglazing” the cylinder walls.
2. The cylinder wall should be honed to straighten the cylinder when the wall is wavy or scuffed. If honing is being done with the crankshaft remaining in the block, the crankshaft should be protected to keep honing chips from getting on the shaft.

Two types of hones are used for cylinder service.

- A *deglazing hone* removes the hard surface glaze remaining in the cylinder. It is a flexible hone that follows the shape of the cylinder wall, even when the wall is wavy. It cannot be used to straighten the cylinder. A brush-type (ball-type) deglazing hone is shown in **FIGURE 34–26.**
- A *sizing hone* can be used to straighten the cylinder and to provide a suitable surface for the piston rings. Honing the cylinder removes the fractured metal that is created by boring. The cylinders must be honed a minimum of 0.002 in. (0.05 mm) after boring to cut below the rough surface and provide an adequate finish. Honing leaves a plateau surface that can support the oil film for the rings and piston skirt. This plateau surface is achieved by first using a coarse stone followed by a smooth stone to achieve the desired surface. The process of using a coarse and fine stone is called **plateau honing.** **SEE FIGURE 34–27.**

Its honing stones are held in a rigid fixture with an expanding mechanism to control the size of the hone. The sizing hone can be used to straighten the cylinder taper by honing the lower cylinder diameter more than the upper diameter. As it rotates, the sizing hone only cuts the high spots so that cylinder out-of-round is also reduced. The cylinder wall surface finish is about the same when the cylinder is refinished with either type of hone. **SEE FIGURE 34–28.**

FREQUENTLY ASKED QUESTION

How Do I Determine What Oversize Bore Is Needed?

An easy way to calculate oversize piston size is to determine the amount of taper, double it, and add 0.010 in. (Taper × 2 + 0.010 in. = Oversize piston). Common oversize measurements include:

- 0.020 in.
- 0.030 in.
- 0.040 in.
- 0.060 in.

Use caution when boring for an oversize measurement larger than 0.030 in. due to potential engine damage caused from too thin cylinder walls.

FREQUENTLY ASKED QUESTION

What Is a Boring Hone?

Many shops now use "boring" hones instead of boring bars. Boring hones have the advantages of being able to resize and finish hone with only one machine setup. Often a diamond hone is used and rough honed to within about 0.003 in. of the finished bore size. Then a finish hone is used to provide the proper surface finish.

TECH TIP

Always Use Torque Plates

Torque plates are thick metal plates that are bolted to the cylinder block to duplicate the forces on the block that occur when the cylinder head is installed. Even though not all machine shops use torque plates during the boring operation, the use of torque plates during the final dimensional honing operation is beneficial. Without torque plates, cylinders can become out-of-round (up to 0.003 in.) and distorted when the cylinder heads are installed and torqued down. Even though the use of torque plates does not eliminate all distortion, their use helps to ensure a truer cylinder dimension. **SEE FIGURE 34–29.**



FIGURE 34–26 An assortment of ball-type deglazing hones. This type of hone does not straighten wavy cylinder walls.

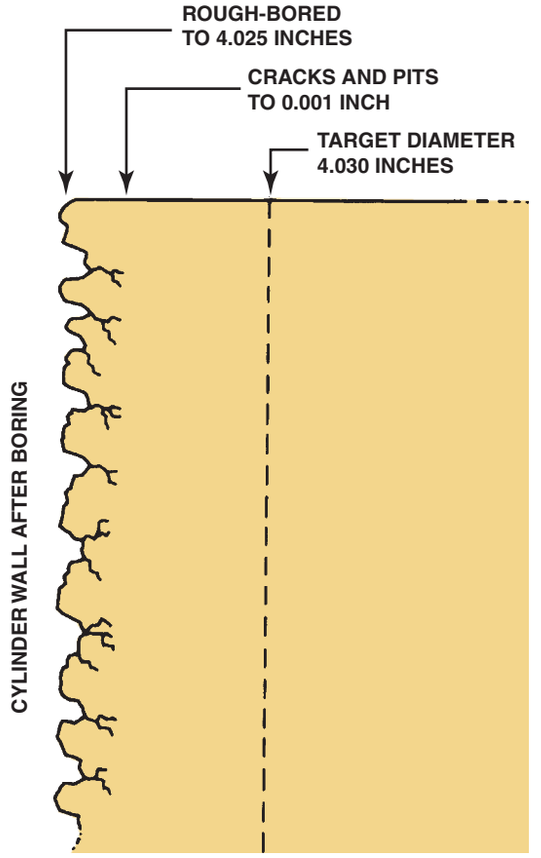


FIGURE 34–27 After boring, the cylinder surface is rough, pitted, and fractured to a depth of about 0.001 in.

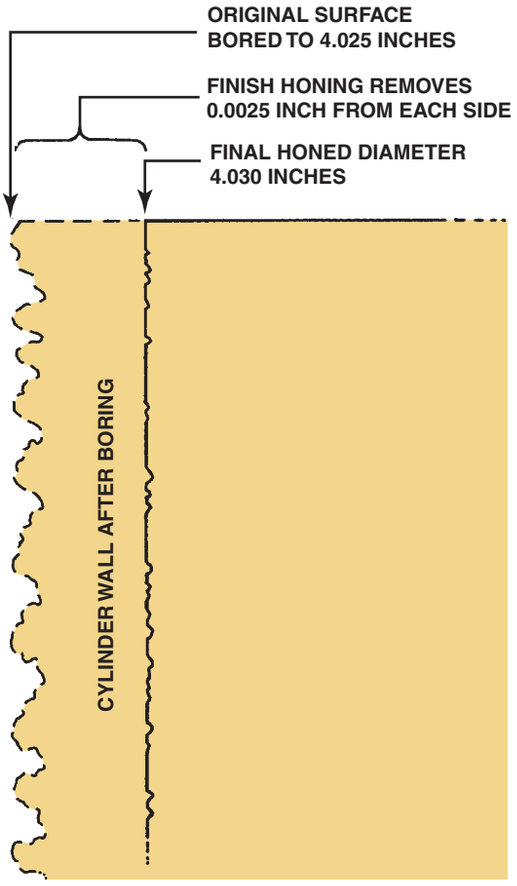


FIGURE 34–28 Honing enlarges the cylinder bore to the final size and leaves a plateau surface finish that retains oil.

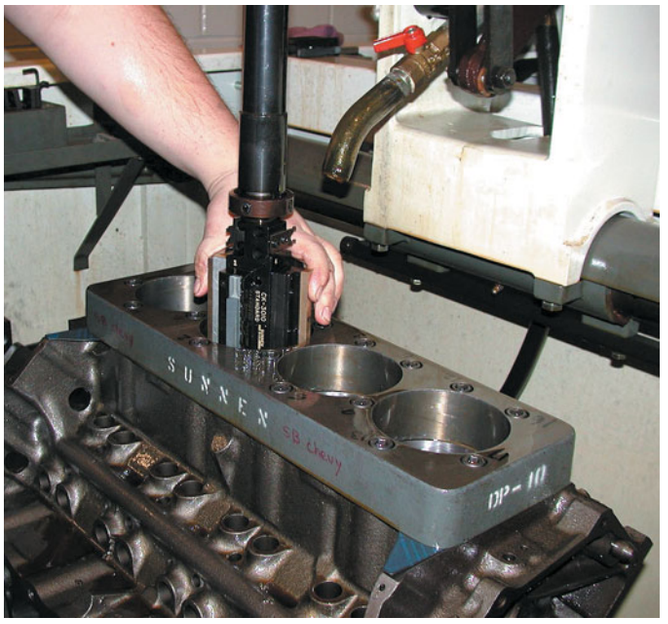


FIGURE 34–29 A torque plate being used during a cylinder honing operation. The thick piece of metal is bolted to the block and simulates the forces exerted on the block by the head bolts when the cylinder head is attached.

The hone is stroked up and down in the cylinder as it rotates to produce a **crosshatch finish** on the cylinder wall which aides in proper ring break-in. The speed that the operator moves the hone up and down controls the angle. Always check service information for the specified crosshatch angle.

The angle of the crosshatch should be between 20 and 60 degrees. Higher angles are produced when the hone is stroked more rapidly in the cylinder. A typical honed cylinder is pictured in ● **FIGURE 34–30.**

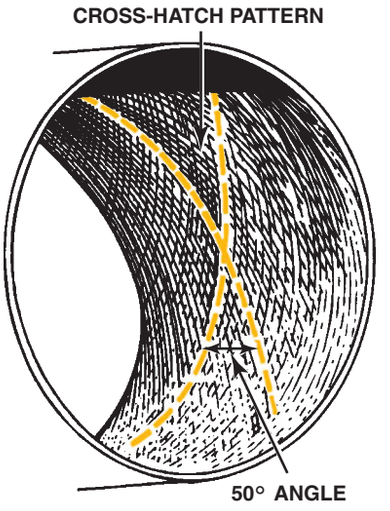


FIGURE 34–30 The crosshatched pattern holds oil to keep the rings from wearing excessively, and also keeps the rings against the cylinder wall for a gas-tight fit.

TECH TIP

Bore to Size, Hone for Clearance

Many engine rebuilders and remanufacturers bore the cylinders to the exact size of the oversize pistons that are to be used. After the block is bored to a standard oversize measurement, the cylinder is honed. The rigid hone stones, along with an experienced operator, can increase the bore size by 0.001 to 0.003 in. (one to three thousandths of an inch) for the typical clearance needed between the piston and the cylinder walls.

For example:

Actual piston diameter = 4.028 in.
Bore diameter = 4.028 in.
Diameter after honing = 4.030 in.
Amount removed by honing = 0.002 in.

NOTE: The minimum amount recommended to be removed by honing is 0.002 in., to remove the fractured metal in the cylinder wall caused by boring.

CYLINDER SURFACE FINISH The size of the abrasive particles in the grinding and honing stones controls the surface finish. The size of the abrasive is called the **grit size.** The abrasive is sifted through a screen mesh to sort out the grit size. A coarse-mesh screen has few wires in each square inch, so large pieces can fall through the screen. A fine-mesh screen has many wires in each square inch so that only small pieces can fall through. The screen is used to separate the different grit sizes. The grit size is the number of wires in each square inch of the mesh. A low-numbered grit has large pieces of abrasive material; a high-numbered grit has small pieces of abrasive material. The higher the grit number is, the smoother the surface finish will be. ● **SEE CHART 34–1.**

A given grit size will produce the same finish as long as the cutting pressure is constant. With the same grit size, light cutting

GRIT SIZING CHART		
GRIT/SIEVE SIZE	INCHES	MILLIMETERS
12	0.063	1.600
16	0.043	1.092
20	0.037	0.939
24	0.027	0.685
30	0.022	0.558
36	0.019	0.482
46	0.014	0.355
54	0.012	0.304
60	0.010	0.254
70	0.008	0.203
80	0.0065	0.165
90	0.0057	0.144
100	0.0048	0.121
120	0.0040	0.101
150	0.0035	0.088
180	0.0030	0.076
220	0.0025	0.063
240	0.0020	0.050

CHART 34–1

Grit size numbers and their dimensions in inches and millimeters.

pressure produces fine finishes, and heavy cutting pressure produces rough finishes.

The surface finish should match the surface required for the type of piston rings to be used. Typical grit and surface finish standards include the following:

- Chrome rings: 180 grit (25 to 35 microinches)
- Cast-iron rings: 200 grit (20 to 30 microinches)
- Moly rings: 220 grit (18 to 25 microinches)

NOTE: The correct honing oil and coolant are critical to proper operation of the honing equipment and to the quality of the finished cylinders.

CYLINDER HONING PROCEDURE The procedure includes the following steps.

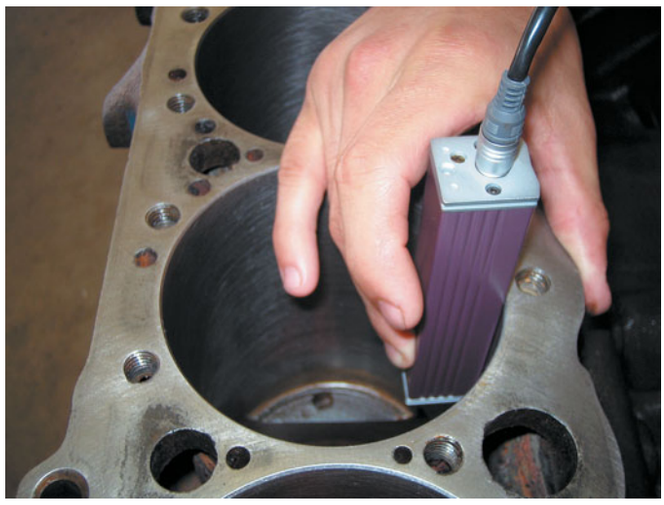
STEP 1 The hone is placed in the cylinder. Before the drive motor is turned on, the hone is moved up and down in the cylinder to get the feel of the stroke length needed. The end of the hone should just break out of the cylinder bore on each end. The hone must *not* be pulled from the top of the cylinder while it is rotating. Also, it must not be pushed so low in the cylinder that it hits the main bearing web or crankshaft.

STEP 2 The sizing hone is adjusted to give a solid drag at the lower end of the stroke.

STEP 3 The hone drive motor is turned on and stroking begins immediately. Stroking continues until the sound of the drag is reduced.

STEP 4 The hone drive motor is turned off while it is still stroking. Stroking is stopped as the rotation of the hone stops. After rotation stops, the hone is collapsed and removed from the cylinder.

STEP 5 The cylinder is examined to check the bore size and finish of the wall. If more honing is needed, the cylinder is again coated with honing oil and the cylinder is honed again. The finished cylinder should be within 0.0005 in. (0.013 mm) on both out-of-round and taper measurements. ● **SEE FIGURE 34–31** for an example of cylinder surface finish reading.



(a)



(b)

FIGURE 34–31 (a) The surface finish tool is being held against the cylinder wall. (b) The reading indicates the Ra roughness of the cylinder. More work is needed if moly piston rings are to be used.

CHAMFERING THE CYLINDER BORES Whenever machining is performed on the block such as boring and decking, the top edge of the cylinder bores have sharp edges. These sharp edges must be removed to allow the piston with rings to be installed. The slight chamfer allows the rings to enter the cylinder easily when the pistons are installed. A tapered rubber cone covered in sanding cloth is used to remove the sharp edges. ● **SEE FIGURE 34–32.**

BLOCK PREPARATION FOR ASSEMBLY

BLOCK CLEANING After the cylinders have been honed and before the block is cleaned, use a sandpaper cone to chamfer the top edge of the cylinder. Cleaning the honed cylinder wall is an important part of the honing process. If any grit remains on the cylinder



FIGURE 34–32 Using a tapered sanding cone to remove the sharp edges at the top of the cylinders created when the block was machined.

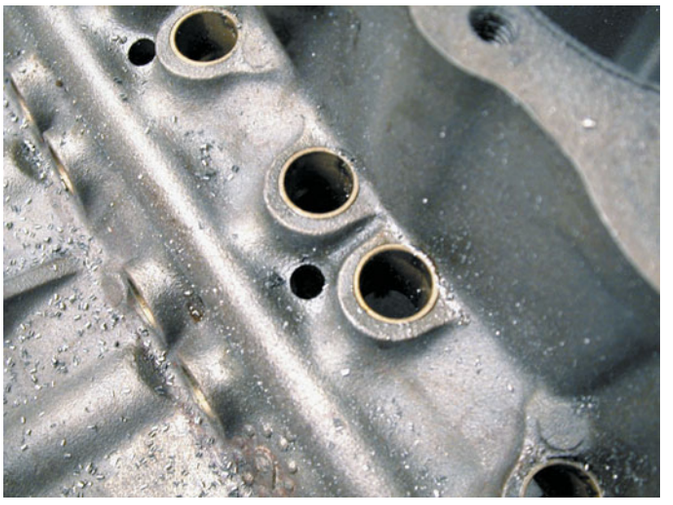


FIGURE 34–33 High-performance engine builders will often install bronze sleeves in the lifter bores.

TECH TIP

Install Lifter Bore Bushings

Lifter bores in a block can be out-of-square with the camshaft, resulting in premature camshaft wear and variations in the valve timing from cylinder to cylinder. To correct for this variation, the lifter bores are bored and reamed oversize using a fixture fastened to the block deck to ensure proper alignment. Bronze lifter bushings are then installed and finish honed to achieve the correct lifter-to-bore clearance. ● **SEE FIGURE 34–33.**

The lifter bores should be "honed" with a ball-type hone. This should be done even if they are "in-line" and do not need bushings. This is often overlooked by technicians and can lead to lifter problems later on, causing lifters to stick on the bores.

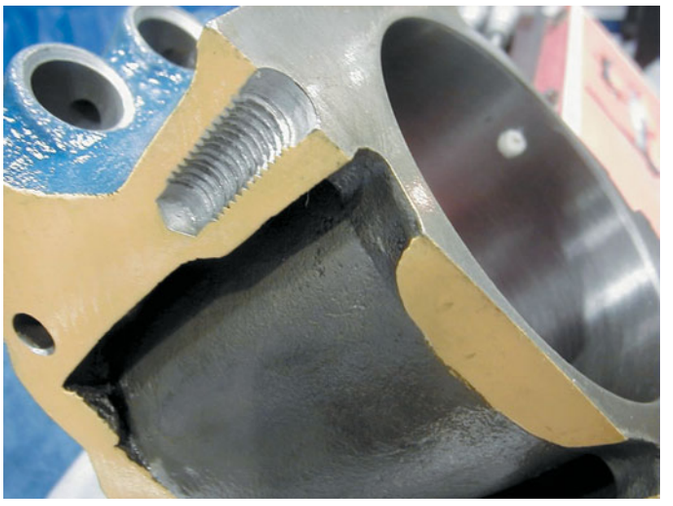


FIGURE 34–34 Notice on this cutaway engine block that some of the head bolt holes do not extend too far into the block and dead end. Debris can accumulate at the bottom of these holes and it must be cleaned out before final assembly.

wall, it will rapidly wear the piston rings. This wear will cause premature failure of the reconditioning job. Degreasing and decarbonizing procedures will only remove the honing oil but will *not* remove the abrasive. The *best* way to clean the honed cylinders is to scrub the cylinder wall with a brush using a mixture of *soap* or *detergent* and *water.* The block is scrubbed until it is absolutely clean. This can be determined by wiping the cylinder wall with a clean lint free cloth. The cloth will pick up no soil when the cylinder wall is clean. Be sure that the cylinders are dried as soon as possible to avoid rust from forming.

BLOCK DETAILING Before the engine block can be assembled, a final detailed cleaning should be performed.

1. All oil passages (galleries) should be cleaned by running a long bottle-type brush through all holes in the block.
2. All tapped holes should have the sharp edges at the top of the holes removed (chamfered) and cleaned with the correct size of thread chaser to remove any dirt and burrs. ● **SEE FIGURES 34–34 AND 34–35.**
3. Coat the newly cleaned block with fogging oil to prevent rust. Cover the block with a large plastic bag to keep out dirt until it is time to assemble the engine.

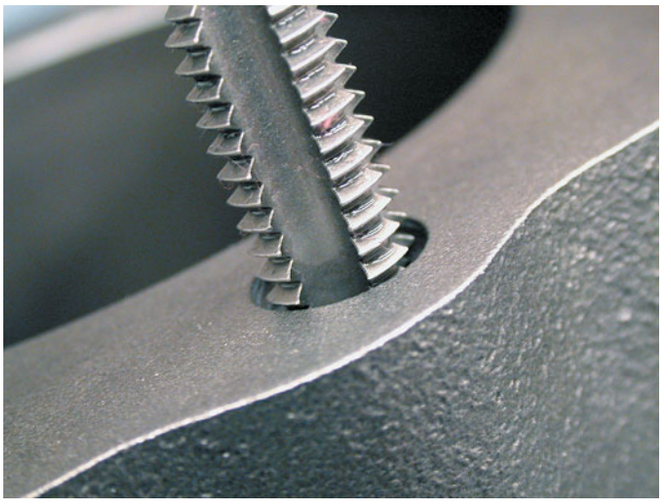


FIGURE 34–35 A tread chaser or bottoming tap should be used in all threaded holes before assembling the engine.

REVIEW QUESTIONS

1. How is Styrofoam used to cast an engine block?
2. What does “decking the block” mean?
3. What is the difference between deglazing and honing a cylinder?
4. What is the best method to use to clean an engine block after honing?

CHAPTER QUIZ

1. The block deck is the _____.
   a. Bottom (pan rail) of the block
   b. Top surface of the block
   c. Valley surface of a V-type engine
   d. Area where the engine mounts are attached to the block
2. The surface finish for the cylinder walls usually depends on _____.
   a. The type of piston rings to be used
   b. The type of engine oil that is going to be used in the engine
   c. The cylinder wall-to-piston clearance
   d. Both b and c
3. What should be installed and torqued to factory specification before machining a block?
   a. Front timing chain cover
   b. Main bearing caps
   c. Oil pan
   d. All of the above
4. Cast iron has about how much carbon content?
   a. Less than 1%
   b. 2%
   c. 3%
   d. 4% or higher
5. Engine blocks can be manufactured using which method(s)?
   a. Sand cast
   b. Sand cast or die cast
   c. Extruded cylinder
   d. Machined from a solid piece of metal (either cast iron or aluminum)
6. A bedplate is located between the _____ and the _____.
   a. Cylinder bores; water jacket
   b. Cylinder head; block deck
   c. Bottom of the block; oil pan
   d. Block deck; cylinder bore
7. Siamese cylinder bores are _____.
   a. Cylinders that do not have a coolant passage between them
   b. Aluminum cylinders
   c. Another name for cylinder liners
   d. Cast-iron cylinders
8. Ultrasonic testing is used to test _____.
   a. For cracks in the block
   b. Surface finish of the cylinder bores
   c. Cylinder wall thickness
   d. Both b and c
9. An engine block should be machined in which order?
   a. Align honing, cylinder boring, block deck machining
   b. Block decking, align honing, cylinder boring
   c. Cylinder boring, align honing, block decking
   d. Align honing, block decking, cylinder boring
10. After the engine block has been machined, it should be cleaned using _____.
    a. Soap and water
    b. SAE 10W-30 oil and a shop cloth
    c. Sprayed-on brake cleaner to remove the cutting oil
    d. Sprayed-on WD-40

chapter 35

CRANKSHAFTS, BALANCE SHAFTS, AND BEARINGS

OBJECTIVES: **After studying Chapter 35, the reader should be able to:** • Prepare for ASE Engine Repair (A1) certification test content area “C” (Engine Block Diagnosis and Repair). • Describe the purpose and function of a crankshaft. • Discuss how to measure crankshafts. • Explain how crankshafts are machined and polished. • Discuss the purpose and function of balance shafts. • Discuss engine bearing construction and installation procedures.

KEY TERMS: Aluminum 375 • Amplitude 369 • Babbitt 375 • Bank 367 • Bearing crown 374 • Bearing shell 375 • Billet 367 • Case hardening 366 • Conformability 376 • Copper-lead alloy 375 • Corrosion resistance 377 • Counterweights 369 • Crankpins 365 • Crankshaft centerline 365 • Crush 378 • Elastomer 369 • Electroplating 375 • Embedability 377 • Fatigue life 376 • Flying web 369 • Frequency 369 • Full round bearing 379 • Fully counterweighted 369 • Half-shell bearing 376 • Hub 369 • Inertia ring 369 • Nitriding 366 • Overlay 375 • Plain bearing 374 • Precision insert-type bearing shells 376 • Primary vibration 371 • Resonate 369 • Score resistance 377 • Secondary vibration 371 • Sleeve bearing 374 • Splay angle 369 • Split-type (half-shell) bearing 379 • Spread 378 • Spun bearing 378 • Surface finish 366 • Thrust bearing 365 • Tuftriding 366 • Work hardened 376

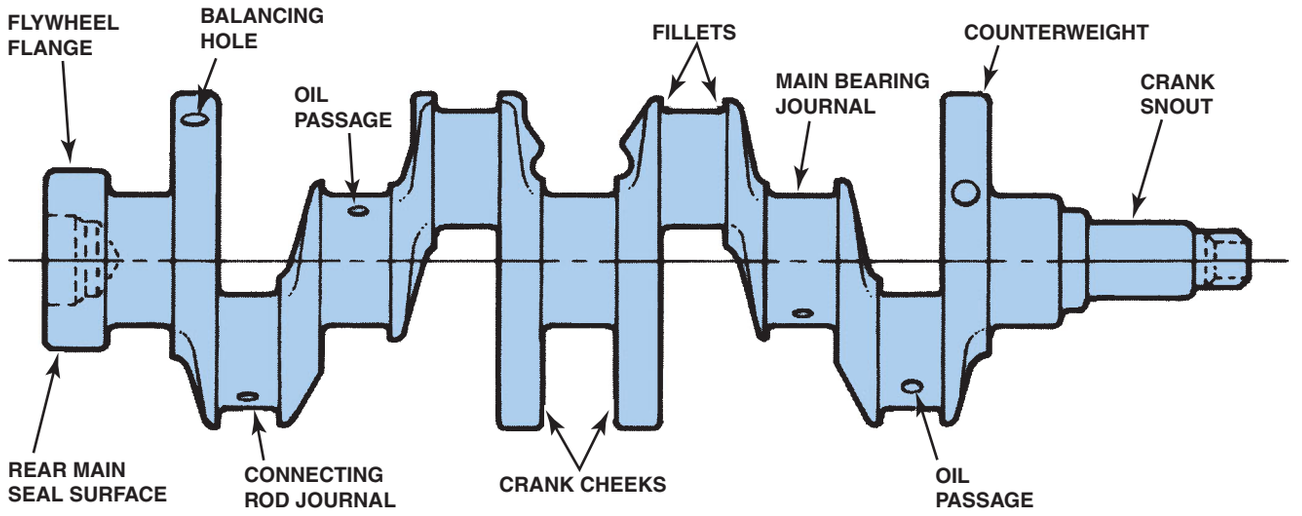


FIGURE 35–1 Typical crankshaft with main journals that are supported by main bearings in the block. Rod journals are offset from the crankshaft centerline.

CRANKSHAFT

PURPOSE AND FUNCTION Power from expanding gases in the combustion chamber is delivered to the crankshaft through the piston, piston pin, and connecting rod. The connecting rods and their bearings are attached to a bearing journal on the crank throw. The crank throw is offset from the **crankshaft centerline.** The distance between the centerline of the connecting rod bearing journal and the centerline of the crankshaft main bearing journal determines the stroke of the engine. The engine stroke is calculated by multiplying the distance between the two centerlines by 2. The combustion force is applied to the crank throw after the crankshaft has moved past top center. This produces the turning effort or torque, which rotates the crankshaft. The crankshaft rotates on the main bearings. These bearings are split in half so that they can be assembled around the crankshaft main bearing journals. The crankshaft includes the following parts.

- Main bearing journals
- Rod bearing journals
- Crankshaft throws
- Counterweights
- Front snout
- Flywheel flange
- Keyways
- Oil passages

● **SEE FIGURE 35–1.**

MAIN BEARING JOURNALS The crankshaft rotates in the cylinder block supported on main bearings. ● **SEE FIGURE 35–2.**

The main bearings support the crankshaft and allow it to rotate easily without excessive wear. The number of cylinders usually determines the number of main bearings.

- Four-cylinder engines and V-8 engines usually have five main bearings.
- Inline 6-cylinder engines usually have seven main bearings.
- V-6 engines normally have only four main bearings.

The crankshaft also must be able to absorb loads applied longitudinally (end to end) or thrust loads from the clutch on a manual transmission vehicle or the torque converter on a vehicle equipped with an automatic transmission. Thrust loads are forces that push and pull the crankshaft forward and rearward in the engine block. A **thrust bearing** supports these loads and maintains the front-to-rear position of the crankshaft in the block. ● **SEE FIGURE 35–3.**

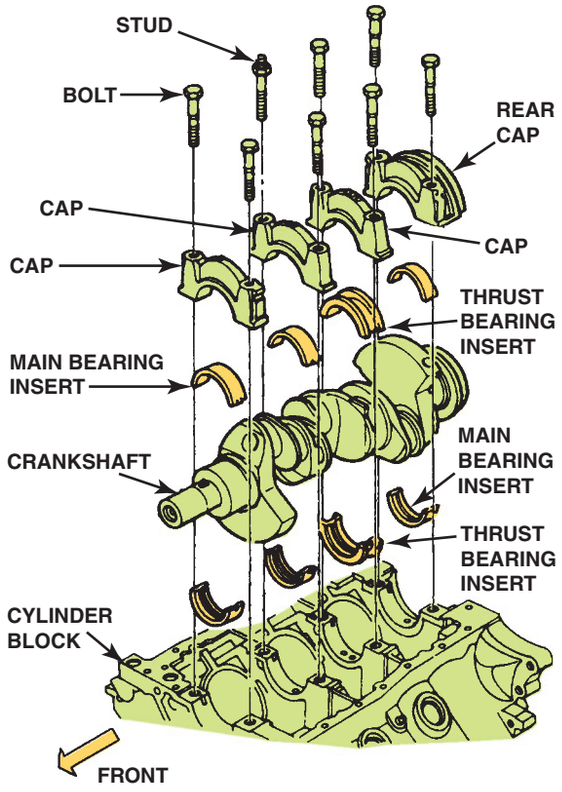


FIGURE 35–2 The crankshaft rotates on main bearings. Longitudinal (end-to-end) movement is controlled by the thrust bearing.

The thrust surface on many engines is usually located at the middle or one of the end main bearings. On most engines, the bearing insert for the main bearing is equipped with thrust bearing flanges that ride against the thrust surface.

ROD BEARING JOURNALS The rod bearing journals, also called **crankpins,** are offset from the centerline of the crank. Insert-type bearings fit between the big end of the connecting rod and the crankpin of the crankshaft. The crankshaft throw distance that

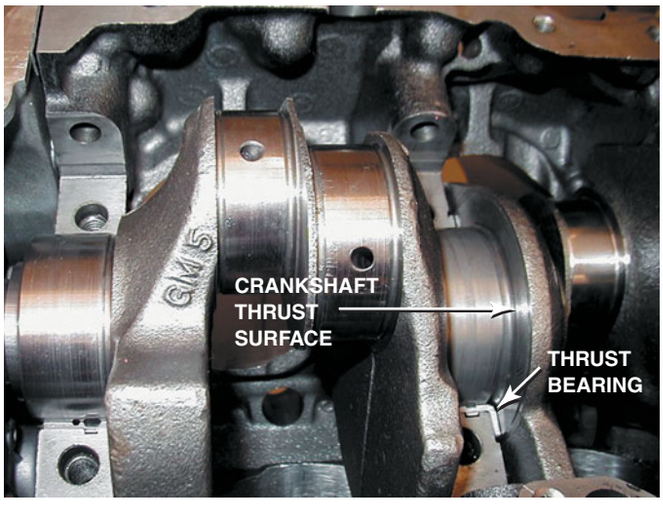


FIGURE 35–3 A ground surface on one of the crankshaft cheeks next to a main bearing supports thrust loads on the crank.



FIGURE 35–5 Wide separation lines of a forged crankshaft.

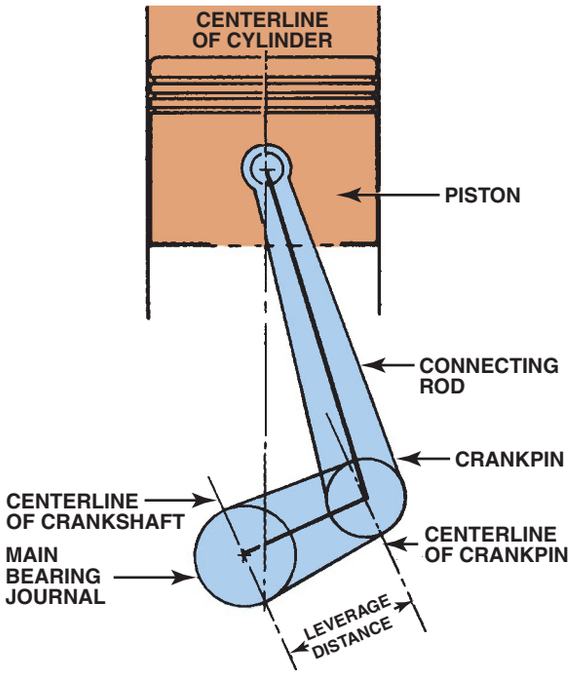


FIGURE 35–4 The distance from the crankpin centerline to the centerline of the crankshaft determines the stroke, which is the leverage available to turn the crankshaft.

measures one-half of the stroke has a direct relationship to the displacement of the engine.

Engine stroke is equal to *twice* the leverage distance or two times the length of the crankshaft throw. ● **SEE FIGURE 35–4.**

SURFACE FINISH All crankshaft journals are ground to a very smooth finish. **Surface finish** is measured in microinches; and the smaller the number, the smoother the surface. The typical specification for main and rod crankshaft journals is between 10 and 20 roughness average (Ra). This very smooth surface finish is achieved by polishing the crank journals after the grinding operation.

JOURNAL HARDNESS To improve wear resistance, some manufacturers harden the crankshaft journals. Methods used to harden the crankshaft journals include:

- **Case hardening,** where only the outer portion of the surface is hardened. Case hardening involves heating the crankshaft and adding carbon to the journals where it causes the outer surface to become harder than the rest of the crankshaft. If the entire crankshaft was hardened, it would become too brittle to absorb the torsional stresses of normal engine operation.
- **Nitriding,** when the crankshaft is heated to about 1,000°F (540°C) in a furnace filled with ammonia gas, and then allowed to cool. The process adds nitrogen (from the ammonia) into the surface of the metal-forming hard nitrides in the surface of the crankshaft to a depth of about 0.007 in. (0.8 mm).
- **Tuftriding,** another variation of this process, involves heating the crankshaft in a molten cyanide salt bath. Tuftriding is a trade name of General Motors.

CRANKSHAFT CONSTRUCTION

FORGED Crankshafts used in high-production automotive engines may be either forged or cast. Forged crankshafts are stronger than the cast crankshaft, but they are more expensive. Forged crankshafts may have a wide separation line. The wide separation line is the result of a grinding process to remove the metal that was extruded from the forging die during the forging process. ● **SEE FIGURE 35–5.**

Most high-performance forged crankshafts are made from SAE 4340 or a similar type of steel. The crankshaft is formed from a hot steel billet through the use of a series of forging dies. Each die changes the shape of the billet slightly. The crankshaft blank is finally formed with the last die. The blanks are then machined to finish the crankshaft. Forging makes a very dense, tough crankshaft with the metal's grain structure running parallel to the principal direction of stress.

Two methods are used to forge crankshafts.

- One method is to forge the crankshaft *in place.* This is followed by straightening. The forging in place method is primarily used with forged 4- and 6-cylinder crankshafts.
- A second method is to forge the crankshaft in a *single plane.* It is then twisted in the main bearing journal to index the throws at the desired angles. Most newer crankshafts are not twisted.

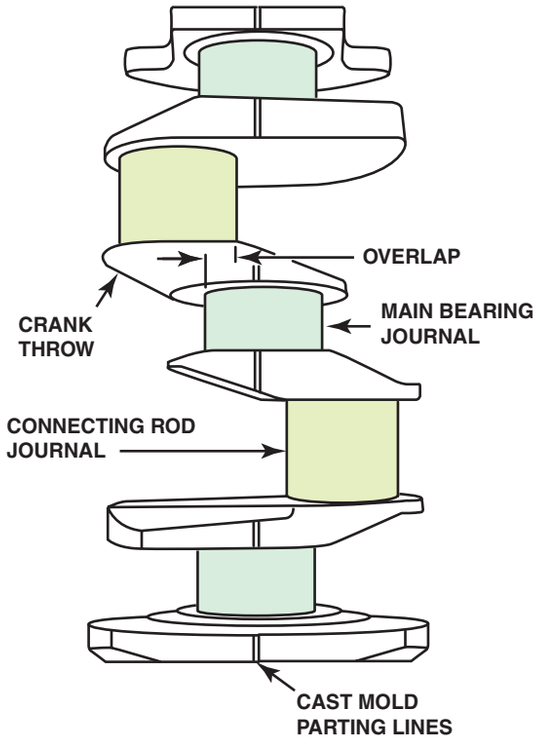


FIGURE 35–6 Cast crankshaft showing the bearing journal overlap and a straight, narrow cast mold parting line. The amount of overlap determines the strength of the crankshaft.

CAST CRANKSHAFTS

Casting materials and techniques have improved cast crankshaft quality so that cast crankshafts are used in most production automotive engines. Automotive crankshafts may be cast in steel, nodular iron, or malleable iron. Advantages of a cast crankshaft are as follows:

- Crankshaft material and machining costs are less than they are with forging. The reason is that the crankshaft can be made close to the required shape and size, including all complicated counterweights. The only machining required on a carefully designed cast crankshaft is the grinding of bearing journal surfaces and the finishing of front and rear drive ends.
- Metal grain structure in the cast crankshaft is uniform and random throughout; therefore, the shaft is able to handle loads from all directions.
- Counterweights on cast crankshafts are slightly larger than counterweights on a forged crankshaft, because the cast shaft metal is less dense and therefore somewhat lighter.

The narrow mold parting surface lines can be seen on the cast crankshaft in ● **FIGURE 35–6.**

BILLET CRANKSHAFTS

A billet crankshaft is machined from a solid piece of forged steel called a **billet.** This solid piece of steel, usually SAE 4340, is then machined through several operations to create a finished crankshaft.

The advantages of a billet crankshaft include:

- Uniform grain structure created by the forging process
- Stiff, strong, and very durable

The disadvantage is the high cost. Billet crankshafts tend to be very expensive because of the large amount of material removal during the machining process and the high material cost and the additional heat treatment required. ● **SEE FIGURE 35–7.**

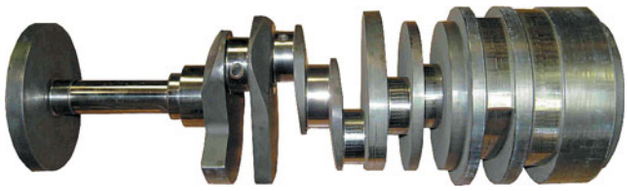


FIGURE 35–7 A billet crankshaft showing how it is machined from a large round roll of steel, usually 4340 steel, at the right and the finished crankshaft on the left.

CRANKSHAFT OILING HOLES

PURPOSE AND FUNCTION

The crankshaft is drilled to allow oil from the main bearing oil groove to be directed to the connecting rod bearings. ● **SEE FIGURE 35–8.**

The oil on the bearings forms a hydrodynamic oil film to support bearing loads. Some of the oil may be sprayed out through a spit or bleed hole in the connecting rod. The rest of the oil leaks from the edges of the bearing. It is thrown from the bearing against the inside surfaces of the engine. Some of the oil that is thrown from the crankshaft bearings will land on the camshaft to lubricate the lobes. A part of the throw-off, oil splashes on the cylinder wall to lubricate the piston and rings.

Stress tends to concentrate at oil holes drilled through the crankshaft journals. These holes are usually located where the crankshaft loads and stresses are the lowest. The edges of the oil holes are carefully chamfered to relieve as much stress concentration as possible. Chamfered oil holes are shown in ● **FIGURE 35–9.**

ENGINE CRANKSHAFT TYPES

V-8 ENGINE ARRANGEMENT

The V-8 engine has four inline cylinders in each of the two blocks that are placed at a 90-degree angle to each other. Each group of four inline cylinders is called a **bank.** The crankshaft for the V-8 engine has four throws. The connecting rods from two cylinders are connected to each throw, one from each bank. This arrangement results in a condition of being only minimally unbalanced.

The V-8 engine crankshaft has two planes, so there is one throw every 90 degrees. A plane is a flat surface that cuts through the part. These planes could be seen if the crankshaft were cut lengthwise through the center of the main bearing and crankpin journals. Looking at the front of the crankshaft:

- The first throw is at 360 degrees (up).
- The second throw is at 90 degrees (to the right).
- The third throw is at 270 degrees (to the left).
- The fourth throw is at 180 degrees (down).

In operation with this arrangement, one piston reaches top center at each 90 degrees of crankshaft rotation so that the engine operates smoothly with even firing at each 90 degrees of crankshaft rotation.

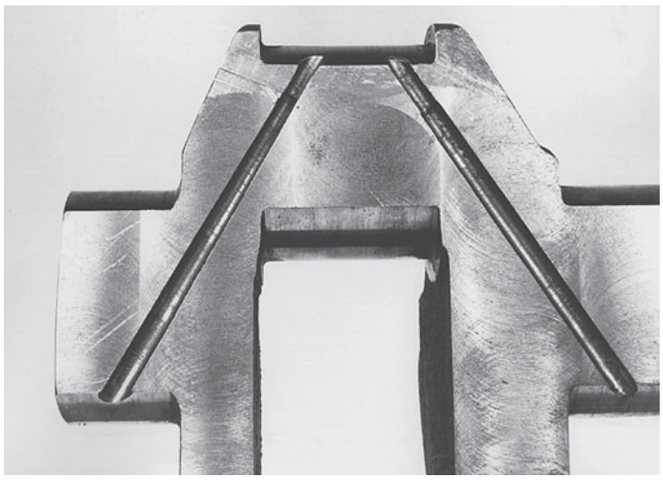


FIGURE 35–8 Crankshaft sawed in half, showing drilled oil passages between the main and rod bearing journals.

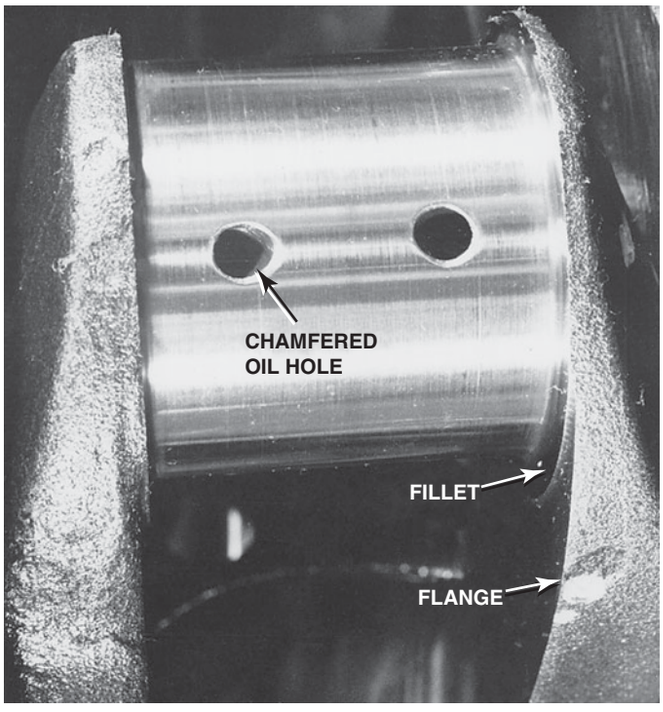


FIGURE 35–9 Typical chamfered hole in a crankshaft bearing journal.

FOUR-CYLINDER ENGINE CRANKSHAFTS

The crankshaft used on 4-cylinder inline engines has four throws on a single plane. There is usually a main bearing journal between each throw, making it a five main bearing crankshaft. Pistons also move as pairs in this engine.

- Pistons in cylinders 1 and 4 move together, and pistons 2 and 3 move together.
- Each piston in a pair is 360 degrees out-of-phase with the other piston in the 720-degree four-stroke cycle. With this arrangement, the 4-cylinder inline engine fires one cylinder at each 180 degrees of crankshaft rotation.

A 4-cylinder opposed (flat) engine and a 90-degree V-4 engine have crankshafts that look like that of the 4-cylinder inline engine.

FIVE-CYLINDER ENGINE CRANKSHAFTS

The inline 5-cylinder engine has a five-throw crankshaft with one throw at each 72 degrees. Six main bearings are used on this crankshaft. The piston in one cylinder reaches top center at each 144 degrees of crankshaft rotation. Dynamic balancing has been one of the major problems with this engine design, yet the vibration was satisfactorily dampened and isolated on both the Audi and Acura 5-cylinder engines.

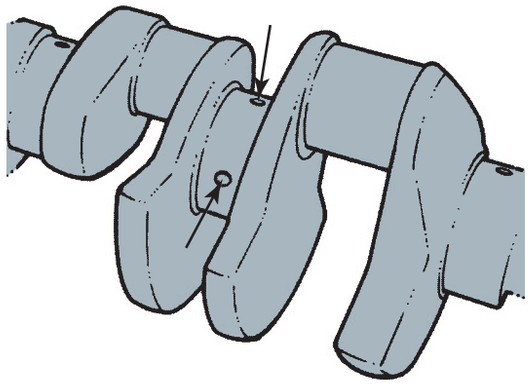


FIGURE 35–10 A cross-drilled crankshaft is used on some production engines and is a common racing modification.

FREQUENTLY ASKED QUESTION

What Does a "Cross-Drilled Crankshaft" Mean?

A cross-drilled crankshaft means that there are two instead of only one oil hole leading from the main bearing journal to the rod bearing journal. Oil is supplied to the main bearing journals through oil galleries in the block. A cross-drilled crankshaft has two outlet holes for oil to reach the drilled passage that supplies oil to the rod journal. ● **SEE FIGURE 35–10.**

REAL WORLD FIX

The Mysterious Engine Vibration

A Buick 3.8 liter V-6 engine vibrated the whole car after a new short block had been installed. The technician who had installed the replacement engine did all of the following:

1. Checked the spark plugs
2. Checked the spark plug wires
3. Disconnected the torque converter from the flex plate (drive plate) to eliminate the possibility of a torque converter or automatic transmission pump problem
4. Removed all accessory drive belts one at a time

Yet the vibration still existed.

Another technician checked the engine mounts and found that the left (driver's side) engine mount was out of location, ripped, and cocked. The transmission mount was also defective. After the technician replaced both mounts and made certain that all mounts were properly set, the vibration was eliminated. The design and location of the engine mounts are critical to the elimination of vibration, especially on 90-degree V-6 engines.

THREE-CYLINDER ENGINE CRANKSHAFTS

A 3-cylinder engine uses a 120-degree three-throw crankshaft with four main bearings. This engine requires a balancing shaft that turns at crankshaft speed, but in the opposite direction, to reduce the vibration to an acceptable level.

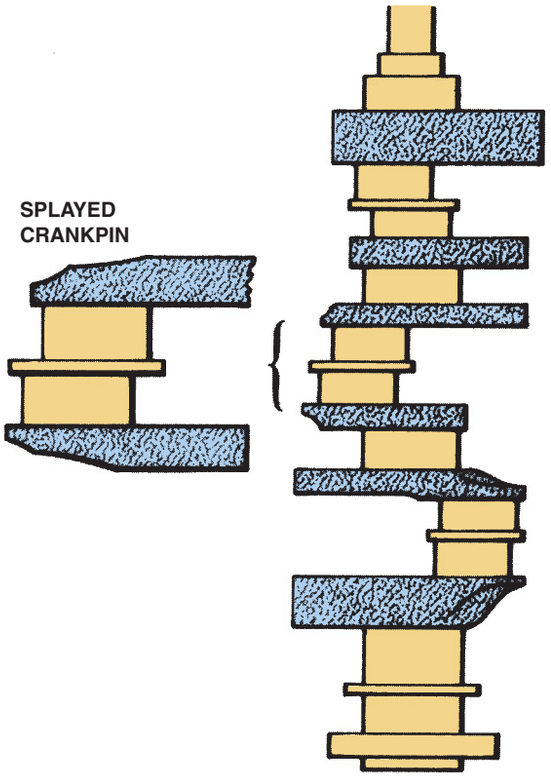


FIGURE 35–11 A splayed crankshaft design is used to create an even-firing 90-degree V-6.

INLINE SIX-CYLINDER ENGINE CRANKSHAFT Inline six cylinder engine crankshafts ride on four or seven main bearings and use six crank throws in three planes 120 degrees apart. An inline six cylinder is in perfect primary and secondary balance.

90-DEGREE V-6 ENGINE CRANKSHAFTS The crank throws for an even-firing V-6 engine are split, making separate crankpins for each cylinder. The split throw can be seen in ● **FIGURE 35–11.**

This angle between the crankpins on the crankshaft throws is called a **splay angle.** A flange was left between the split crankpin journals. This provides a continuous fillet or edge for machining and grinding operations. It also provides a normal flange for the rod and bearing. This flange between the splayed crankpin journals is sometimes called a **flying web.**

60-DEGREE V-6 ENGINE CRANKSHAFTS The 60-degree V-6 engine is similar to the even-firing 90-degree V-6 engine. The adjacent pairs of crankpins on the crankshaft used in the 60-degree V-6 engine have a splay angle of 60 degrees.

The crankshaft of the 60-degree V-6 engine also uses four main bearings.

COUNTERWEIGHTS

PURPOSE AND FUNCTION Crankshafts are balanced by **counterweights,** which are cast, forged, or machined as part of the crankshaft. A crankshaft that has counterweights on both sides of each connecting rod journal is called **fully counterweighted.** ● **SEE FIGURE 35–12.**

A fully counterweighted crankshaft is the smoothest running and most durable design, but it is also the heaviest and most expensive to manufacture. Most vehicle manufacturers do not use fully counterweighted crankshafts in an effort to lighten the rotating mass of the engine. An engine with a light crankshaft allows the engine to accelerate quicker. Even crankshafts that are not fully counterweighted are still balanced.

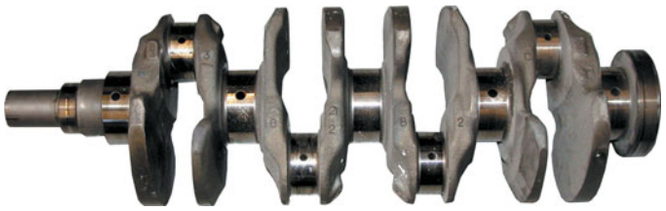


FIGURE 35–12 A fully counterweighted 4-cylinder crankshaft.

? FREQUENTLY ASKED QUESTION

What Is an Offset Crankshaft?

To reduce side loads, some vehicle manufacturers offset the crankshaft from center. For example, if an engine rotates clockwise as viewed from the front, the crankshaft may be offset to the left to reduce the angle of the connecting rod during the power stroke. ● **SEE FIGURE 35–13.**

The offset usually varies from 1/16 to 1/2 in., depending on make and model. Many inline 4-cylinder engines used in hybrid electric vehicles use an offset crankshaft.

VIBRATION DAMAGE Each time combustion occurs, the force deflects the crankshaft as it transfers torque to the output shaft. This deflection occurs in two ways, to bend the shaft sideways and to twist the shaft in torsion. The crankshaft must be rigid enough to keep the deflection forces to a minimum.

Crankshaft deflections are directly related to the operating roughness of an engine. When back-and-forth deflections occur at the same vibration **frequency** (number of vibrations per second) as that of another engine part, the parts will vibrate together. When this happens, the parts are said to **resonate.** These vibrations may become great enough to reach the audible level, producing a thumping sound. If this type of vibration continues, the crankshaft may fail. ● **SEE FIGURE 35–14.**

Harmful crankshaft twisting vibrations are dampened with a torsional vibration damper. It is also called a harmonic balancer. This damper or balancer usually consists of a cast-iron **inertia ring** mounted to a cast-iron **hub** with an **elastomer** sleeve.

HINT: Push on the rubber (elastomer sleeve) of the vibration damper with your fingers or a pencil. *If the rubber does not spring back, replace the damper.*

Elastomers are actually synthetic, rubberlike materials. The inertia ring size is selected to control the **amplitude** of the crankshaft vibrations for each specific engine model. ● **SEE FIGURE 35–15.**

EXTERNALLY AND INTERNALLY BALANCED ENGINES

DEFINITION Most crankshaft balancing is done during manufacture. Holes are drilled in the counterweight to lighten and improve balance. Sometimes these holes are drilled after the crankshaft is installed in the engine. Some manufacturers are able to control casting

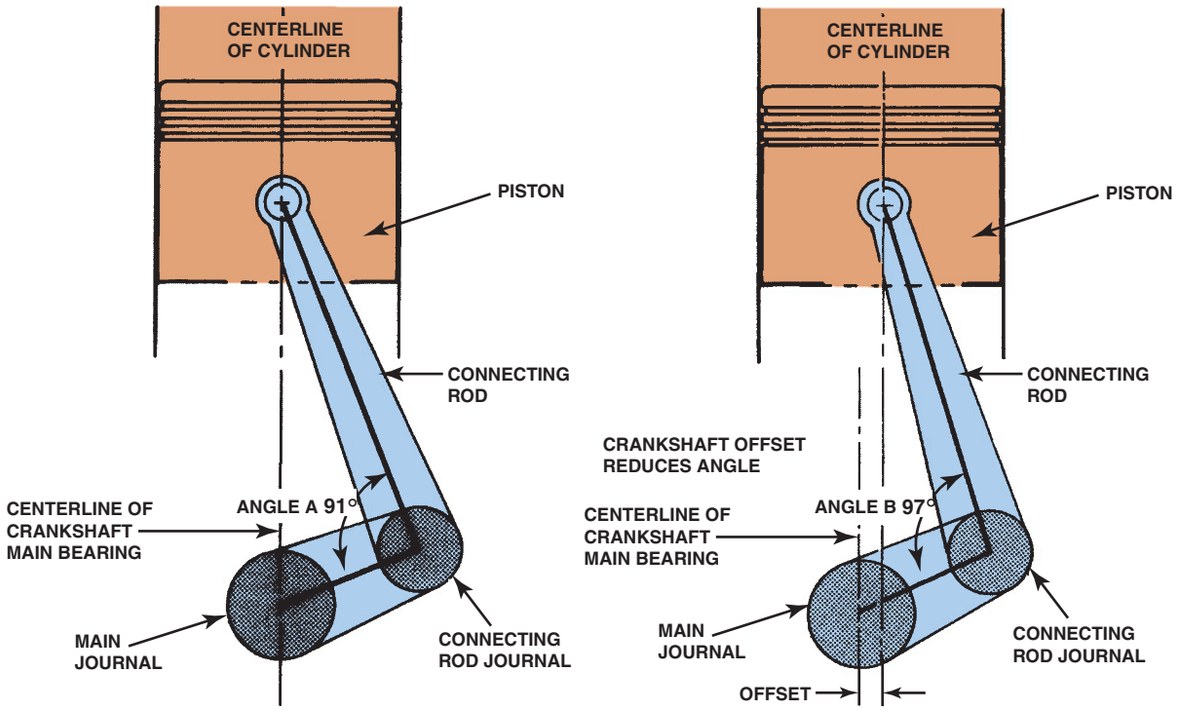


FIGURE 35–13 The crank throw is halfway down on the power stroke. The piston on the left without an offset crankshaft has a sharper angle than the engine on the right with an offset crankshaft.



FIGURE 35–14 A crankshaft broken as a result of using the wrong torsional vibration damper.

TECH TIP

High Engine Speeds Require High-Performance Parts

Do not go racing with stock parts. A stock harmonic balancer can come apart and the resulting vibration can break the crankshaft if the engine is used for racing. Check the Internet or race part suppliers for the recommended balancer to use. ● **SEE FIGURE 35–16.**

quality so closely that counterweight machining for balancing is not necessary.

Engine manufacturers balance an engine in one of two ways.

- **Externally balanced.** Weight is added to the harmonic balancer (vibration damper) and flywheel or the flexplate.
- **Internally balanced.** All rotating parts of the engine are individually balanced, including the harmonic balancer and flywheel (flexplate).

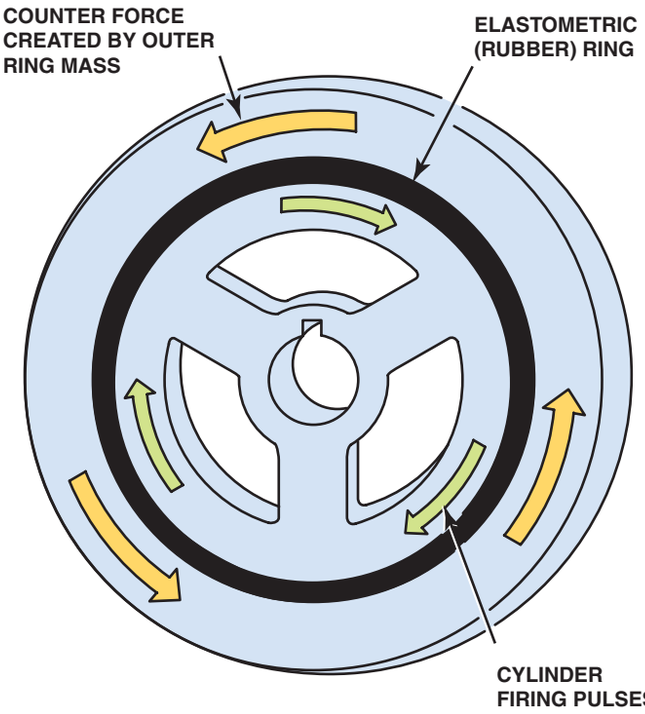


FIGURE 35–15 The hub of the harmonic balancer is attached to the front of the crankshaft. The elastomer (rubber) between the inertia ring and the center hub allows the absorption of crankshaft firing impulses.

For example, the 350-cubic-inch Chevrolet V-8 is internally balanced, whereas the 400-cubic-inch Chevrolet V-8 uses an externally balanced crankshaft. The harmonic balancer used on an externally balanced engine has additional weight.

ENGINE BALANCE

PRIMARY AND SECONDARY BALANCE Anything that rotates will vibrate. This means that an engine will vibrate during



FIGURE 35–16 A General Motors high-performance balancer used on a race engine.

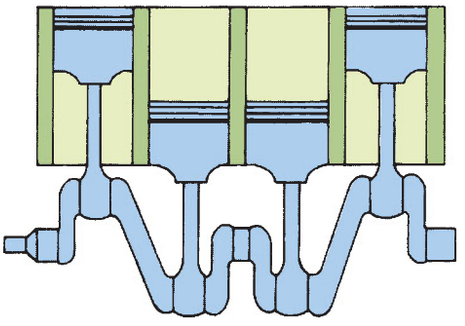


FIGURE 35–17 In a 4-cylinder engine, the two outside pistons move upward at the same time as the inner pistons move downward, which reduces primary unbalance.

operation, although engine designers attempt to reduce the vibration as much as possible.

- **Primary balance.** When pistons move up and down in the cylinders they create a **primary vibration,** which is a strong low-frequency vibration.

  A counterweight on the crankshaft opposite the piston/rod assembly helps reduce this vibration. An inline 4-cylinder engine has very little primary vibration, because as two pistons are traveling upward in the cylinders, two are moving downward at the same time, effectively canceling out primary unbalances. ● **SEE FIGURE 35–17.**

- **Secondary balance.** Four-cylinder engines, however, suffer from a vibration at twice engine speed. This is called a **secondary vibration,** which is a weak high-frequency vibration caused by a slight difference in the inertia of the pistons at top dead center compared to bottom dead center. This vibration is most noticeable at high engine speeds, especially if the engine size is greater than 2 liters. The larger the displacement of the engine, the larger the bore and the heavier the pistons contribute to the buzzing-type secondary vibration. ● **SEE FIGURE 35–18.**

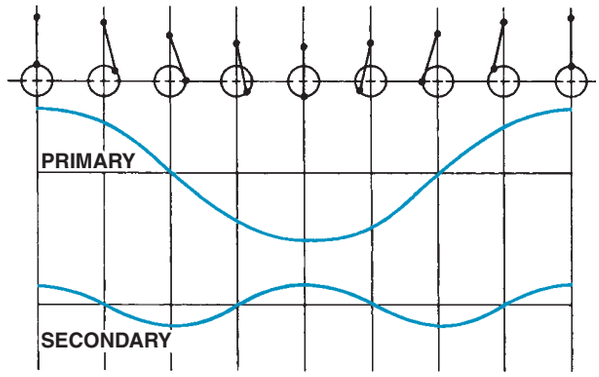


FIGURE 35–18 Primary and secondary vibrations in relation to piston position.

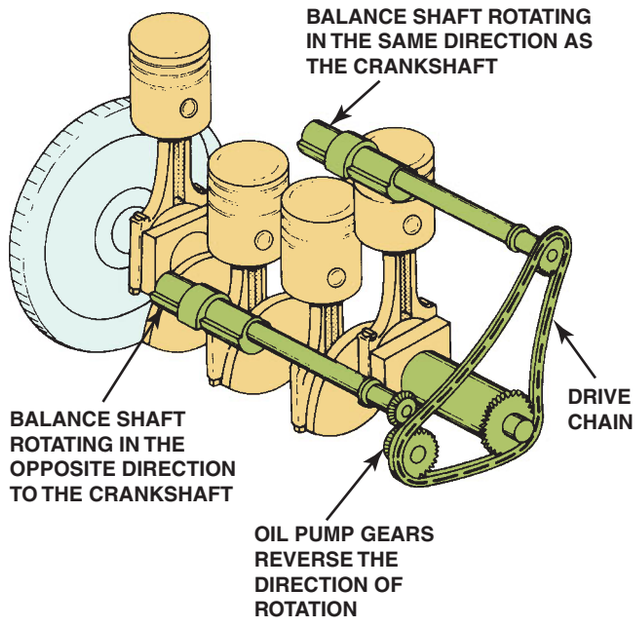


FIGURE 35–19 Two counterrotating balance shafts used to counterbalance the vibrations of a 4-cylinder engine.

BALANCE SHAFTS

PURPOSE AND FUNCTION

Some engines use balance shafts to dampen normal engine vibrations. *Dampening* is reducing the vibration to an acceptable level. A balance shaft that is turning at crankshaft speed, but in the opposite direction, is used on a 3-cylinder inline engine. Weights on the ends of the balance shaft move in a direction opposite to the direction of the end piston. When the piston goes up, the weight goes down, and when the piston goes down, the weight goes up. This reduces the end-to-end rocking action on the 3-cylinder inline engine.

Another type of balance shaft system is designed to counterbalance vibrations on a four-stroke, 4-cylinder engine. Two shafts are used, and they turn at *twice* the engine speed. In most applications, both shafts rotate in the same direction and are driven by a chain or gear off the crankshaft. Counterweights on the balance shafts are positioned to oppose the natural rolling action of the engine, as well as the secondary vibrations caused by the piston and rod movements. ● **SEE FIGURE 35–19.**

BALANCE SHAFT APPLICATIONS

Balance shafts are commonly found on the larger displacement (over 2 liter) 4-cylinder automotive engines.

- Most 4-cylinder engines larger than 2.2 liters use balance shafts. These are often located underneath the crankshaft. ● **SEE FIGURE 35–20.**
- Since the late 1980s, both Ford and General Motors added a balance shaft to many of their V-6 engines. These 90-degree V-6 engines use a split crank journal to create an even-firing

arrangement, but these engines suffer from forces that cause the engine to rock back and forth. This motion is called a *rocking couple* and is dampened by the use of a balance shaft. ● **SEE FIGURE 35–21.**

The addition of balance shafts makes a big improvement in the smoothness of the engine. In V-6 engines, the improvement is most evident during idling and low-speed operation, whereas in the 4-cylinder engines, balance shafts are especially helpful at higher engine speeds. The V-6 engines that use a 60-degree design do not create a rocking couple and, therefore, do not need a balance shaft.

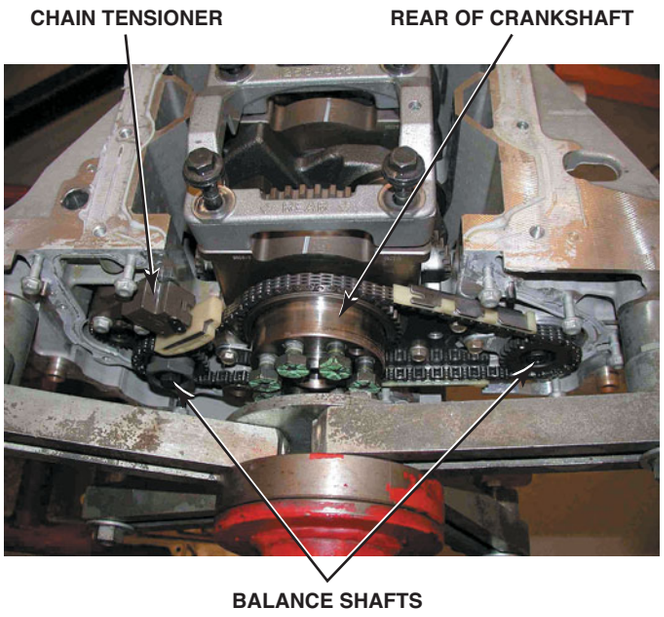


FIGURE 35–20 This General Motors 4-cylinder engine uses two balance shafts driven by a chain at the rear of the crankshaft.

CRANKSHAFT SERVICE

CRANKSHAFT VISUAL INSPECTION

Crankshaft damage includes:

- Worn journals
- Scored bearing journals
- Bends or warpage
- Cracks
- Thread damage (flywheel flange or front snout)
- Worn front or rear seal surfaces

Damaged shafts must be reconditioned or replaced. The crankshaft is one of the most highly stressed engine parts. *The stress on the crankshaft increases by four times every time the engine speed doubles.* Any sign of a crack is a cause to reject the crankshaft. Most cracks can be seen during a close visual inspection. Crankshafts should also be checked with Magnaflux, which will highlight tiny cracks that would lead to failure.

Bearing journal scoring is a common crankshaft defect. Scoring appears as scratches around the bearing journal surface. Generally, there is more scoring near the center of the bearing journal, as shown in ● **FIGURE 35–22.**

Crankshaft journals should be inspected for nicks, pits, or corrosion. Roughness and slight bends in journals can be corrected by grinding the journals.

HINT: If your fingernail catches on a groove when rubbed across a bearing journal, the journal is too rough to reuse and must be reground. Another test is to rub a copper penny across the journal. If any copper remains on the crankshaft, it must be reground.

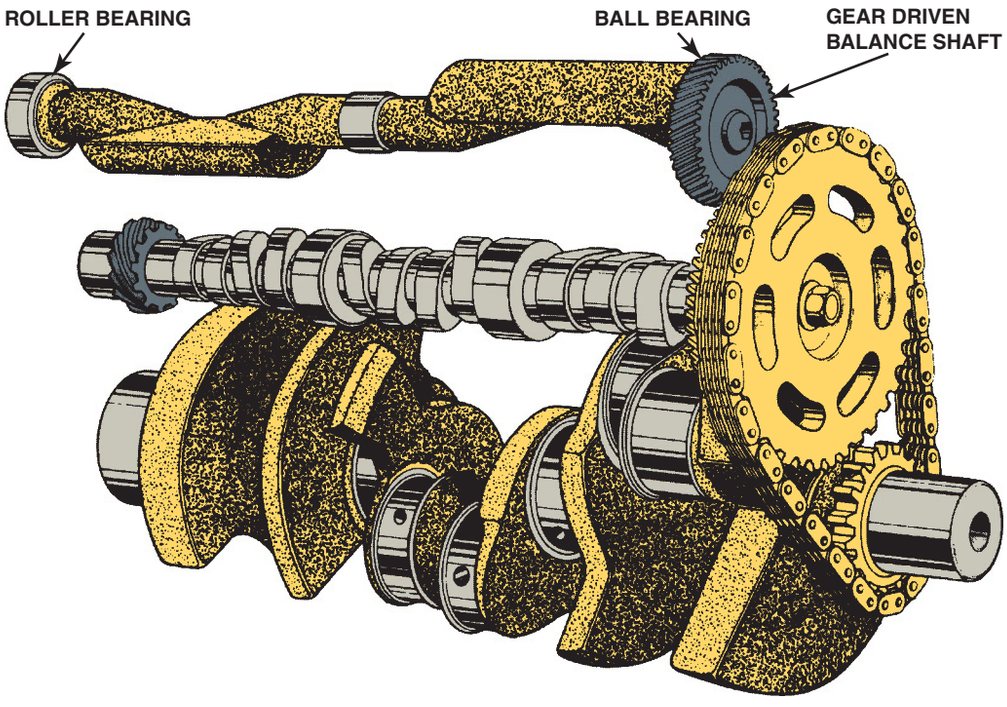


FIGURE 35–21 Many 90-degree V-6 engines use a balance shaft to reduce vibrations and effectively cancel a rocking motion (rocking couple) that causes the engine to rock front to back.

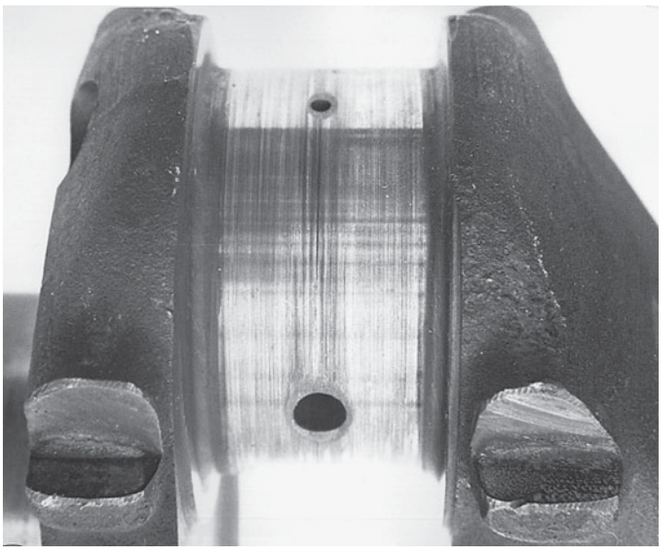


FIGURE 35–22 Scored connecting rod bearing journal.



FIGURE 35–23 All crankshaft journals should be measured for diameter as well as taper and out-of-round.

MEASURING THE CRANKSHAFT

Crankshafts should be carefully measured to determine the following:

- Size of main and rod bearing journals compared to factory specifications
- Each journal checked for out-of-round condition
- Each journal checked for taper

● **SEE FIGURES 35–23 AND 35–24.**

CRANKSHAFT GRINDING

Crankshaft journals that have excessive scoring, out-of-round, or taper should be reground.

The typical procedure includes the following steps.

STEP 1 Crankshafts may require straightening before grinding.

STEP 2 Both crankshaft ends are placed in rotating heads on one style of crankshaft grinder.

STEP 3 The main bearing journals are ground on the centerline of the crankshaft.

STEP 4 The crankshaft is then offset in the two rotating heads just enough to make the crankshaft main bearing journal centerline rotate around the centerline of the crankpin. The crankshaft will then be rotating around the crankpin centerline. The journal on the crankpin is reground in this position.

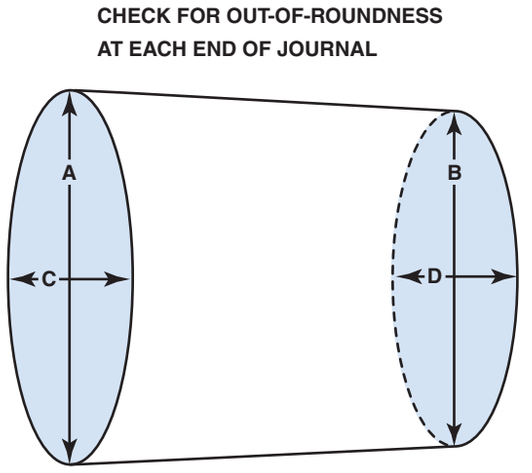


FIGURE 35–24 Check each journal for taper and out-of-round.

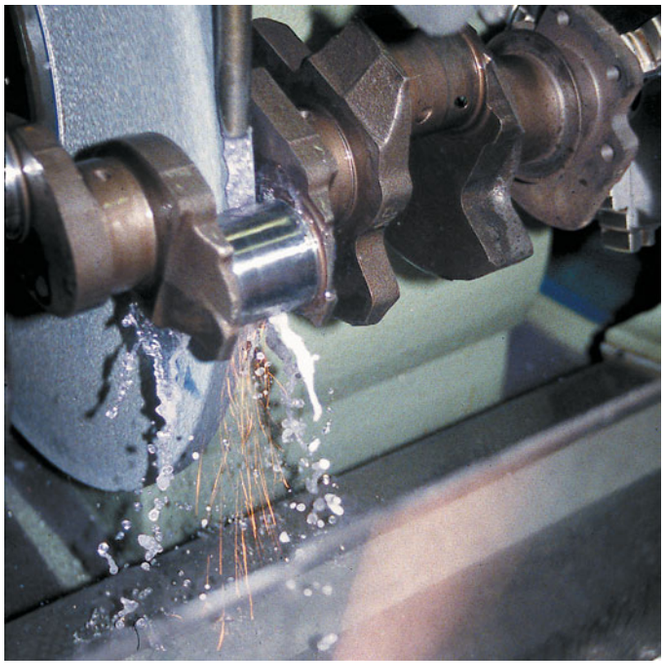


FIGURE 35–25 The rounded fillet area of the crankshaft is formed by the corners of the grinding stone.

STEP 5 The crankshaft must be repositioned for each different crankpin center.

In another type of crankshaft grinder, the crankshaft always turns on the main bearing centerline. The grinding head is programmed to move in and out as the crankshaft turns to grind the crankpin bearing journals.

Crankshafts are usually ground to the following undersize.

- 0.010 in.
- 0.020 in.
- 0.030 in.

The finished journal should be accurately ground to size with a smooth surface finish. The radius of the fillet area on the sides of the journal should also be the same as the original. ● **SEE FIGURE 35–25.**

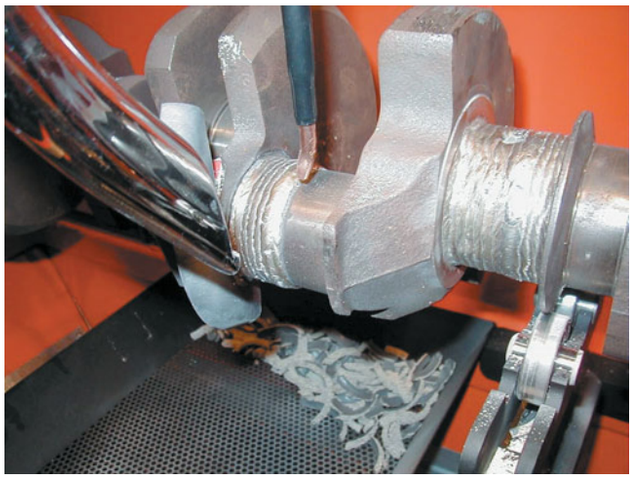


FIGURE 35–26 An excessively worn crankshaft can be restored to useful service by welding the journals, and then machining them back to the original size.

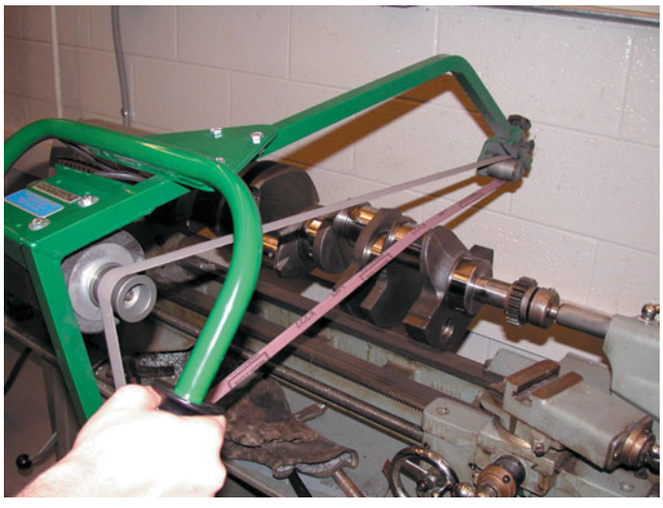


FIGURE 35–27 All crankshafts should be polished after grinding. Both the crankshaft and the polishing cloth are being revolved.

CRANKSHAFT POLISHING The journal is polished after grinding using a 320-grit polishing cloth and oil to remove the fine metal "fuzz" remaining on the journal. This fuzz feels smooth when the shaft turns in its direction. As the shaft turns in the opposite direction, the fuzz feels like a fine milling cutter. Polishing removes this fuzz. The crankshaft is rotated in its normal direction of rotation so that the polishing cloth can remove the fuzz. This leaves a smooth shaft with the proper surface finish. *Most crankshaft grinders grind in the direction opposite of rotation and then polish in the same direction as rotation.* ● **SEE FIGURE 35–26.**

The crankshaft oil passages should be cleaned and the journals tagged with the undersize dimensions.

WELDING A CRANKSHAFT Sometimes it is desirable to salvage a crankshaft by building up a bearing journal and then grinding it to the original journal size. This is usually done by either electric arc welding or a metal spray. ● **SEE FIGURE 35–27.**

STRESS RELIEVING THE CRANKSHAFT The greatest area of stress on a crankshaft is the fillet area. Stress relief is achieved by *shot peening* the fillet area of the journals with #320 steel shot. This strengthens the fillet area and helps to prevent the development of cracks in this area. Gray duct tape is commonly used to cover the journal to prevent damage to the rest of it. Stress relief procedures are usually performed after the grinding and polishing of the crankshaft.

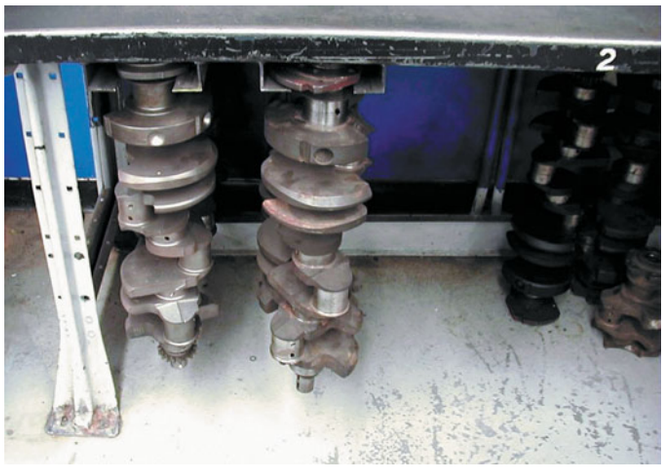


FIGURE 35–28 Crankshafts should be stored vertically to prevent possible damage or warpage. This clever bench-mounted tray for crankshafts not only provides a safe place to store crankshafts but is also out of the way and cannot be accidentally tipped.

STORING CRANKSHAFTS All crankshafts should be coated with oil to keep them from rusting, and stored vertically until time for engine assembly. All crankshafts should be placed on the floor vertically to help prevent warping due to gravity. ● **SEE FIGURE 35–28.**

ENGINE BEARINGS

INTRODUCTION Engine bearings are the main supports for the major moving parts of any engine. Engine bearings are important for the following reasons.

1. The clearance between the bearings and the crankshaft is a major factor in maintaining the proper oil pressure throughout the entire engine. Most engines are designed to provide the maximum protection and lubrication to the engine bearings above all else.
2. Engine durability relies on bearing life. Bearing failure usually results in immediate engine failure.
3. Engine bearings are designed to support the operating loads of the engine and, with the lubricant, provide minimum friction. This must be achieved at all designed engine speeds. The bearings must be able to operate for long periods of time, even when small foreign particles are in the lubricant.

TYPES OF BEARINGS Most engine bearings are one of two types.

- **Plain bearing**
- **Sleeve bearing**

● **SEE FIGURE 35–29.**

Most bearing halves, or shells, do not have uniform thickness. The wall thickness of most bearings is largest in the center, called the **bearing crown.** The bearing thickness then tapers to a thinner measurement at each parting line. ● **SEE FIGURE 35–30.**

The tapered wall keeps bearing clearances close at the top and bottom of the bearing, which are the more loaded areas and

allow more oil flow at the sides of the bearing. Both need a constant flow of lubricating oil. In automotive engines, the lubricating system supplies oil to each bearing continuously when the engine runs. Bearings and journals *only* wear when the parts come in contact with each other or when foreign particles are present.

Oil enters the bearing through the oil holes and grooves. It spreads into a smooth wedge-shaped oil film that supports the bearing load.

BEARING MATERIALS

Three materials are used for automobile engine bearings.

- **Babbitt**
- **Copper-lead alloy**
- **Aluminum**

A layer of the bearing materials that is 0.01 to 0.02 in. (0.25 to 0.5 mm) thick is applied over a low carbon steel backing. An engine bearing is called a **bearing shell,** which is a steel backing with a surface coating of bearing material. The steel provides support needed for the shaft load. The bearing material meets the rest of the bearing operating requirements.

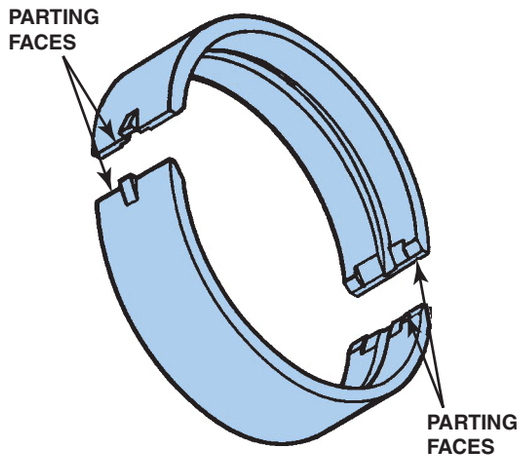


FIGURE 35–29 The two halves of a plain bearing meet at the parting faces.

- **Babbitt.** Babbitt is the oldest automotive bearing material. Isaac Babbitt (1799–1862) first formulated this material in 1839. An excellent bearing material, it was originally made from a combination of lead, tin, and antimony. Lead and tin are alloyed with small quantities of copper and antimony to give it the required strength. Babbitt is still used in applications in which material is required for soft shafts running under moderate loads and speeds. It will work with occasional borderline lubrication and oil starvation without failure.
- **Trimetal.** Copper-lead alloy is a stronger and more expensive bearing material than babbitt. It is used for intermediate- and high-speed applications. Tin, in small quantities, is often alloyed with the copper-lead bearings. This bearing material is most easily damaged by corrosion from acid accumulation in the engine oil. Corrosion results in bearing journal wear as the bearing is eroded by the acids. Many of the copper-lead bearings have an **overlay,** or third layer, of metal. This overlay is usually of babbitt. Babbitt-overlayed bearings have high fatigue strength, good conformity, good embedability, and good corrosion resistance. The overplated bearing is a premium bearing. It is also the most expensive because the overplating layer, from 0.0005 to 0.001 in. (0.0125 to 0.025 mm) thick, is put on the bearing with an **electroplating** process. The layers of bearing material on a bearing shell are illustrated in **FIGURE 35–31.**
- **Aluminum.** Aluminum was the last of the three materials to be used for automotive bearings. Automotive bearing aluminum has small quantities of tin and silicone alloyed with it. This makes a stronger but more expensive bearing than either babbitt or copper-lead alloy. Most of its bearing characteristics are equal to or better than those of babbitt and copper lead. Aluminum bearings are well suited to high-speed, high-load conditions and do not contain lead, which is a benefit to the environment both at the manufacturing plant and for the technician who may be exposed to the bearings.

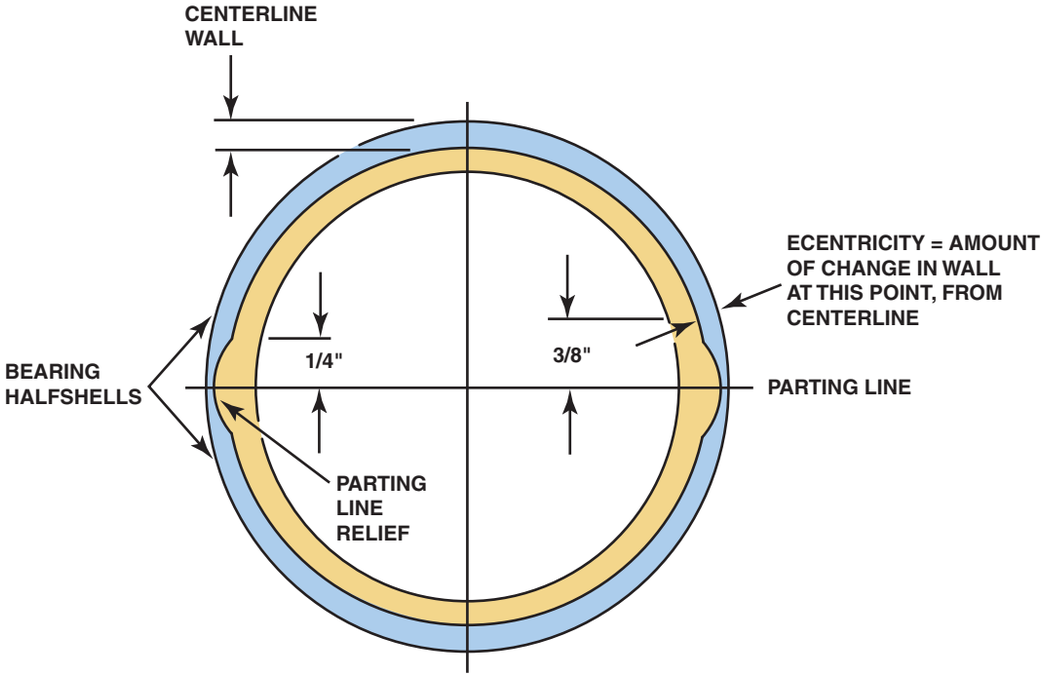
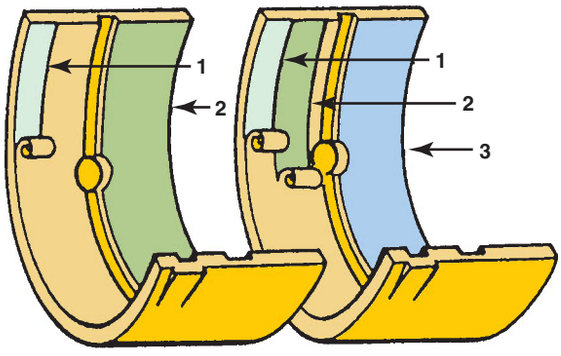


FIGURE 35–30 Bearing wall thickness is not the same from the center to the parting line. This is called *eccentricity* and is used to help create an oil wedge between the journal and the bearing.



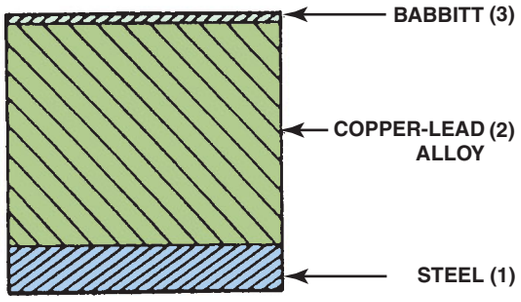


FIGURE 35–31 Typical two- and three-layer engine bearing inserts showing the relative thickness of the various materials.

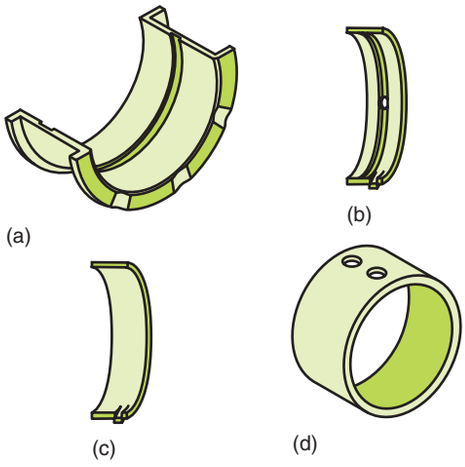


FIGURE 35–32 Typical bearing shell types found in modern engines: (a) half-shell thrust bearing, (b) upper main bearing insert, (c) lower main bearing insert, (d) full round-type camshaft bearing.

BEARING MANUFACTURING

Modern automotive engines use **precision insert-type bearing shells,** sometimes called **half-shell bearings.** The bearing is manufactured to very close tolerance so that it will fit correctly in each application. The bearing, therefore, must be made from precisely the correct materials under closely controlled manufacturing conditions. ● **FIGURE 35–32** shows the typical bearing types found in most engines.

BEARING SIZES

Bearings are usually available in standard (std.) size, and in measurements 0.010, 0.020, and 0.030 in. *undersize.* ● **SEE FIGURE 35–33.**

Even though the bearing itself is thicker for use on a machined crankshaft, the bearing is referred to as undersize because the crankshaft journals are undersize. Factory bearings may be available in 0.0005 or 0.001 in. undersize for precision fitting of a production crankshaft.

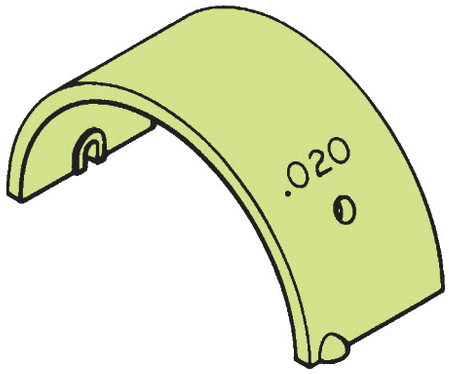


FIGURE 35–33 Bearings are often marked with an undersize dimension. This bearing is used on a crankshaft with a ground journal that is 0.020 in. smaller in diameter than the stock size.

Before purchasing bearings, be sure to use a micrometer to measure *all* main and connecting rod journals. Replacement bearings are also available in 0.001, 0.002, and 0.003 in., to allow the technician to achieve the proper bearing clearance without needing to machine the crankshaft.

BEARING LOADS

The forces on the engine bearings vary with engine speed and load. On the intake stroke, the inertia force is opposed by the force of drawing in the air-fuel mixture. On the compression and power strokes, there is also an opposing force on the rod bearings. On the exhaust stroke, however, there is no opposing force to counteract the inertia force of the piston coming to a stop at TDC. The result is a higher force load on the *bottom* rod bearing due to inertia at TDC of the exhaust stroke. These forces tend to stretch the big end of the rod in the direction of rod movement.

1. As engine speed (RPM) increases, rod bearing loads decrease because of the balancing of inertia and opposing loads.
2. As engine speed (RPM) increases, the main bearing loads increase.

   NOTE: This helps explain why engine blocks with four-bolt main bearing supports are only needed for high-engine speed stability.

3. Because the loads on bearings vary and affect both rod and main bearings, it is generally recommended that *all* engine bearings be replaced at one time.

BEARING FATIGUE

Bearings tend to flex or bend slightly under changing loads. This is especially noticeable in reciprocating engine bearings. Bearing metals, like other metals, tend to fatigue and break after being flexed or bent a number of times. Flexing starts fatigue, which shows up as fine cracks in the bearing surface because the bearing material became **work hardened.** These cracks gradually deepen almost to the bond between the bearing metal and the backing metal. The cracks then cross over and intersect with each other. In time, this will allow a piece of bearing material to fall out. The length of time before fatigue will cause failure is called the **fatigue life** of the bearing. ● **SEE FIGURE 35–34.**

BEARING CONFORMABILITY

The ability of bearing materials to creep or flow slightly to match shaft variations is called **conformability.** The bearing conforms to the shaft during the engine break-in period. In modern automobile engines, there is little need for bearing conformability or break-in, because automatic processing has achieved machining tolerances that keep the shaft very close to the designed size.

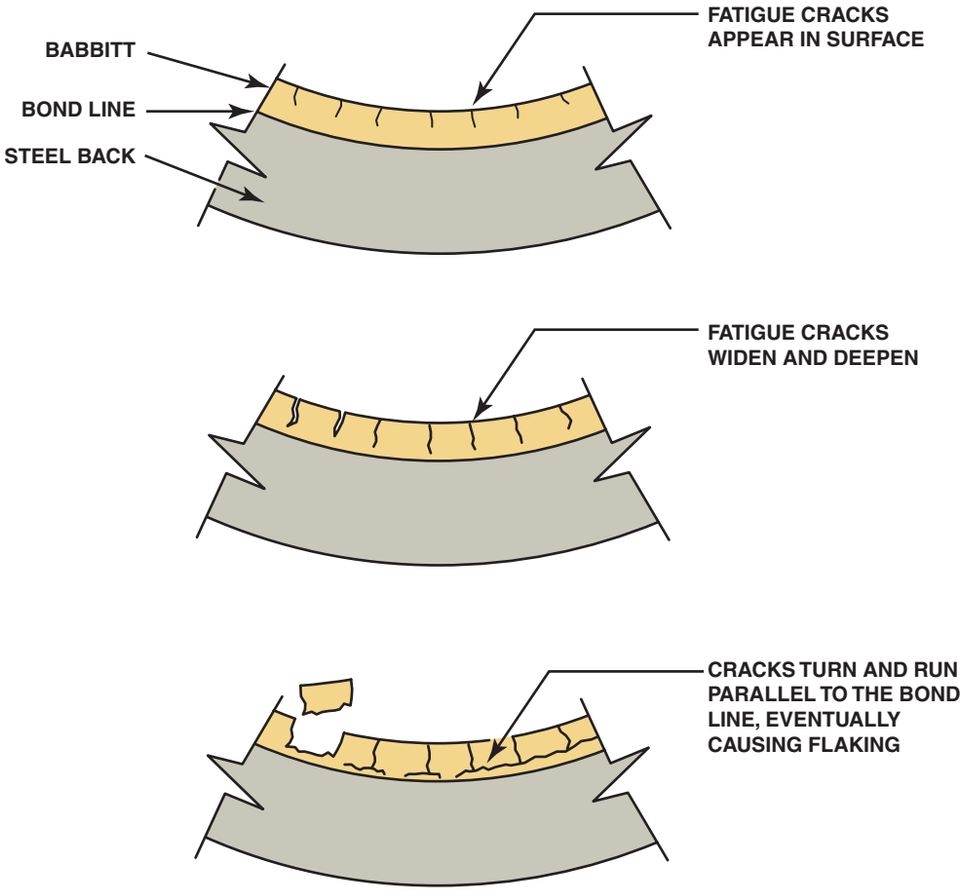


FIGURE 35–34 Work hardened bearing material becomes brittle and cracks, leading to bearing failure.

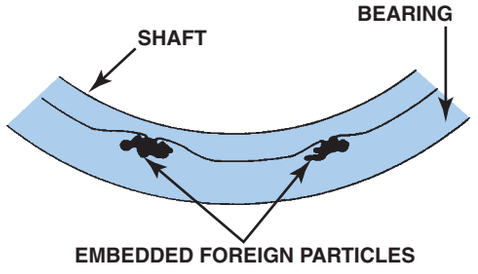


FIGURE 35–35 Bearing material covers foreign material (such as dirt) as it embeds into the bearing.

BEARING EMBEDABILITY

Engine manufacturers have designed engines to produce minimum crankcase deposits. This has been done by providing them with oil filters, air filters, and closed crankcase ventilation systems that minimize contaminants. Still, some foreign particles get into the bearings. The bearings must be capable of embedding these particles into the bearing surface so that they will not score the shaft. To fully embed the particle, the bearing material gradually works across the particle, completely covering it. The bearing property that allows it to do this is called **embedability.** ● **SEE FIGURE 35–35.**

BEARING DAMAGE RESISTANCE

Under some operating conditions, the bearing will be temporarily overloaded. This will cause the oil film to break down and allow the shaft metal to come in contact with the bearing metal. As the rotating crankshaft contacts the bearing high spots, the spots become hot from friction. The friction causes localized hot spots in the bearing material that seize or weld to the crankshaft. The crankshaft then breaks off particles of the bearing material and pulls the particles around with it, scratching or scoring the bearing surface.

Bearings have a characteristic called **score resistance.** It prevents the bearing materials from seizing to the shaft during oil film breakdown.

By-products of combustion form acids in the oil. The bearings' ability to resist attack from these acids is called **corrosion resistance.** Corrosion can occur over the entire surface of the bearing. This will remove material and increase the oil clearance. It can also leach or eat into the bearing material, dissolving some of the bearing material alloys. Either type of corrosion will reduce bearing life.

BEARING CLEARANCE

IMPORTANCE OF PROPER CLEARANCE

The bearing-to-journal clearance may be from 0.0005 to 0.0025 in. (0.025 to 0.06 mm), depending on the engine. Doubling the journal clearance will allow more than *four* times more oil to flow from the edges of the bearing. The oil clearance must be large enough to allow an oil film to build up, but small enough to prevent excess oil leakage, which would cause loss of oil pressure. A large amount of oil leakage at one of the bearings would starve other bearings farther along in the oil system. This would result in the failure of the oil-starved bearings.

CHECKING BEARING CLEARANCE

Bearing oil clearance can be checked in the following ways.

1. Using Plastigage® between the crankshaft journal and the bearing. The thin plasticlike strip material will deform depending on the clearance.

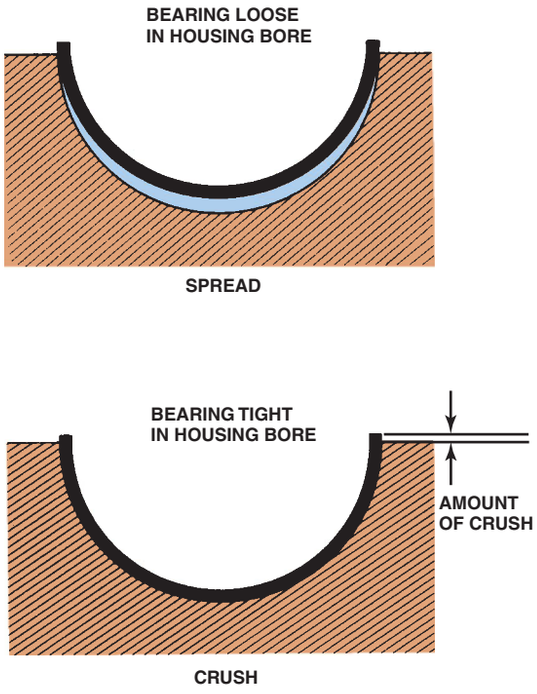


FIGURE 35–36 Bearing spread and crush.

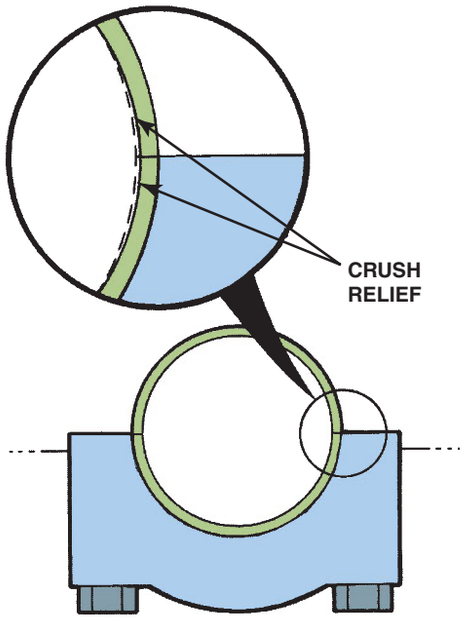


FIGURE 35–37 Bearings are thinner at the parting line faces to provide crush relief.

2. Measuring the crankshaft journal diameter and the inside diameter of the bearing as it is installed and subtracting the two measurements. The difference is the bearing clearance.

BEARING SPREAD AND CRUSH The bearing design also includes bearing **spread** and **crush.** ● **SEE FIGURE 35–36.**

- **Bearing spread.** The bearing shell has a slightly larger arc than the bearing housing. This difference, called bearing spread, makes the shell 0.005 to 0.02 in. (0.125 to 0.5 mm) wider than the housing bore. Spread holds the bearing shell in the housing while the engine is being assembled.
- **Bearing crush.** When the bearing is installed, each end of the bearing shell is slightly above the parting surface. When the bearing cap is tightened, the ends of the two bearing shells touch and are forced together. This force is called bearing crush. Crush holds the bearing in place and keeps the bearing from turning when the engine runs. Crush must exert a force of at least 12,000 PSI (82,740 kPa) at 250°F (121°C) to hold the bearing securely in place. A stress of 40,000 PSI (275,790 kPa) is considered maximum to avoid damaging the bearing or housing. ● **SEE FIGURE 35–37.**

  Bearing shells that do not have enough crush may rotate with the shaft. The result is called a **spun bearing.** ● **SEE FIGURE 35–38.**
- **Bearing tang.** A *tang* or lip helps locate the bearing shell in the housing. When the bearing clearance and "crush" have been worn or destroyed, the bearing can "spin," thus creating catastrophic failure. The tang often helps prevent this from occurring. ● **SEE FIGURE 35–39.**

Many newer engines do *not* use a tang on the bearing. Always check service information for the exact bearings and procedures to use for the engine being serviced.

Replacement bearings should be of a quality as good as or better than that of the original bearings. The replacement bearings must also have the same oil holes and grooves.

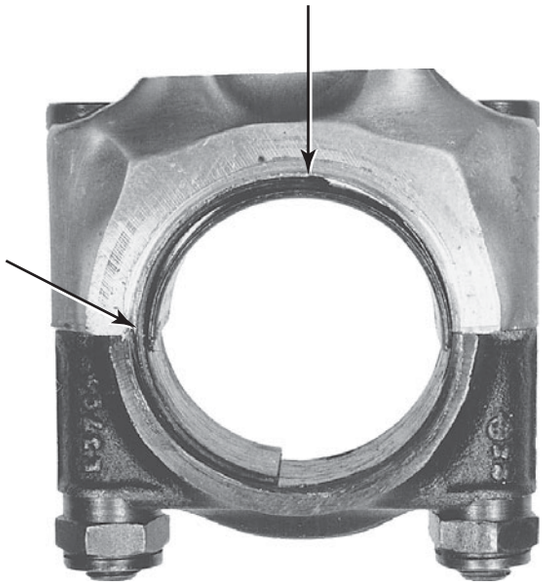


FIGURE 35–38 Spun bearing. The lower cap bearing has rotated under the upper rod bearing.

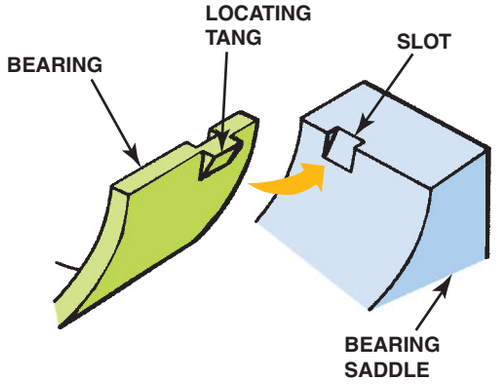


FIGURE 35–39 The tang and slot help index the bearing in the bore.

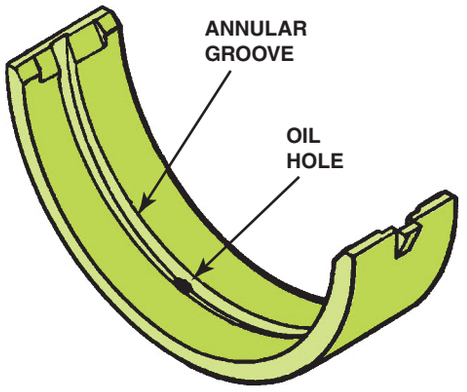


FIGURE 35–40 Many bearings are manufactured with a groove down the middle to improve the oil flow around the main journal.

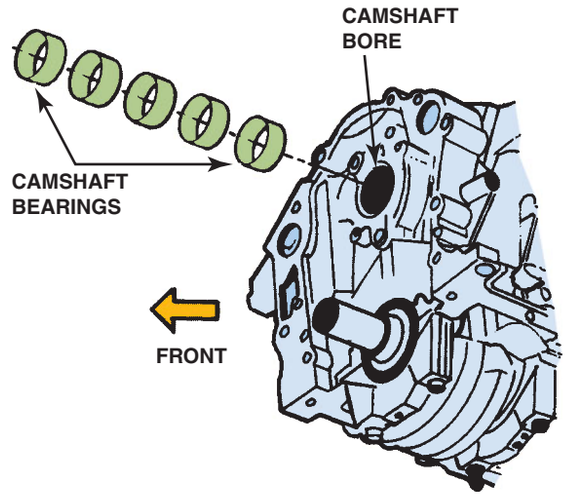


FIGURE 35–41 Cam-in-block engines support the camshaft with sleeve-type bearings.

TECH TIP

Count Your Blessings and Your Pan Bolts!

Replacing cam bearings can be relatively straightforward or can involve keeping count of the number of oil pan bolts. For example, Buick-built V-6 engines use different cam bearings depending on the number of bolts used to hold the oil pan to the block.

- **Fourteen bolts in the oil pan.** The front bearing is special, but the rest of the bearings are the same.
- **Twenty bolts in the oil pan.** Bearings 1 and 4 use two oil feed holes. Bearings 2 and 3 use single oil feed holes.

CAUTION: Some bearings may have oil holes in the top shell only. If these are installed incorrectly, no oil will flow to the connecting or main rods, resulting in instant engine failure. To help the oil spread across the entire bearing, some bearings use an oil groove. ● **SEE FIGURE 35–40.**

Modified engines have more demanding bearing requirements and therefore usually require a higher quality bearing to provide satisfactory service.

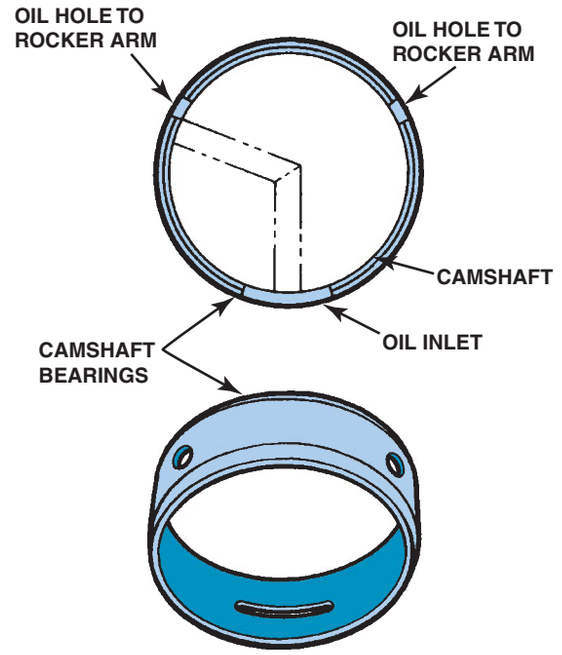


FIGURE 35–42 Camshaft bearings must be installed correctly so that oil passages are not blocked.

CAMSHAFT BEARINGS

TYPES OF CAMSHAFT BEARINGS The camshaft in pushrod engines rotates in sleeve bearings that are pressed into bearing bores within the engine block. Overhead camshaft bearings may be one of two sleeve-type bushings, depending on the design of the bearing supports.

- **Full round bearings**
- **Split-type (half-shell) bearings**

The split-type bearing has direct contact with aluminum saddles integral with the head depending on the design of the bearing supports. The integral aluminum head bearing design often requires the replacement of the entire cylinder head in the event of bearing failure from lack of lubrication.

In pushrod engines, the cam bearings are installed in the block. ● **SEE FIGURE 35–41.**

CAMSHAFT BEARING INSTALLATION The best rule of thumb to follow is to replace the cam bearings whenever the main bearings are replaced. The replacement cam bearings must have the correct outside diameter to fit snugly in the cam bearing bores of the block. They must have the correct oil holes and be positioned correctly. ● **SEE FIGURE 35–42.**

Cam bearings must also have the proper inside diameter to fit the camshaft bearing journals. Details regarding cam bearings include the following:

- In many engines, each cam bearing is a different size. The largest is in the front and the smallest is in the rear.
- The cam bearing journal size must be checked and each bearing identified before assembly is begun.
- The location of each new cam bearing can be marked on the outside of the bearing with a felt-tip marker to help avoid mixing up bearings. Marking in this way will not affect the bearing size or damage the bearing in any way.
- Many vehicle manufacturers specify that the cam bearings should be installed "dry" (not oiled) to prevent the cam bearing from moving (spinning) after installation. If the cam bearing

were oiled, the rotation of the camshaft could cause the cam bearing to rotate and block oil holes that lubricate the camshaft.

- Many aluminum cylinder heads have "integral" cam bearings that are not replaceable. The entire cylinder head may need to be replaced if a lubrication problem occurs to the cam bearings, because the entire cylinder head may need to be replaced.
- Camshaft bearings used on overhead camshaft engines may be either full round or split depending on the engine design. **SEE FIGURE 35–43.**

Always follow the installation tool instructions when installing cam bearings.

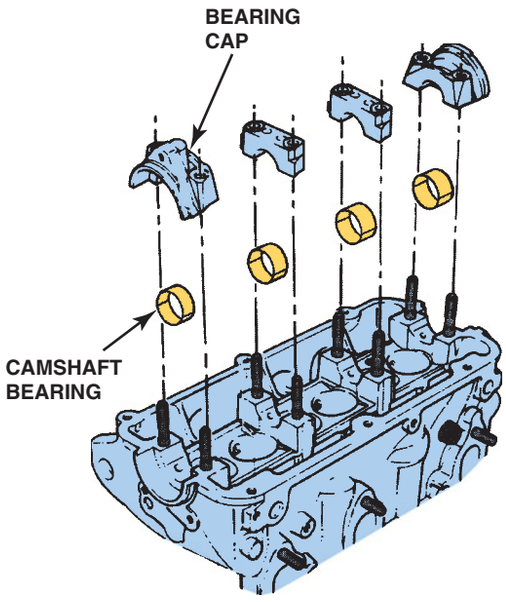


FIGURE 35–43 Some overhead camshaft engines use split bearing inserts.

REVIEW QUESTIONS

1. How many degrees of crankshaft rotation are there between cylinder firings on an inline 4-cylinder engine, an inline 6-cylinder engine, and a V-8 engine?
2. List the types of engine bearing materials.
3. Describe bearing crush and bearing spread.

CHAPTER QUIZ

1. A forged crankshaft has a _____.
   a. Wide parting line
   b. Thin parting line
   c. Parting line in one plane
   d. Both b and c
2. A typical V-8 engine crankshaft has _____ main bearings.
   a. Three
   b. Four
   c. Five
   d. Seven
3. A 4-cylinder engine fires one cylinder at every _____ degrees of crankshaft rotation.
   a. 27
   b. 180
   c. 120
   d. 90
4. A splayed crankshaft is a crankshaft that _____.
   a. Is externally balanced
   b. Is internally balanced
   c. Has offset main bearing journals
   d. Has offset rod journals
5. The thrust bearing surface is located on one of the main bearings to control thrust loads caused by _____.
   a. Lugging the engine
   b. Torque converter or clutch release forces
   c. Rapid deceleration forces
   d. Both a and c
6. If any crankshaft is ground, it must also be _____.
   a. Shot peened
   b. Chrome plated
   c. Polished
   d. Externally balanced
7. If bearing-to-journal clearance is doubled, how much oil will flow?
   a. One-half as much
   b. The same amount if the pressure is kept constant
   c. Double the amount
   d. Four times the amount
8. Typical journal-to-bearing clearance is _____.
   a. 0.00015 to 0.00018 in.
   b. 0.0005 to 0.0025 in.
   c. 0.15 to 0.25 in.
   d. 0.02 to 0.035 in.
9. A bearing shell has a slightly larger arc than the bearing housing. This difference is called _____.
   a. Bearing crush
   b. Bearing tang
   c. Bearing spread
   d. Bearing saddle
10. Bearing _____ occurs when a bearing shell is slightly above the parting surface of the bearing cap.
    a. Overlap
    b. Crush
    c. Cap lock
    d. Interference fit

chapter 36

GASKETS AND SEALANTS

OBJECTIVES: **After studying Chapter 36, the reader should be able to:** • Prepare for ASE Engine Repair (A1) certification test content area "C" (Engine Block Diagnosis and Repair). • Describe the various types of gaskets. • Explain why the surface finish is important for head gaskets. • List the types of sealers and their applications. • Explain the use and precautions associated with cover gaskets.

KEY TERMS: Anaerobic sealers 386 • Armor 381 • Fire ring 381 • Formed in place gaskets (FIPG) 384 • Fretting 384 • Multilayered steel (MLS) gaskets 381 • No-retorque-type gaskets 381 • Perforated steel core gaskets 381 • Room-temperature vulcanization (RTV) 385 • Rubber-coated metal (RCM) gaskets 384

INTRODUCTION

NEED FOR GASKETS AND SEALANTS

Gaskets and sealants are used in engines to seal gaps and potential gaps between two or more parts. Gaskets and sealants must be able to withstand:

- Temperatures to which the engine part may be exposed during normal operation
- Vibrations produced in the engine and the accessories that are attached to the engine
- Acids and other chemicals that are found in and throughout an engine
- Expanding and contracting at different rates (They must be able to seal even though the two parts are expanding and contracting at different rates as the engine is started at low temperature all the way to normal operating temperature and repeating this cycle every time the engine is operated.)

SEE FIGURE 36–1.

HEAD GASKETS

REQUIREMENTS NEEDED

The head gasket is under the highest clamping loads. It must seal passages that carry coolant and often is required to seal a passage that carries hot engine oil. The most demanding job of the head gasket is to seal the combustion chamber. As a rule of thumb, about 75% of the head bolt clamping force is used to seal the combustion chamber. The remaining 25% seals the coolant and oil passages. **SEE FIGURE 36–2.**

The gasket must seal when the temperature is as low as –40°F (–40°C) and as high as 400°F (204°C). The combustion pressures can get up to 1,000 PSI (6,900 kPa) on gasoline engines.

Cylinder head bolts are tightened to a specified torque, which stretches the bolt. The following forces are applied to a head gasket.

- The combustion pressure tries to push the head upward and the piston downward on the power stroke. This puts additional stress on the head bolts and it reduces the clamping load on the head gasket just when the greatest seal is needed.
- A partial vacuum during the intake stroke tries to pull the head down against the gasket.
- As the crankshaft rotates, the force on the head changes from pressure on the combustion stroke to vacuum on the intake stroke, then back to pressure.

Newer engines have lightweight thin-wall castings. The castings are quite flexible, so that they move as the pressure in the combustion chamber changes from high pressure to vacuum. The gasket must be able to compress and recover fast enough to maintain a seal as the pressure in the combustion chamber changes back and forth between pressure and vacuum. As a result, head gaskets are made of several different materials that are assembled in numerous ways, depending on the engine.

NOTE: Older head gasket designs often contained asbestos and required that the head bolts be retorqued after the engine had been run to operating temperature. Head gaskets today are dense and do not compress like those older-style gaskets. Therefore, most head gaskets are called no-retorque-type gaskets, meaning the cylinder head bolts do not have to be retorqued after the engine has run. New gaskets do not contain asbestos.

TYPES OF HEAD GASKETS

- **Perforated steel core gaskets.** A perforated steel core gasket uses a wire mesh core with fiber facings. Another design has rubber-fiber facings cemented to a solid steel core with an adhesive. **SEE FIGURES 36–3 AND 36–4.**

  The thickness of the gasket is controlled by the thickness of the metal core. The facing is thick enough to compensate for minor warpage and surface defects. The fiber facing is protected around the combustion chamber with a metal **armor** (also called a **fire ring**). **SEE FIGURE 36–5.**

  The metal also increases the gasket thickness around the cylinder so that it uses up to 75% of the clamping force and forms a tight combustion seal.
- **Multilayered steel gaskets.** The **multilayered steel (MLS) gaskets** are constructed in the following manner.

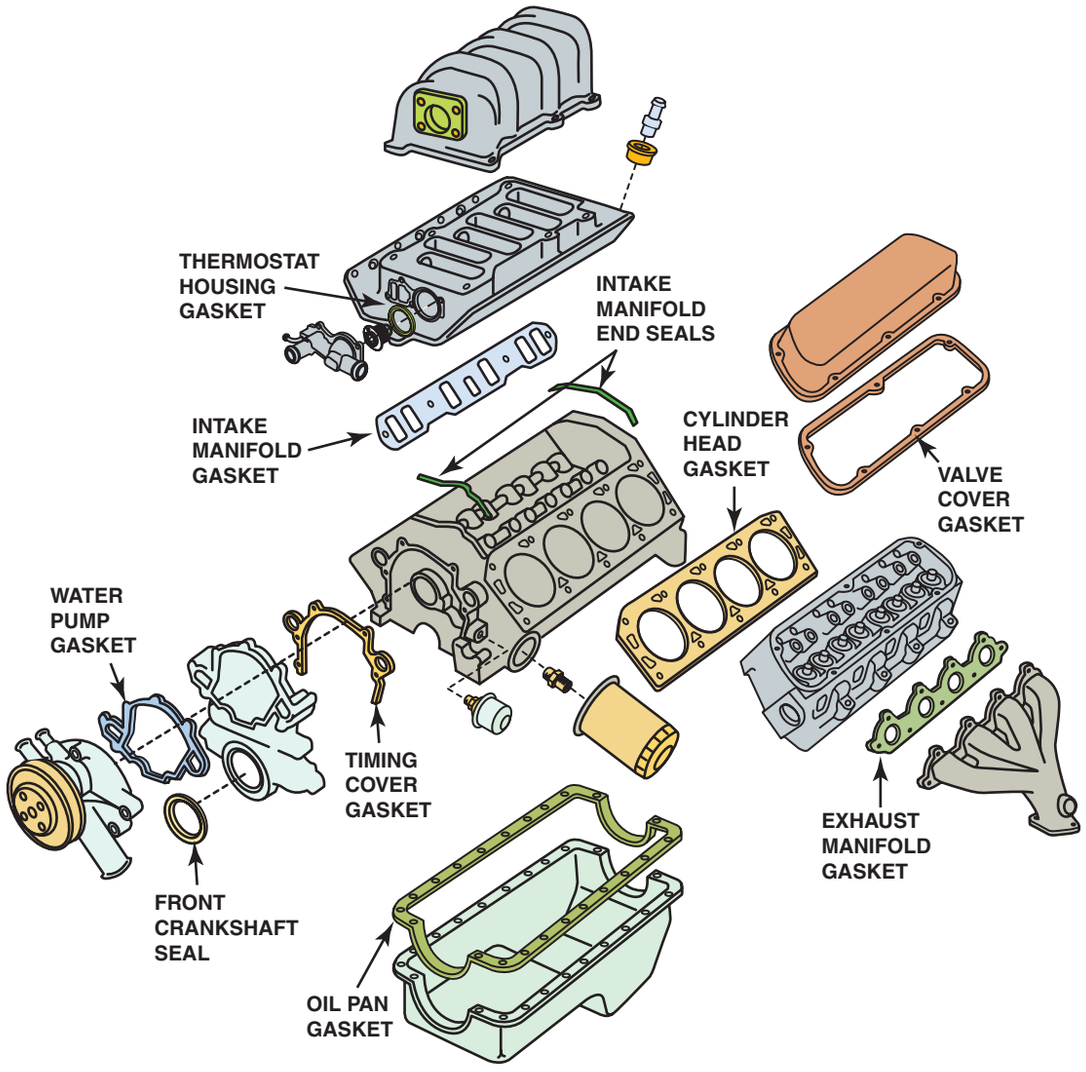


FIGURE 36–1 Gaskets are used in many locations in the engine.

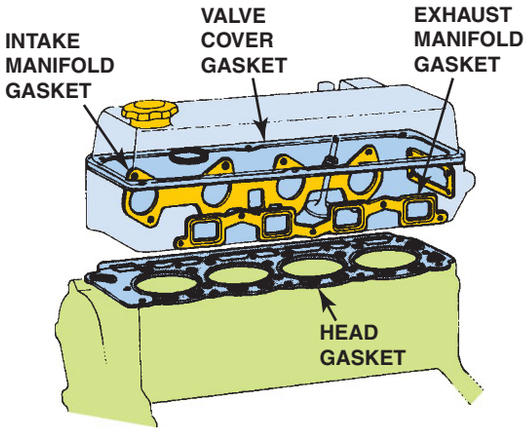


FIGURE 36–2 Gaskets help prevent leaks between two surfaces.

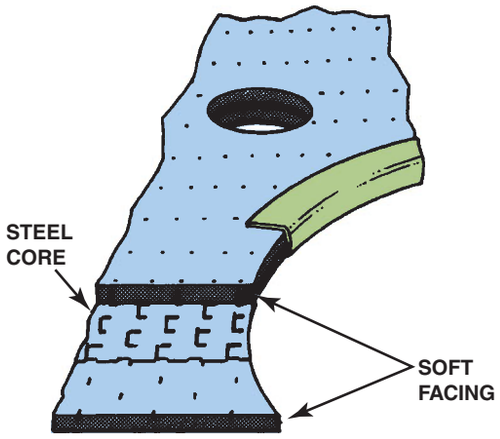


FIGURE 36–3 A typical perforated steel core head gasket with a graphite or composite facing material.

- Three to five layers of stainless steel sheet are separated by elastomer (rubber) material.
- The elastomer material is between the layers of the sheet metal and on both surfaces.
- The multiple layers of metal provide a springlike effect to the gasket, which allows it to keep the combustion chamber sealed.

The many layers of thin steel reduce bore and overhead camshaft distortion with less clamping force loss than previous designs. ● **SEE FIGURE 36–6.**

The use of multilayered steel gaskets also reduces the torque requirement and, therefore, reduces the stresses on the fastener and engine block. MLS gaskets are used in most engines that use aluminum cylinder heads and cast-iron blocks. The use of MLS head gaskets requires that both the head and the block deck surface have a smooth surface finish of 15 to 30 microinches. This smooth surface finish allows the head to move slightly during operation and not damage the gasket.

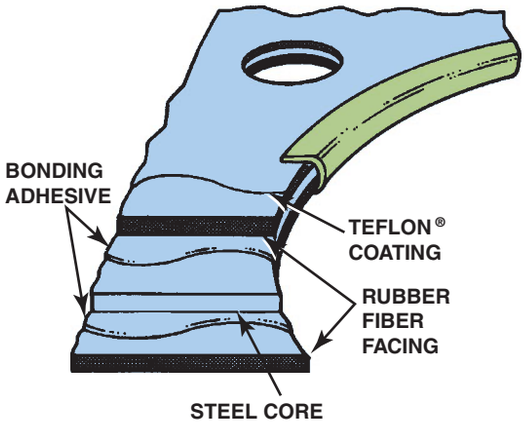


FIGURE 36–4 A solid steel core head gasket with a nonstick coating, which allows some movement between the block and the head, and is especially important on engines that use cast-iron blocks with aluminum cylinder heads.

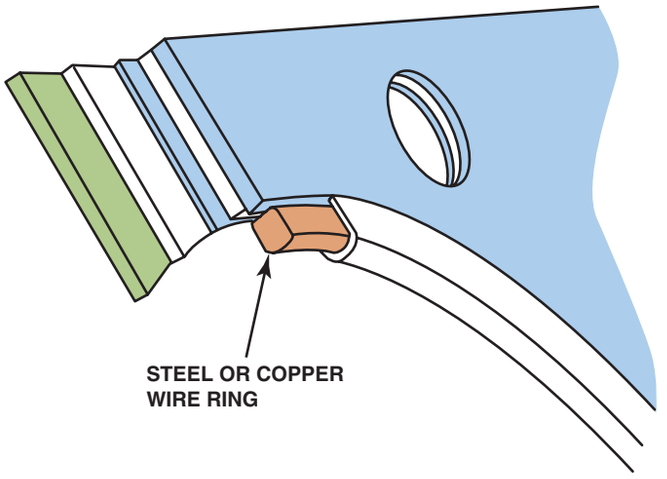


FIGURE 36–5 The armor ring can be made from steel or copper.

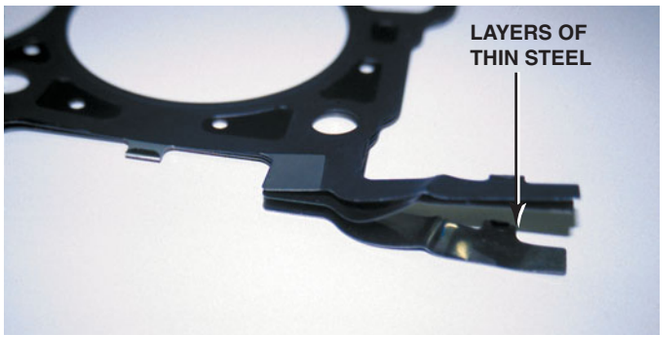


FIGURE 36–6 Multilayer steel (MLS) gaskets are used on many newer all-aluminum engines as well as on engines that use a cast block with aluminum cylinder heads. This type of gasket allows the aluminum to expand without losing the sealing ability of the gasket.

COVER GASKET MATERIALS

COVER GASKET REQUIREMENTS

Cover gaskets are used to seal valve covers, oil pans, timing chain and other covers. The gasket must be *impermeable* to the fluids it is designed to seal in or out. The gasket must *conform* to the shape of the surface, and it must be *resilient,* or elastic, to maintain the sealing force as it is compressed. Gaskets work best when they are compressed about 30%.

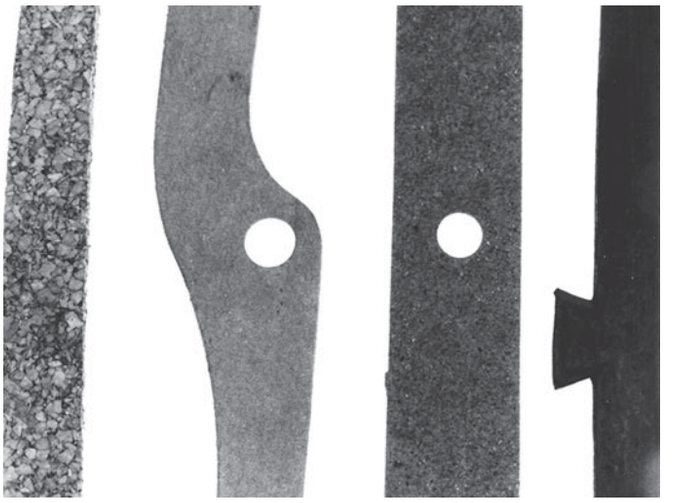


FIGURE 36–7 Left to right: Cork-rubber, paper, composite, and synthetic rubber (elastomer) gaskets.

TECH TIP

Wow! I Can't Believe a Cylinder Can Deform That Much!

An automotive instructor used a dial bore gauge in a 4-cylinder, cast-iron engine block to show students how much a block can deform. Using just one hand, the instructor was able to grasp both sides of the block and then squeeze it. The dial bore gauge showed that the cylinder deflected about 0.0003 in. (3/10,000 of an inch) just by squeezing the block with one hand—and that was with a cast-iron block!

After this demonstration, the students were more careful during engine assembly and always used a torque wrench on each and every fastener that was installed in or on the engine block.

CORK GASKETS

Older engines often used gaskets made from cork. Cork is the bark from a Mediterranean cork oak tree. It is made of very small, flexible, 14-sided, air-filled fiber cells, about 0.001 in. (0.025 mm) in size. Disadvantages of cork gaskets include the following:

- Because cork is mostly wood, it expands when it gets wet and shrinks when it dries. This causes cork gaskets to change in size when they are in storage and while installed in the engine.
- Oil gradually wicks through the organic binder of the cork, so a cork gasket often looks like it is leaking.
- Problems with cork gaskets led the gasket industry to develop cork cover gaskets using synthetic rubber as a binder for the cork. This type of gasket is called a *cork-rubber gasket.* These cork-rubber gaskets are easy to use, and they outlast the old cork gaskets.

FIBER GASKETS

Some oil pans use fiber gaskets. Covers with higher clamping forces use gaskets with fibers that have greater density. For example, timing covers may have either fiber or paper gaskets.

SYNTHETIC RUBBER GASKETS

Molded, oil-resistant synthetic rubber is being used in more applications to seal covers. When it is compounded correctly, it forms a superior cover gasket. It operates at high temperatures for a longer period of time than does a cork-rubber cover gasket. ● **SEE FIGURE 36–7.**

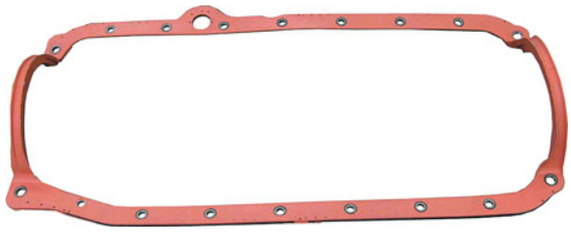


FIGURE 36–8 Rubber-coated steel gaskets have replaced many oil pan gaskets that once had separate side rail gaskets and end seals.



FIGURE 36–9 Formed in place gaskets often use silicone rubber and are applied at the factory using a robot. Check gasket manufacturers for the correct gasket replacement.

TECH TIP

Rubber and Contact Cement

One of the reasons why gaskets fail is due to their movement during installation. Some gaskets, such as cork or rubber valve cover gaskets or oil pan gaskets, can be held onto the cover using a rubber or contact cement.

To use a rubber or contact cement, use the following steps.

STEP 1 Apply a thin layer to one side of the gasket and to the cover where the gasket will be placed.

STEP 2 Allow the surfaces to air dry until touch free.

STEP 3 Carefully place the gaskets onto the cover being sure to align all of the holes.

CAUTION: Do not attempt to remove the gasket and reposition it. The glue is strong and the gasket will be damaged if removed. If the gasket has been incorrectly installed, remove the entire gasket, clean the gasket surface, and repeat the installation using a new gasket.

RUBBER-COATED METAL GASKETS

The **rubber-coated metal (RCM) gasket** uses a metal core to give strength to the gasket. The metal is coated with a layer on both sides with silicone rubber and molded in sealing beads. RCM gaskets are used in many places, including:

- Water pump gaskets
- Valve cover gaskets
- Oil pan gaskets

SEE FIGURE 36–8.

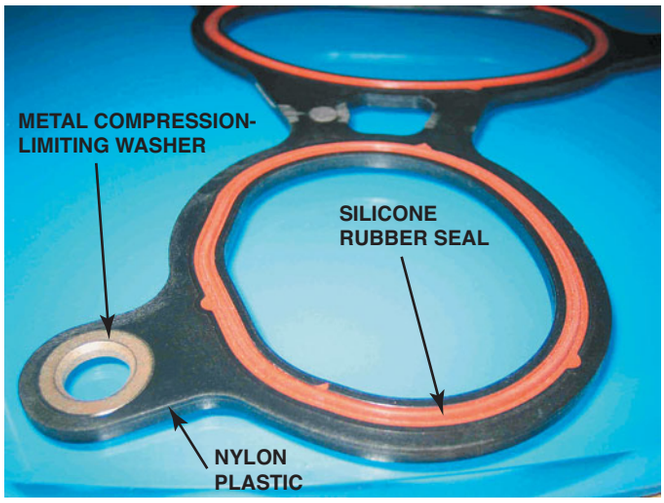


FIGURE 36–10 A typical intake manifold gasket showing the metal washer at each fastener location which keeps the gasket from being compressed too much.

FORMED IN PLACE GASKETS

Formed in place gaskets (FIPG) are commonly used because they can be applied at the engine plant using a robot. The sealing material is extruded and placed onto the sealing surface and then the two parts being sealed are placed together and the fasteners tightened. When FIPG are being replaced during an engine repair or overhaul, check service information for the exact gasket material to use. **SEE FIGURE 36–9.**

PLASTIC/RUBBER GASKETS

Most intake manifold gaskets use a nylon (usually nylon 6.6) reinforced body with silicone rubber sealing surfaces.

The nylon is used for two reasons.

1. It provides a thermal barrier to help stop the heat from the cylinder heads to flow to the intake manifold. This helps keep the intake air cooler, resulting in increased engine power.
2. The nylon plastic is strong and provides a stable foundation for the silicone rubber seal.

SEE FIGURE 36–10.

GASKET FAILURES

CAUSES OF GASKET FAILURE

Gaskets can fail to seal properly, but the root cause is often a severe condition. A head gasket can fail for the following reasons.

- Detonation (spark knock or ping) may cause extreme pressure to be exerted on the armor of the head gasket, causing it to deform.
- A plugged PCV system can increase crankcase pressure resulting in engine gasket failures such as oil pan, valve cover, timing cover, and main oil seals.
- Improper installation such as incorrect torquing sequence can cause gasket failure.

FRETTING

Fretting is a condition that can destroy intake manifold gaskets, caused by the unequal expansion and contraction of two different engine materials. For example, if the intake manifold is constructed of aluminum and the cylinder heads are cast iron, the intake manifold will expand more than the cylinder heads. This



FIGURE 36–11 This intake manifold gasket was damaged due to fretting. Newer designs allow for more movement between the intake manifold and the cylinder head.

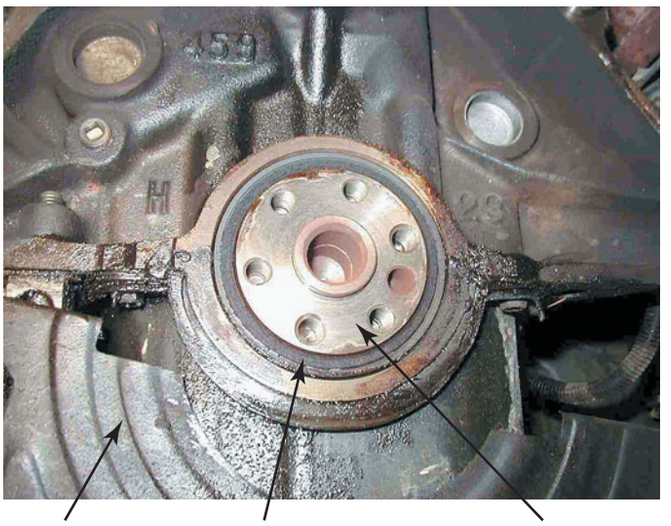


FIGURE 36–12 A rear main seal has to be designed to seal oil from leaking around the crankshaft under all temperature conditions.

TECH TIP

Hints for Gasket Usage

1. **Never reuse an old gasket.** A used gasket or seal has already been compressed, has lost some of its resilience, and has taken a set. If a used gasket does reseal, it will not seal as well as a new gasket or seal.
2. **A gasket should be checked to make sure it is the correct gasket.** Also check the list on the outside of the gasket set to make sure that the set has all the gaskets that may be needed *before* the package is opened.
3. **Read the instruction sheet.** An instruction sheet is included with most gaskets. It includes a review of the things the technician should do to prepare and install the gaskets, to give the best chance of a good seal. The instruction sheet also includes special tips on how to seal spots that are difficult to seal or that require special care to seal on a particular engine.

causes a shearing effect, which can destroy the gasket. Therefore, before assembling an engine, check for the latest design gaskets that are often different from the type originally used in the engine. **SEE FIGURE 36–11.**

OIL SEALS

PURPOSE AND FUNCTION Oil seals allow the shaft to rotate and seal the area around the shaft to prevent oil or coolant from leaking. Seals come in varied sizes and styles.

SEAL MATERIALS Most seals use a steel backing for strength and a variety of sealing materials, including:

- Buna-N
- Viton® (fluorocarbon)
- Teflon® (polytetrafluorethylene, also called PTFE)

SEE FIGURE 36–12.

TECH TIP

Always Check the VIN

There are so many variations in engines that it is important that the correct gasket or seal be used. For example, a similar engine may be used in a front-wheel-drive or a rear-wheel-drive application and this could affect the type or style of gasket or seal used. For best results, the wise technician should know the vehicle identification number (VIN) when ordering any engine part.

CAUTION: Do not use oil on a Teflon® seal because this type of seal requires that some of the material be transferred to the rotating shaft to seal properly. If oil is used on the seal, the seal will leak.

ASSEMBLY SEALANTS

RTV SILICONE RTV silicone is used by most technicians in sealing engines. **RTV, or room-temperature vulcanization,** means that the silicone rubber material will cure at room temperature. It is not really the temperature that causes RTV silicone to cure, but the moisture in the air. RTV silicone cures to a tack-free state in about 45 minutes. It takes 24 hours to fully cure.

RTV silicone is available in several different colors. The color identifies the special blend within a manufacturer's product line. Equal grades of silicone made by different manufacturers may have different colors. RTV silicone can be used in two ways in engine sealing.

1. It can be used as a gasket substitute between a stamped cover and a cast surface.
2. It is used to fill gaps or potential gaps. A joint between gaskets or between a gasket and a seal is a potential gap.

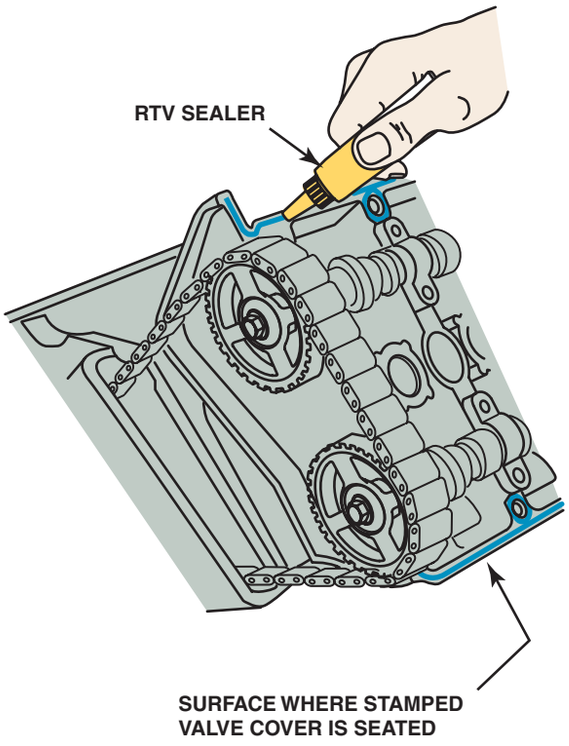


FIGURE 36–13 Room-temperature vulcanization (RTV) is designed to be a gasket substitute on nonmachined surfaces. Be sure to follow the instructions as printed on the tube for best results.

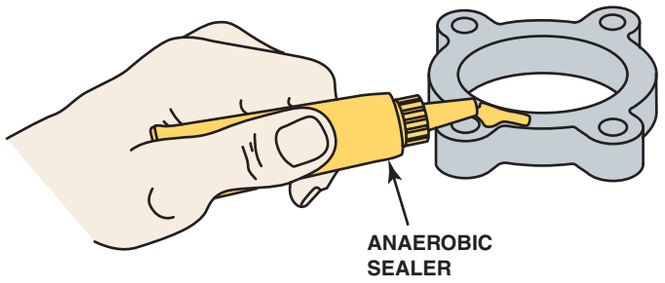


FIGURE 36–14 Anaerobic sealer is used to seal machined surfaces. Always follow the instructions on the tube for best results.

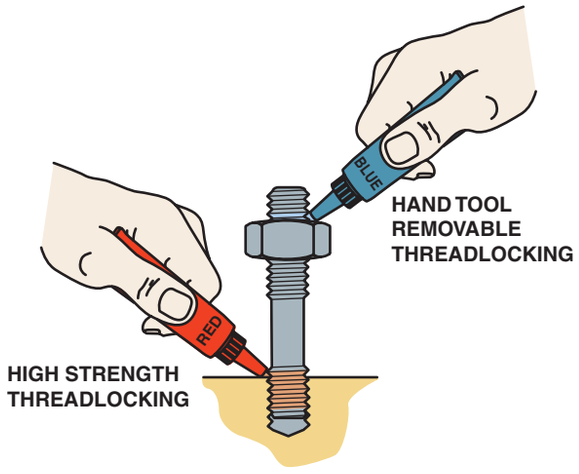


FIGURE 36–15 The strength of the thread locker depends on whether the fastener is to be removed by hand (blue). High-strength thread locker (red) can only be removed if heated.

RTV precautions include:

1. Some RTV silicone sealers use *acetic acid,* and the fumes from this type can be drawn through the engine through the PCV system and cause damage to oxygen sensors. Always use an *amine-type* RTV silicone or one that states on the package that it is safe for oxygen sensors.
2. RTV should not be used with a gasket as a sealer because it is slippery and could easily cause the gasket to move out of proper location.
3. RTV silicone should *never* be used around fuel because the fuel will cut through it. Silicone should not be used as a sealer on gaskets. It will squeeze out to leave a bead inside and a bead outside the flange. The inside bead might fall into the engine, plugging passages and causing engine damage. The thin film still remaining on the gasket stays uncured, just as it would be in the original tube. The uncured silicone is likely to let the gasket or seal slip out of place. ● **SEE FIGURE 36–13.**

ANAEROBIC SEALERS

Anaerobic sealers cure in the absence of air. They are used as thread lockers (such as Loctite®), and they are used to seal rigid machined joints between cast parts. Anaerobic sealers lose their sealing ability at temperatures above 300°F (149°C). On production lines, the curing process is speeded up by using ultraviolet light.

When the anaerobic sealer is used on threads, air does not get to it so it hardens to form a seal to prevent the fastener from loosening. Anaerobic sealers can be used to seal machined surfaces without a gasket. The surfaces *must* be thoroughly clean to get a good seal. Special primers are recommended for use on the sealing surface to get a better bond with anaerobic sealers. ● **SEE FIGURES 36–14 AND 36–15.**

NONHARDENING SEALERS

Sealers are nonhardening materials. Examples of sealer trade names include:

- Form-A-Gasket 2
- Pli-A-Seal
- Tight Seal 2
- Aviation Form-A-Gasket
- Brush Tack
- Copper Coat
- Spray Tack
- High Tack

Sealers are always used to seal the threads of bolts that break into coolant passages. Sealers for sealing threads may include Teflon. Sealer is often recommended for use on shim-type head gaskets and intake manifold gaskets. These gaskets have a metal surface that does not conform to any small amounts of surface roughness on the sealing surface. The sealer fills the surface variations between the gasket and the sealing surface.

Sealer may be used as a sealing aid on paper and fiber gaskets if the gasket needs help with sealing on a scratched, corroded, or rough surface finish. The sealer may be used on one side or on both sides of the gasket.

CAUTION: Sealer should *never* be used on rubber or cork-rubber gaskets. Instead of holding the rubber gasket or seal, it will help the rubber to slip out of place because the sealer will never harden.



FIGURE 36–16 Applying antiseize compound to the threads of a bolt helps prevent the threads from galling or rusting.

ANTISEIZE COMPOUNDS

Antiseize compounds are used on fasteners in the engine that are subjected to high temperatures to prevent seizing caused by galvanic action between dissimilar metals. These compounds minimize corrosion from moisture. Exhaust manifold bolts or nuts, and oxygen sensors, keep them from seizing. The antiseize compound minimizes the chance of threads being pulled or breaking as the oxygen sensor is removed. Always follow the vehicle manufacturer's recommendations found in service information. ● **SEE FIGURE 36–16.**

SEALANT SUMMARY

● **SEE CHART 36–1.**

PRODUCTS	COMMON TRADE NAMES	USES	EXAMPLES
RTV (room-temperature vulcanization)	Silicone	As a gasket substitute or fill gaps	Valve covers, oil pans, intake manifold end seals, timing covers, transmission pans
Anaerobic sealer (threadlocker) medium strength	Loctite® Blue	Keeps fasteners from vibrating loose	For nut and bolt applications 1/4 to 3/4 in. (6 to 20 mm)
Anaerobic sealer (threadlocker) high temperature, high strength	Loctite® Red	Heavy-duty applications	For larger fasteners 3/8 to 1 in. (9.5 to 25 mm)
Antiseize (general purpose)	Neverseez™ Kopr Kote™ E-Z Break™	For preventing corrosion seizing	Oxygen sensors, spring bolts, exhaust manifold bolts/nuts
Antiseize (nickel)	Neverseez™ Thred-Gard™	For stainless steel and other metal applications	Harsh chemical environments
Hardening gasket sealant	Permatex® #1	Holds gaskets in place during assembly; also seals paper and cork gaskets	Transmission and engine oil pan gaskets, timing cover (paper gaskets) valve cover gaskets, and intake manifold gaskets
Nonhardening sealant	Permatex® #2	Allows repeated disassembly and reassembly	Thermostat housings, differential coverings, intake manifolds, fuel injectors and fuel pumps, transmission and torque converter seals
Aviation cement/contact cement	Aviation Form-A-Gasket #3™	Holds gaskets in place for assembly	All types of hoses and gaskets

CHART 36–1

Summary chart showing where sealants are used and their common trade names.

REVIEW QUESTIONS

1. What is the purpose of a gasket?
2. What are the types of cover gaskets?
3. Why is armor used in head gaskets?
4. What is the difference between RTV and anaerobic sealers?

CHAPTER QUIZ

1. What force causes a head gasket to be drawn downward during engine operation?
   a. Intake stroke vacuum
   b. Gravity
   c. Head bolt torque
   d. Exhaust gas pressure
2. Where is a multilayered steel (MLS) gasket most often used in an engine?
   a. Valve cover gasket
   b. Oil pan gasket
   c. Head gasket
   d. Intake manifold gasket

3. A steel or copper wire used in a head gasket around the cylinder is called _____.
   a. Armor **c.** Ridge block
   b. Fire ring **d.** Either a or b
4. A one-piece oil pan gasket often uses _____ in the middle to add strength.
   a. Plastic (nylon) **c.** Hard rubber
   b. Steel **d.** Carbon fiber
5. Some gaskets use a steel washer around each bolt hole. The purpose of this washer is to _____.
   a. Improve the strength of the gasket
   b. Help seal around the bolt hole
   c. Help prevent the gasket from shrinking
   d. Prevent the gasket from being overly compressed
6. A gasket failure caused by the movement of dissimilar materials is called _____.
   a. Fretting **c.** Collapsing
   b. Corrosion **d.** Tearing
7. Which type of oil seal must *not* have oil applied for it to work correctly?
   a. Silicone rubber **c.** Teflon®
   b. Buna-N **d.** Viton®
8. Which type of *sealer* is to be used on nonmachined surfaces?
   a. RTV **c.** Either a or b
   b. Anaerobic sealer **d.** Neither a nor b
9. Which product requires heat to remove?
   a. Red thread locker
   b. Blue thread locker
   c. RTV
   d. Antiseize
10. What precautions should be followed when using gaskets?
   a. Never reuse an old gasket.
   b. A gasket should be checked to make sure it is the correct gasket.
   c. Read the instruction sheet.
   d. All of the above

chapter 37

ENGINE ASSEMBLY AND DYNAMOMETER TESTING

OBJECTIVES: **After studying Chapter 37, the reader should be able to:** • Describe the steps that should be followed in preparation for assembly. • Explain clamping force. • Define the torque-to-yield method of fastener tightening. • Discuss the advantages of performing a trial assembly of the engine. • List the steps needed to assemble an engine. • Describe what dynamometer testing can determine about the engine.

KEY TERMS: Assembly lube 392 • Clamping force 402 • Corrected torque 411 • Correction factor 411 • Dry bulb temperature 411 • Expansion plugs 393 • Fogging oil 392 • Freeze plugs 393 • Lash 406 • Piston ring compressor 399 • Soft core plugs 393 • Torque-to-yield (TTY) 403 • Transducers 411 • Welsh plugs 393

DETAILS, DETAILS, DETAILS

Successful engine assembly depends on getting all of the details right. Where to start? Start when all parts have been purchased or prepared for assembly.

When starting to assemble the engine, be sure to have all of the instructions from all of the parts used.

- **Read.** Read *all* instructions that are included with all new parts and gaskets. Often very important information or suggested specifications are included and may be at the end.
- **Understand.** Be sure to fully understand everything that is stated in the instructions. If unsure as to what is meant, ask a knowledgeable technician or call the company to be sure that all procedures are clearly understood. This is especially important if working on an engine that is not very common, such as the Audi/Volkswagen W-8. This engine has seven rotating shafts, including:
  - Four overhead camshafts
  - Two counterrotating balance shafts
  - One crankshaft

  The block and cylinder arrangement is also unique. ● **SEE FIGURE 37–1**.
- **Follow.** Be sure to follow *all* of the instructions. Do not pick the easy procedures and skip others.

SHORT BLOCK PREPARATION

ITEMS TO CHECK The following engine block details should be checked.

- All passages should be clean and free of rust and debris.
- All gasket surfaces are properly cleaned and checked for burrs and scratches.

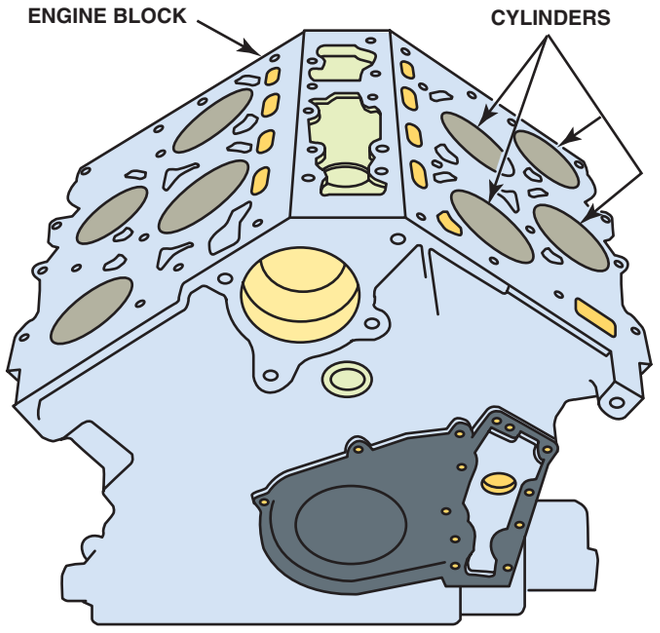


FIGURE 37–1 A uniquely designed W-8 engine installed in some Audi and Volkswagen vehicles. Rebuilding the engine would require detailed service information to be sure that all steps are taken for proper assembly.



FIGURE 37–2 Deburring all sharp edges is an important step to achieve proper engine assembly.

- All cups and plugs should be installed.
- The final bore dimension is correct for the piston.
- The surface finish of the cylinder bore matches with the specified finish required for the piston rings that are going to be used.
- All sharp edges and burrs have been removed. ● **SEE FIGURE 37–2**.
- The main bearing bores (saddles) are straight and inline.
- The lifter bores have been honed and checked for proper dimension.

SURFACE FINISH

The surface finish is important for the proper sealing of any gasket.

- **Surface too rough.** If the surface finish is too rough, the gasket will not be able to seal the deep grooves in the surface.

ENGINE PART MATERIAL	GASKET MATERIAL	ACCEPTABLE SURFACE FINISH (RA)
Cast iron/cast iron	Composite	60 to 80 µin.
Aluminum/cast iron	Composite	20 to 30 µin.
Aluminum/cast iron	Rubber-coated multilayered steel (MLS)	15 to 30 µin.

CHART 37–1

The surface finish of the block and cylinder head depends on the type of gasket being used.

- **Surface too smooth.** If the surface finish is too smooth, the gasket can move out of proper location, causing leakage.

Surface finish is measured in microinches, usually abbreviated by using the Greek letter mu (µ) and the abbreviation for inches together (µin.).

- The higher the microinch finish, the rougher the surface.
- The lower the microinch finish, the smoother the surface. The specification for surface finish is usually specified in roughness average, or Ra.

● **SEE CHART 37–1** for the acceptable roughness for the head gasket surface.

Check the instruction sheet that comes with the gasket for the specified surface finish.

CHECKING SURFACES BEFORE ASSEMBLY

All surfaces of an engine should be clean and straight and have the specified surface finish and flatness. Flatness is a measure of how much the surface varies in any 6 in. span. An industry standard maximum limit for flatness is usually 0.002 in. If the surface is not flat, the gaskets will not be able to seal properly.

PREPARING THE BLOCK FOR STUDS

Using studs instead of head bolts for cylinder heads is recommended for all high-performance applications. However, studs should not be used on a street-driven vehicle engine, because the studs would prevent the cylinder heads from being removed unless the engine is first removed from the vehicle. Most vehicles do not have enough room under the hood to allow the cylinder heads to be moved upward far enough for removal.

Studs provide for more accurate and consistent torque loading and clamping force. For example, when a bolt is used to attach a cylinder head, it is being twisted and pulled at the same time. In comparison, a stud is only being stretched. Also, a stud uses a fine thread for the retaining nut, which allows for more precise torque readings.

● **SEE FIGURE 37–3**.

The use of studs for the main bearing saddles helps main cap alignment, because the torque applied is more consistent and there is less chance of the bearing cap moving during the tightening operation. ● **SEE FIGURE 37–4**.

Screw the studs into the block but finger tighten only. Do not tighten a stud more than finger tight. A nut should not be used to double nut a stud to keep it in position.

NOTE: The tightening torque in the installation instructions is for the *nut* and not the stud itself.

In most cases, a thread locker such as Loctite® 242 can be used on the threads of the stud being inserted into the block to make the installation of the stud more permanent.

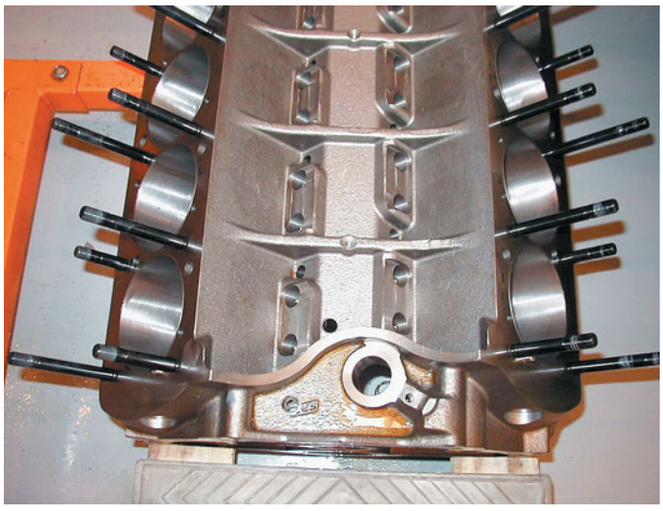


FIGURE 37–3 Studs installed in the block, replacing head bolts.

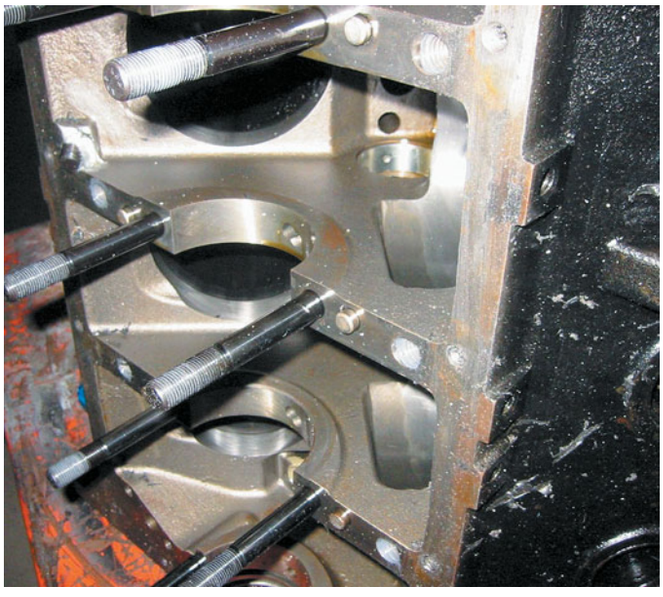


FIGURE 37–4 Main bearing studs installed on a V-8 block.

TECH TIP

Be Aware of BMW Engine Procedures

If rebuilding a BMW engine, check service information carefully because most BMW engines require that threaded inserts be installed in all head bolt threads. Performing this operation can increase the cost and time needed. Always follow all recommended service procedures on the engine being serviced. ● **SEE FIGURE 37–5.**

CAUTION: If a thread locker is used, be sure to immediately install the main bearing caps before the compound cures to help avoid misalignment.

PREPARING THREADED HOLES

STEP 1 All threads in the block should be thoroughly cleaned. Many experts recommend using a thread chaser, because a tap could cut and remove metal. A chaser will restore the threads without removing metal. ● **SEE FIGURE 37–6.**



FIGURE 37–5 A Cadillac Northstar engine being rebuilt. The shop doing the work is installing Heli-coils® in all threaded cylinder head bolt holes as a precaution. Using duct tape to cover the engine helps prevent aluminum chips from getting into passages.

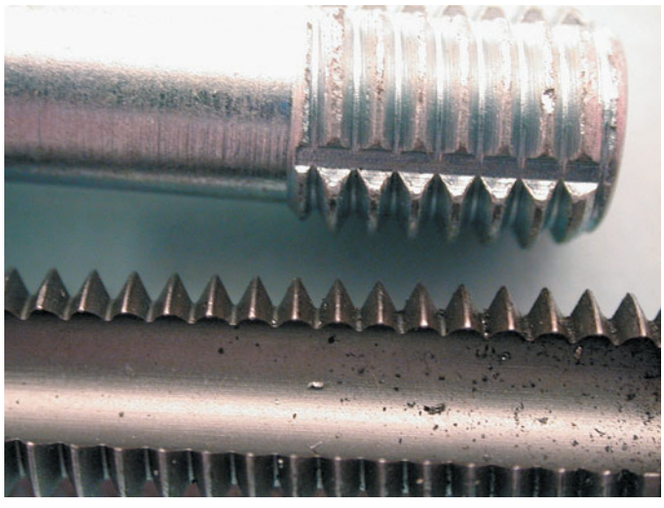


FIGURE 37–6 A thread chaser (top) is the preferred tool to clean threaded holes because it cleans without removing metal compared to a tap (bottom).

STEP 2 Check that all liquid has been removed from the bolt holes in the block. If liquid is in the bottom of a blind hole, the block can be cracked when the bolt is installed.

CYLINDER HEAD PREPARATION

ITEMS TO CHECK Check the following details on the cylinder head(s).

- The surface finish of the fire deck is as specified for the head gasket type to be used.



FIGURE 37–7 Using a plastic trash bag is an excellent way to keep the engine clean during all stages of assembly.

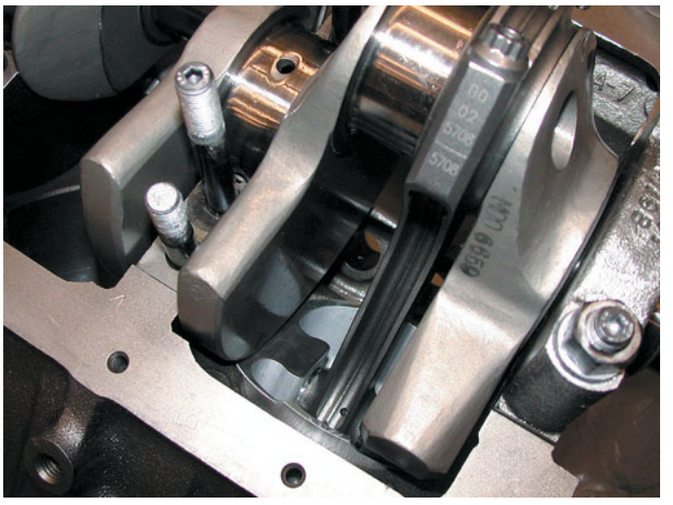


FIGURE 37–8 A trial assembly showed that some grinding of the block will be needed to provide clearance for the counterweight of the crankshaft. Also, notice that the engine has been equipped with studs for the four-bolt main bearing caps.

TECH TIP

Keep the Engine Covered

Using a large plastic trash bag is an excellent way to keep the engine clean when storing it between work sessions. ● **SEE FIGURE 37–7**.

- All valves should be checked for leakage by pouring mineral spirits into the intake and exhaust parts and look for leakage past the valves.
- All valve springs should be checked for even spring pressure and installed height.
- Check for proper pushrod length. If the cylinder head(s) has been machined and/or the block deck machined, the pushrods may be too long. If the pushrods are too long, the rocker arm geometry will not be correct. One problem that can occur with incorrect rocker arm geometry is spring bind, which can cause severe engine damage.
- If replacement rocker arms are used, be sure that the geometry and total lift will be okay.

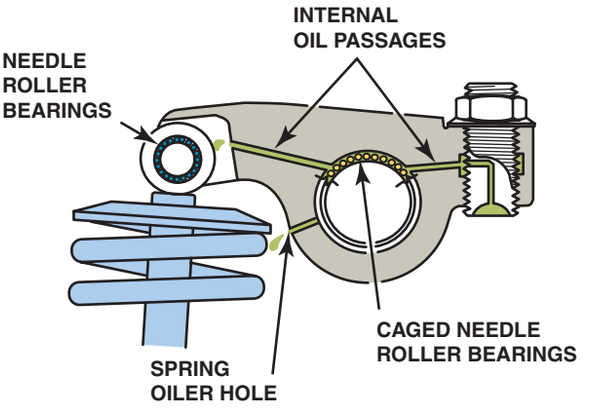


FIGURE 37–9 A typical high-performance aftermarket rocker arm which is equipped with needle roller bearings at the valve stem end and caged needle bearing at the pivot shaft end to reduce friction, which increases engine horsepower and improves fuel economy.

REAL WORLD FIX

Valve Springs Can Vary

A technician was building a small block Chevrolet V-8 engine at home and was doing the final detailed checks, and found that many of the valve springs did not have the same tension. Using a borrowed valve spring tester, the technician visited a local parts store and measured all of the valve springs that the store had in stock. The technician selected and purchased the 16 valve springs that were within specification and within a very narrow range of tension. Although having all valve springs equal may or may not affect engine operation, the technician was pleased that all of the valve springs were equal.

TRIAL ASSEMBLY

SHORT BLOCK Before performing final engine assembly, the wise technician checks that all parts will fit and work. This is especially important if using a different crankshaft that changes the stroke. ● **SEE FIGURE 37–8** for an example of a 400 cu. in. Chevrolet crankshaft being fitted to a 350 cu. in. Chevrolet engine.

VALVE TRAIN Another place where a trial fit is needed is in the valve train. Some timing chain mechanisms require more space than the stock component so some machining may be needed.

If the rocker arms have been upgraded to roller rockers, these should be installed and checked that the tip of the roller rests at the center of the valve stem. ● **SEE FIGURE 37–9**.

If there is a problem, further investigation will be needed because the pushrods may be too long due to machining of the block deck and/or cylinder head. Rotate the engine and check for proper clearance throughout the entire opening and closing of the valves. Use a feeler gauge between the coils of the valve spring to check for coil bind. If coil bind occurs, a different camshaft or valve spring should be used.



FIGURE 37–10 Fogging oil is used to cover bare metal parts when the engine is being stored to prevent corrosion.



FIGURE 37–11 Engine assembly lube is recommended to be used on engine parts during assembly.

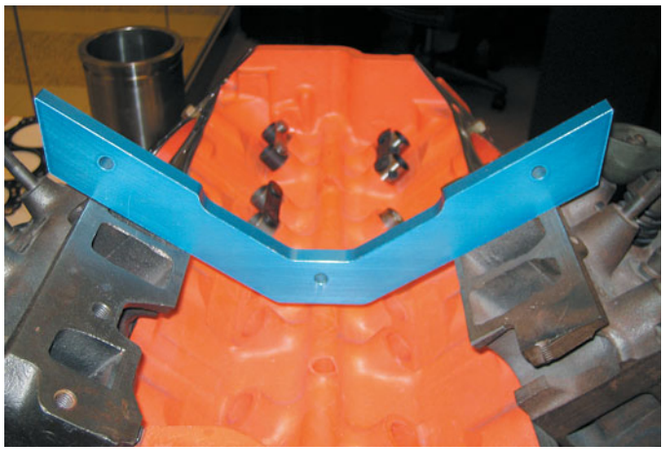


FIGURE 37–12 An angle gauge being used to check the angle between the cylinder heads on this small block Chevrolet V-8 engine.

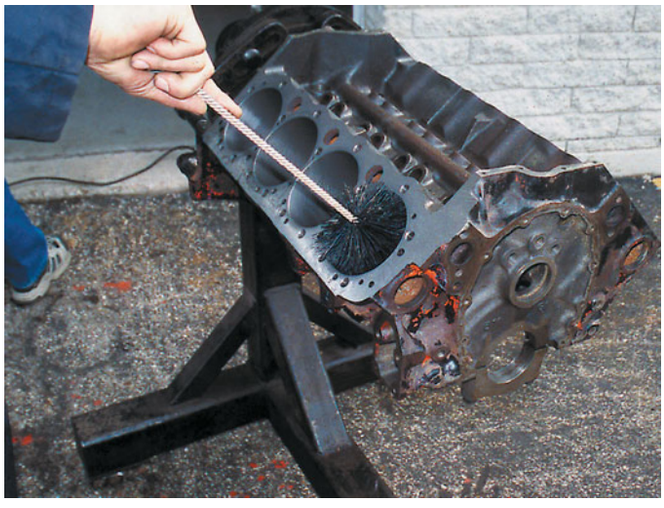


FIGURE 37–13 The best way to thoroughly clean cylinders is to use soap (detergent), water, and a large washing brush. This method floats the machining particles out of the block and washes them away.

CHECK THE ANGLE BETWEEN HEADS

During the trial assembly, use a gauge to check that the heads are at the correct angle to ensure proper intake manifold gasket sealing. If the angle is not correct, then remachining of the head or block will be needed. ● **SEE FIGURE 37–12**.

TECH TIP

Fogging Oil and Assembly Lube

When assembling an engine, the parts should be coated with a light oil film to keep them from rusting. This type of oil is commonly referred to as **fogging oil** and is available in spray cans. ● **SEE FIGURE 37–10**.

During engine assembly, the internal parts should be lubricated. While engine oil or grease could be used, most experts recommend the use of a specific lubricant designed for engine assembly. This lubricant, designed to remain on the parts and not drip or run, is called **assembly lube.** ● **SEE FIGURE 37–11**.

FINAL SHORT BLOCK ASSEMBLY

BLOCK PREPARATION

All surfaces should be checked for damage resulting from the machining processes. Items that should be done before assembly begins include the following:

1. The block, including the oil gallery passages, should be thoroughly cleaned. ● **SEE FIGURES 37–13 AND 37–14**.
2. All threaded bolt holes should be chamfered.
3. All threaded holes should be cleaned with a thread chaser before final assembly.



FIGURE 37–14 All oil galleries should be cleaned using soap (detergent), water, and a long oil gallery cleaning brush.

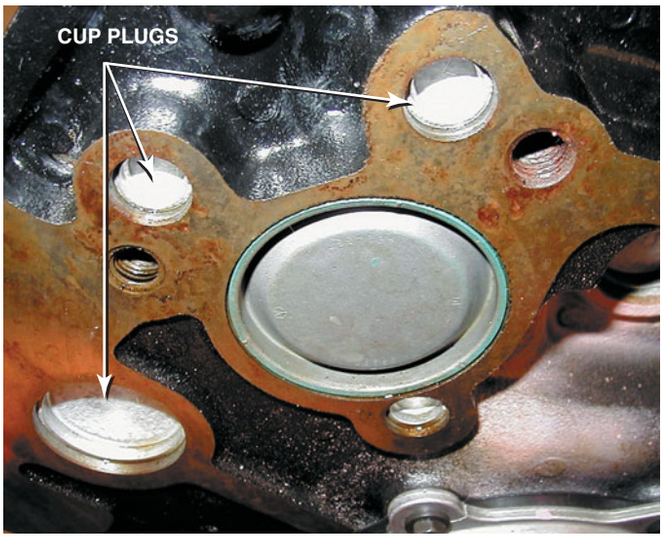


FIGURE 37–15 This engine uses many cup plugs to block off coolant and oil passages as well as a large plug over the end of the camshaft bore.

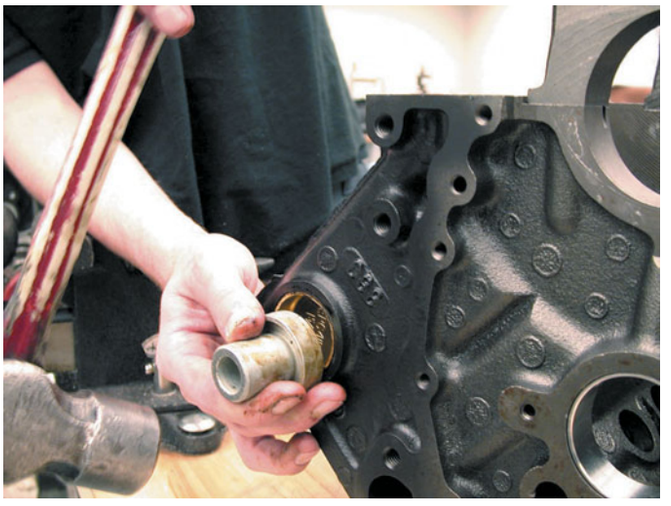


FIGURE 37–16 Sealer should be applied to the cup plug before being driven into the block.

INSTALLING CUPS AND PLUGS

Oil gallery plugs should be installed using sealant on the threads.

CAUTION: Avoid using Teflon tape on the threads of oil gallery plugs or coolant drain plugs. The tape is often cut by the threads, and thin strips of the tape are then free to flow through the oil galleries where the tape can cause a clog, thereby limiting lubricating engine oil to important parts of the engine.

Core holes left in the external block wall are machined and sealed with **soft core plugs** or **expansion plugs** (also called **freeze plugs** or **Welsh plugs**).

Soft plugs are of two designs.

- **Convex type.** The core hole is counterbored with a shoulder. The convex soft plug is placed in the counterbore, convex side out. It is driven in with a fitted seating tool. This causes the edge of the soft plug to enlarge to hold it in place. A convex plug should be driven in until it reaches the counterbore of the core plug hole.
- **Cup type.** This most common type fits into a smooth, straight hole. The outer edge of the cup is slightly bell mouthed. The bell mouth causes it to tighten when it is driven into the hole to the correct depth with a seating tool. An installed cup-type soft plug is shown in ● **FIGURE 37–15**.

A cup plug is installed about 0.02 to 0.05 in. (0.5 to 1.3 mm) below the surface of the block, using sealant to prevent leaks. ● **SEE FIGURE 37–16**.

CAM BEARINGS

A cam bearing installing tool is required to insert the new cam bearing without damaging the bearing. A number of tool manufacturers design and sell cam bearing installation tools. Their common feature is a shoulder on a bushing that fits inside the cam bearing, with a means of keeping the bearing aligned as it is installed.

The bearing is placed on the bushing of the tool and rotated to properly align the oil hole. The bearing is then forced into the bearing

? FREQUENTLY ASKED QUESTION

What Causes Premature Bearing Failure?

According to a major manufacturer of engine bearings, the major causes of premature (shortly after installation) bearing failure include the following:

Dirt (45%)
Misassembly (13%)
Misalignment (13%)
Lack of lubrication (11%)
Overloading or lugging (10%)
Corrosion (4%)
Other (4%)

Many cases of premature bearing failure may result from a combination of several of these items. Therefore, to help prevent bearing failure, *keep everything as clean as possible.*

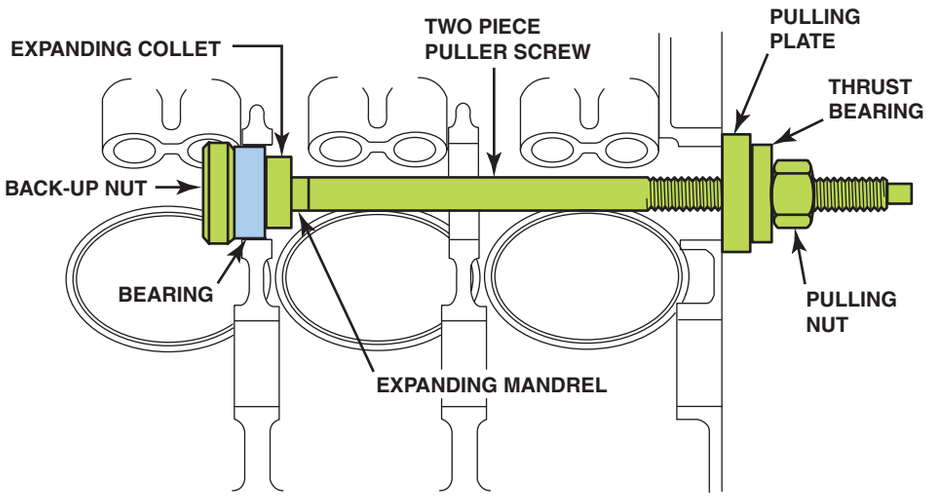


FIGURE 37–17 Screw-type puller being used to install a new cam bearing. Most cam bearings are crush fit. The full round bearing is forced into the cam bearing bore. Most vehicle manufacturers specify that the cam bearings be installed "dry" without lubrication to help prevent them from spinning, which would cause the bearing to block the oil feed hole.

bore of the block by either a pulling screw or a slide hammer. A pulling screw type of tool is illustrated in ● **FIGURE 37–17.**

The installed bearing must be checked to ensure that it has the correct depth and that the oil hole is indexed with the oil passage in the block. No additional service is required on cam bearings that have been properly installed. The opening at the back of the camshaft is closed with a cup plug.

MEASURING MAIN BEARING CLEARANCE

The main bearings are properly fit *before* the crankshaft is lubricated or turned. The oil clearance of both main and connecting rod bearings is set by selectively fitting the bearings. In this way, the oil clearance can be adjusted to within 0.0005 in. of the desired clearance.

CAUTION: Avoid touching bearings with bare hands. The oils on your fingers can start corrosion of the bearing materials. Always wear protective cloth or rubber gloves to avoid the possibility of damage to the bearing surface.

Bearings are usually made in 0.010, 0–020, and 0.030 in. *undersize* for use on reground journals. ● **SEE FIGURE 37–18** for a typical main bearing set.

The crankshaft bearing journals should be measured with a micrometer to select the required bearing size.

- Each of the main bearing caps will only fit one location and the caps must be positioned correctly.
- The correct-size bearings should be placed in the block and cap, making sure that the bearing tang locks into its slot.
- The upper main bearing has an oil feed hole. The lower bearing does not have an oil hole.
- Lower the crankshaft squarely so that it does not damage the thrust bearing. Carefully rest the clean crankshaft in the block on the upper main bearings.
- After making sure that there is no oil on the crank journal of the bearing, place a strip of Plastigage® (gauging plastic) on each main bearing journal. Install the main bearing caps and tighten the bolts to specifications.
- Remove each cap and check the width of the Plastigage® with the markings on the gauge envelope, as shown in ● **FIGURE 37–19**.
- The width of the plastic strip indicates the oil clearance.

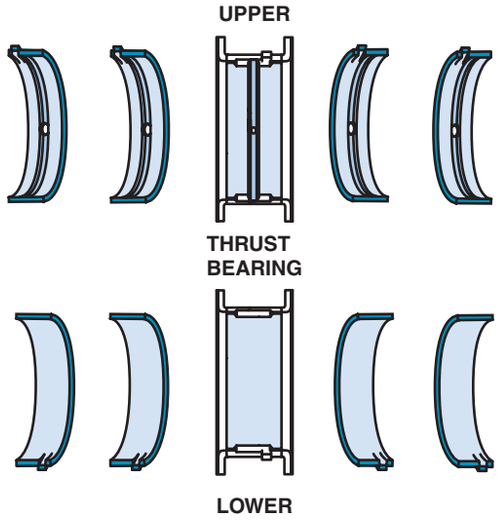


FIGURE 37–18 Typical main bearing set. Note that the upper halves are grooved for better oil flow and the lower halves are plain for better load support. This bearing set uses the center main bearing for thrust control. Notice that the upper bearing set has the holes for oil, whereas the lower set does not.

CORRECTING BEARING CLEARANCE

Oil clearances normally run from 0.0005 to 0.002 in. (half a thousandth to two thousandths).

- The oil clearance can be reduced by 0.001 in. by replacing both bearing shells with bearing shells that are 0.001 in. undersize.
- The clearance can be reduced by 0.0005 in. by replacing only one of the bearing shells with a bearing shell that is 0.001 in. smaller.
- This smaller bearing shell should be placed in the engine block side of the bearing (the upper shell). Oil clearance can be adjusted accurately using this procedure. Try to avoid mismatching the bearing shells by more than a 0.001 in. difference in size.

LIP SEAL INSTALLATION

Seals are always used at the front and rear of the crankshaft. Overhead cam engines may also have a seal at the front end of the camshaft and at the front end of an auxiliary accessory shaft. Either a lip seal or a rope seal is used in these locations. ● **SEE FIGURE 37–20**.

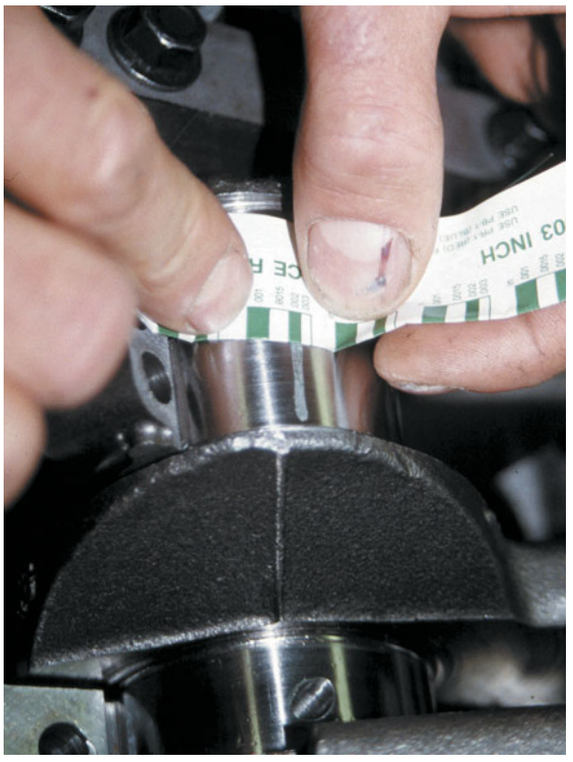


FIGURE 37–19 The width of the plastic gauging strip determines the oil clearance of the main bearing. An alternate method of determining oil clearance includes careful measurement of the crankshaft journal and bearings after they are installed and the main housing bore caps are torqued to specifications.

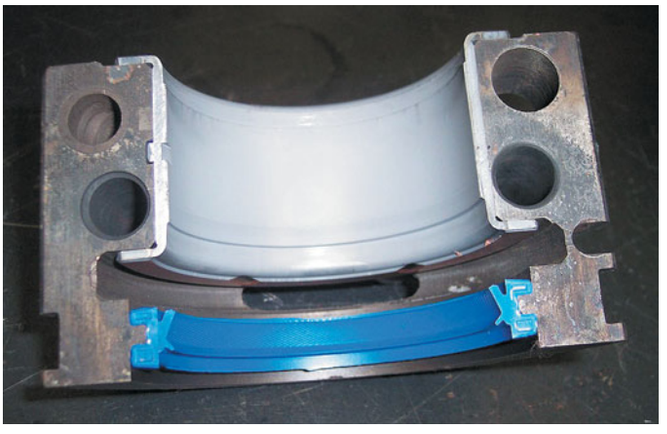


FIGURE 37–20 Lip-type rear main bearing seal in place in the rear main bearing cap. The lip should always be pointing toward the inside of the engine.

The rear crankshaft oil seal is installed after the main bearings have been properly fit. The lip seal may be molded in a steel case or it may be molded around a steel stiffener. The counterbore or guide that supports the seal must be thoroughly clean. In most cases, the back of the lip seal is dry when it is installed. Occasionally, a manufacturer will recommend the use of sealants behind the seal. Check service information for the specified sealing instructions. The lip of the seal should be well lubricated before the shaft and cap are installed. ● **SEE FIGURES 37–21 AND 37–22.**

CAUTION: Teflon seals should *not* be lubricated. This type of seal should be installed dry. When the engine is first started, some of the Teflon transfers to the crankshaft, to create a Teflon-to-Teflon surface. Even touching the seal with your hands could remove some of the outer coating on the seal and cause a leak. Carefully read, understand, and follow the installation instructions that come with the seal.

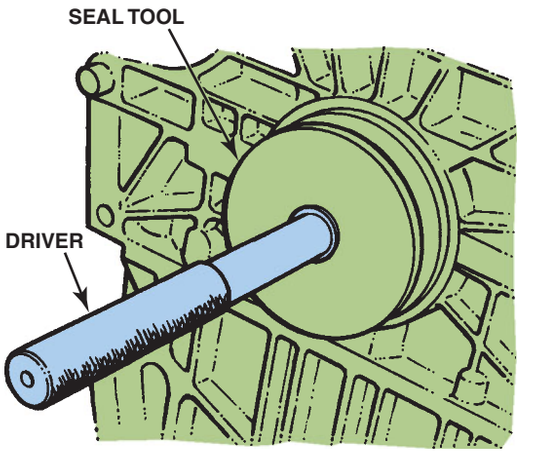


FIGURE 37–21 Always use the proper driver to install a main seal. Never pound directly on the seal.

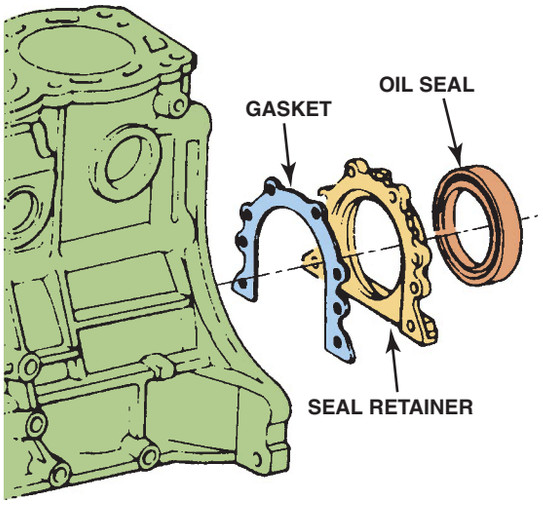


FIGURE 37–22 The rear seal for this engine mounts to a retainer plate. The retainer is then bolted to the engine block.

TECH TIP

"One to Three"

When engine technicians are talking about clearances and specifications, the unit of measure most often used is thousandths of an inch (0.001 in.). Therefore, a clearance expressed as "one to three" would actually be a clearance of 0.001 to 0.003 in. The same applies to parts of a thousandth of an inch. For example, a specification of 0.0005 to 0.0015 in. would be spoken of as simply being "one-half to one and one-half." The unit of a thousandth of an inch is assumed, and this method of speaking reduces errors and misunderstandings.

HINT: Most engine clearance specifications fall within one to three thousandths of an inch. The written specification could be a misprint. Therefore, if the specification does not fall within this general range, double-check the clearance value using a different source.

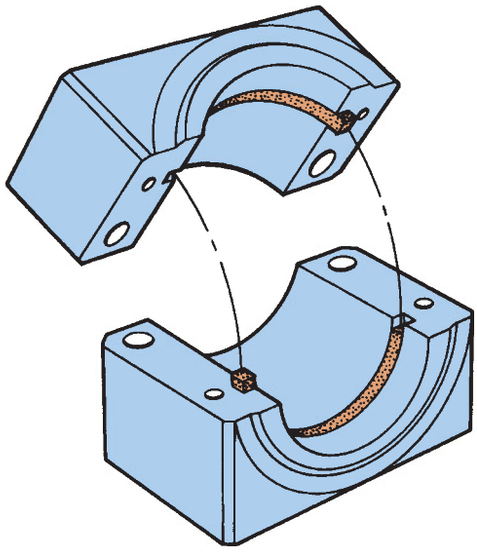


FIGURE 37–23 Many engine builders prefer to stagger the parting lines of a rope-type seal.

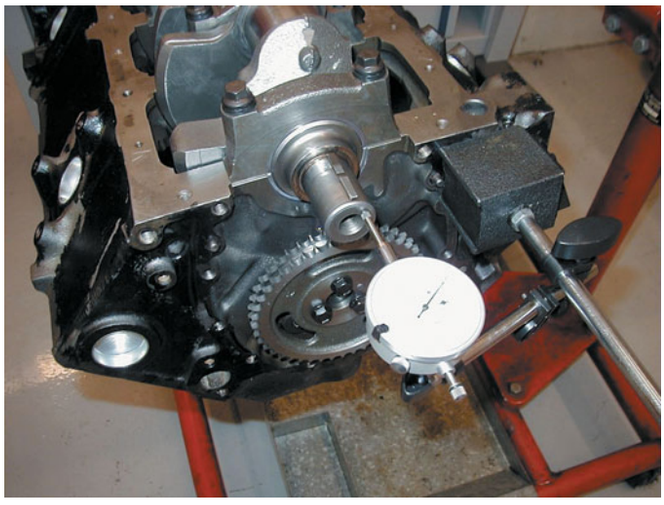


FIGURE 37–24 A dial indicator is being used to check the crankshaft end play, known as thrust bearing clearance. Always follow the manufacturer's recommended testing procedures.



FIGURE 37–25 A thrust bearing insert being installed before the crankshaft is installed.

ROPE SEAL INSTALLATION Some older engines use rope-type seals at both the front and rear of the crankshaft. Rope-type seals, usually called *braided fabric seals,* are sometimes used as rear crankshaft oil seals. Rope-type oil seals must be compressed tightly into the groove so that no oil can leak behind them. With the crankshaft removed, the upper half of the rope seal is put in a clean groove and compressed by rolling a round object against it to force it tightly into the groove. A piece of pipe, a large socket, or even a hammer handle can be used for this.

When the seal is fully seated in the groove, the ends that extend above the parting surface are cut to be flush with the surface using a sharp single-edge razor blade or a sharp tool specially designed to cut the seal. Some technicians find that leaving a little of the seal higher than the bearing cap creates a better seal, because when the bearing cap is installed and tightened, the extra seal length forces the rope seal further into the groove. ● **SEE FIGURE 37–23**.

CRANKSHAFT INSTALLATION The main bearing caps and crankshaft should be removed after checking for proper bearing clearance. The surface of the bearings should then be given a thin coating of oil or assembly lubricant to provide initial lubrication for engine start-up. Install the crankshaft using the following steps.

STEP 1 The crankshaft should be carefully placed in the bearings to avoid damage to the thrust bearing surfaces.

STEP 2 The bearing caps are installed with their identification numbers correctly positioned. The caps were originally machined in place, so they can only fit correctly in their original position.

STEP 3 The main bearing cap bolts are tightened finger tight, and the crankshaft is rotated. It should rotate freely.

THRUST BEARING CLEARANCE Tighten all main bearing cap bolts to factory specification except for the bearing cap that is used for thrust (usually the center or the rear cap). Pry the crankshaft forward and rearward to align the cap half of the thrust bearing with the block saddle half. Most engine specifications for thrust bearing clearance (also called *crankshaft end play*) can range from 0.002 to 0.012 in. (0.02 to 0.3 mm). This clearance or play can be measured with a:

- Feeler gauge
- Dial indicator ● **SEE FIGURE 37–24**.

If the clearance is too great, oversize main thrust bearings may be available for the engine. Semifinished bearings may have to be purchased and machined to size to restore proper tolerance.

NOTE: Some engines use a separate replaceable thrust bearing. ● **SEE FIGURE 37–25.**

MAIN BEARING TIGHTENING PROCEDURE Tighten the main bearing caps to the specified assembly torque, and in the specified sequence. The procedure specified usually includes tightening the main bearing cap bolts in three stages.

- Torque to one-third of the specified torque.
- Then tighten to two-thirds of the specified torque.
- Finally tighten the bolts to the factory specified torque.

Many manufacturers require that the crankshaft be pried forward or rearward during the main bearing tightening process. The crankshaft should turn freely after all main bearing cap bolts are fully torqued.



FIGURE 37–26 Installing a camshaft is easier if the engine is vertical so gravity can help, and this method reduces the possibility of damaging the cam bearings.



FIGURE 37–27 A commercial additive designed to protect a flat-bottom lifter camshaft used in older vehicles when using newer oils that do not have enough ZDDP to protect the camshaft and lifters.

TECH TIP

Use a Long Bolt to Hold the Camshaft

To help install a camshaft without harming the cam bearings, install a long bolt into one of the end threaded holes in the camshaft. Then tilt the engine vertically so that gravity will cause the camshaft to fall straight down while holding onto the camshaft using the long bolt.
● **SEE FIGURE 37–26**.

CRANKSHAFT ROTATING TORQUE It should never require over 5 pound-feet (lb-ft) (6.75 newton-meters, or N-m) of torque to rotate the crankshaft. An increase in the torque needed to rotate the crankshaft is often caused by a foreign particle that was not removed during cleanup. It may be on the bearing surface, on the crankshaft journal, or between the bearing and saddle.

INSTALLING THE CAMSHAFT

PRELUBRICATION When the camshaft is installed, the lobes must be coated with a special lubricant that contains molydisulfide. This special lube helps to ensure proper initial lubrication to the critical cam lobe sections of the camshaft. Many manufacturers recommend multiviscosity engine oil such as SAE 5W-30 or SAE 10W-30. Some camshaft manufacturers recommend using straight SAE 30 or SAE 40 engine oil and not a multiviscosity oil for the first oil fill. Some manufacturers also recommend the use of an antiwear additive such as zinc dithiophosphate (ZDP).

CAMSHAFT PRECAUTIONS Whenever repairing an engine, follow these rules regarding the camshaft and lifters.

1. When installing a new camshaft, always install new valve lifters (tappets).
2. When installing new lifters, if the original cam is not excessively worn and if the pushrods all rotate with the original camshaft, the camshaft may be reused.

TECH TIP

Two Choices If Using Flat-Bottom Lifters

An old or rebuilt engine that uses flat-bottom lifters must use one of two lubricants.

1. Oils that contain at least 0.15% or 1,500 parts per million (ppm) of zinc in the form of ZDDP. Oils that contain this much zinc are designed for off-road use only and in a vehicle that does not have a catalytic converter, such as racing oils. If the vehicle is equipped with a catalytic converter, replace the camshaft and lifters to roller type, so that newer oils with lower levels of zinc can be used.
2. Use a newer oil and an additive such as:
   a. GM engine oil supplement (EOS) (Part #1052367 or #88862586)
   b. Comp Cams® camshaft break-in oil additive (Part #159)
   c. Crane Cams® Moly Paste (Part #99002-1)
   d. Crane Cams® Super Lube oil additive (Part #99003-1)
   e. Lumati Assembly lube (Part #99010)
   f. Mell-Lube camshaft tube oil additive (Part # M-10012)
   g. Other available additives designed to protect the camshaft (● **SEE FIGURE 37–27**).

NOTE: Some manufacturers recommend that a new camshaft always be installed when replacing valve lifters.

3. *Never* use a hydraulic lifter camshaft with solid lifters or hydraulic lifters with a solid lifter camshaft.

PISTON/ROD INSTALLATION

CHECKING PISTON RINGS Before installing the piston assemblies, all piston rings should be checked for proper side clearance and ring gap. ● **SEE FIGURE 37–28**.

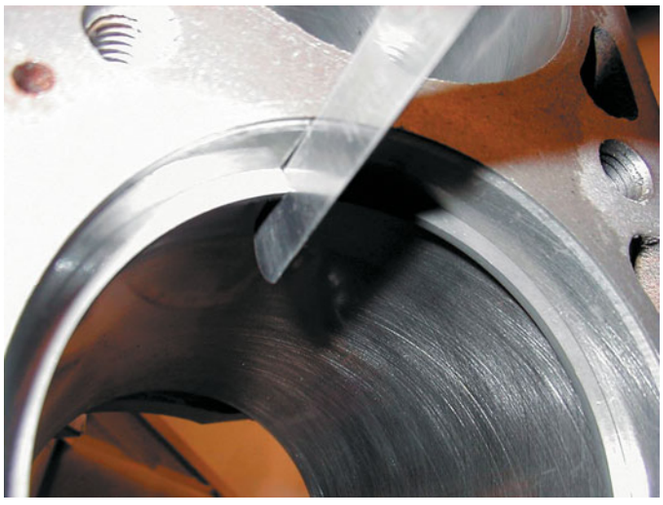


FIGURE 37–28 A feeler gauge is used to check piston ring gap.

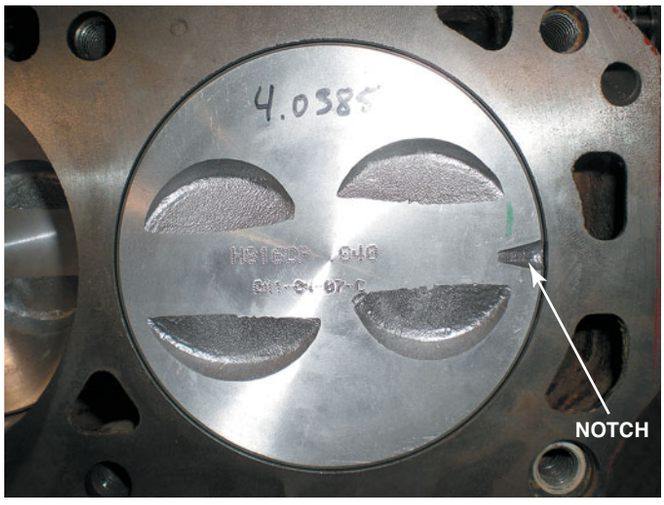


FIGURE 37–29 The notch on a piston should always face toward the front of the engine.

PISTON DIAMETER	RING GAP
2 to 3 in.	0.007 to 0.018 in.
3 to 4 in.	0.01 to 0.02 in.
4 to 5 in.	0.013 to 0.023 in.

CHART 37–2

The approximate ring gap based on the size of the bore in inches. Always check service information for the exact specifications for the engine being assembled.

Typical ring gap clearances are about 0.004 in. per inch of cylinder bore. ● **SEE CHART 37–2.**

NOTE: If the gap is greater than recommended, some engine performance is lost. However, too small a gap will result in scuffing, because ring ends can be forced together during operation, which forces the rings to scrape the cylinders.

- If the ring gap is too large, the ring should be replaced with one having the next oversize diameter.
- If the ring gap is too small, the ring should be removed and filed to make the gap larger.

PISTON MARKINGS

Care must be taken to ensure that the pistons and rods are in the correct cylinder. They must face in the correct direction. There is usually a *notch* on the piston head indicating the *front.* Using this will correctly position the piston pin offset toward the right side of the engine. ● **SEE FIGURE 37–29.**

- The connecting rod *identification marks* on pushrod 4 and 6 cylinder inline engines are normally placed on the camshaft side.
- On V-type engines, the connecting rod cylinder identification marks are on the side of the rods that can be seen from the bottom of the engine when the piston and rod assemblies are installed in the engine. Make sure the connecting rod has been installed on the piston correctly—the chamfer on the side of the big end should face outward (toward the crank throw). ● **SEE FIGURE 37–30.**
- Check service information for any special piston and rod assembly instructions.

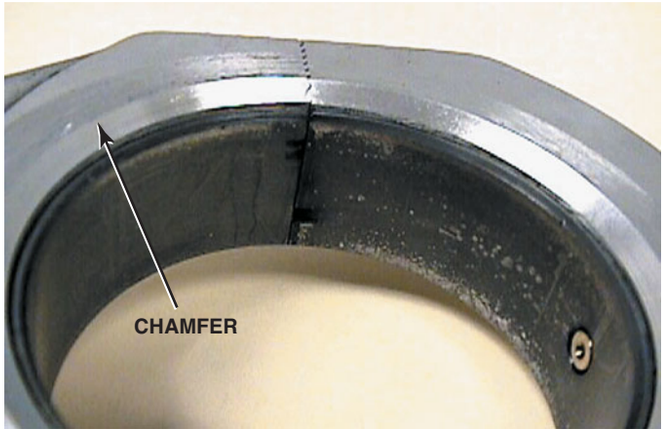


FIGURE 37–30 On V-type engines that use paired rod journals, the side of the rod with the large chamfer should face toward the crank throw (outward).

CONNECTING ROD BEARING CLEARANCE

The rod cap, with the bearing in place, is put on the rod. There are two methods that can be used to check for proper connecting rod bearing clearance.

- Use Plastigage® following the same procedure discussed for main bearing clearance.
- Measure the assembled connecting rod big end devices with the bearing installed and the caps torqued to specification. Subtract the diameter of the rod journal to determine the bearing clearance. ● **SEE FIGURE 37–31.**

NOTE: Be certain to check for piston-to-crankshaft counterweight clearance. Most manufacturers specify a minimum 0.06 in. (1.5 mm).

PISTON INSTALLATION

To install a piston, perform the following steps.

STEP 1 Apply a coating of clean engine oil to the cylinder walls. This oil should be spread over the entire cylinder wall surface by hand.

STEP 2 Apply oil or assembly lube to the rod bearings.

STEP 3 Align the piston ring gaps (ring gap stagger) to the locations specified in service information. ● **SEE FIGURE 37–32.**

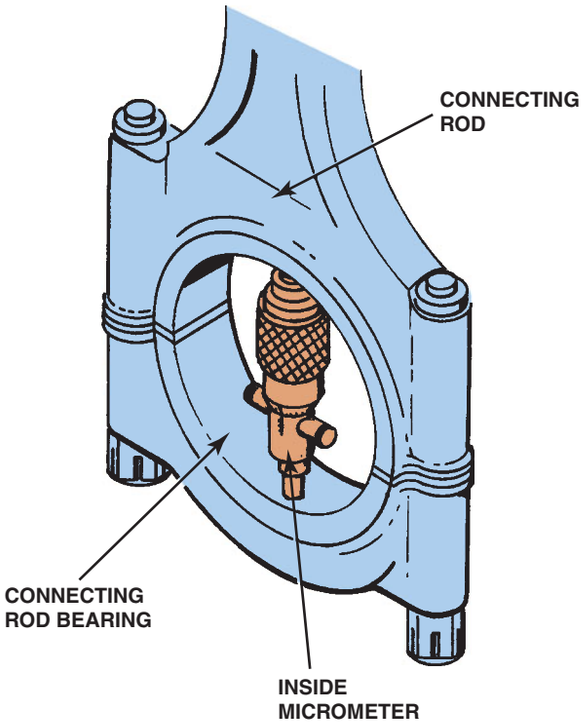


FIGURE 37–31 An inside micrometer can be used to measure the inside diameter of the big end of the connecting rod with the bearings installed. This dimension subtracted from the rod journal diameter is equal to the bearing clearance.

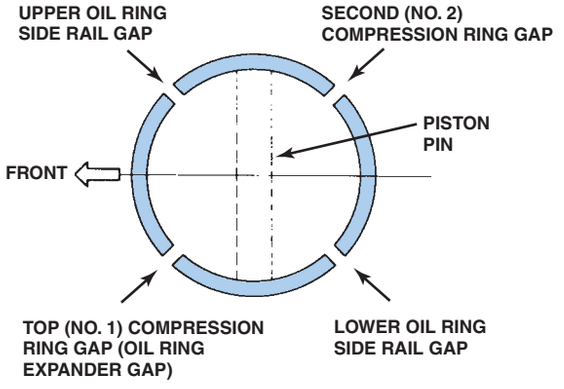


FIGURE 37–32 One method of piston ring installation showing the location of ring gaps. Always follow the manufacturer's recommended method for the location of ring gaps and for ring gap spacing.

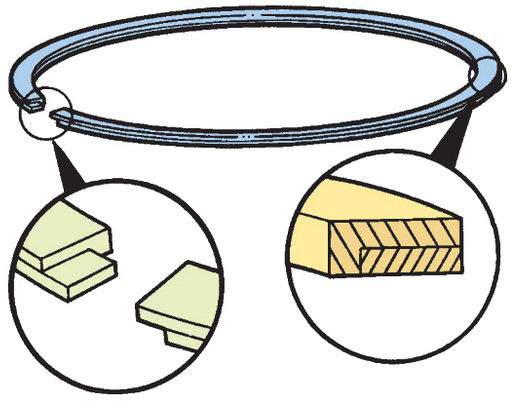


FIGURE 37–33 A gapless ring is made in two pieces that overlap.

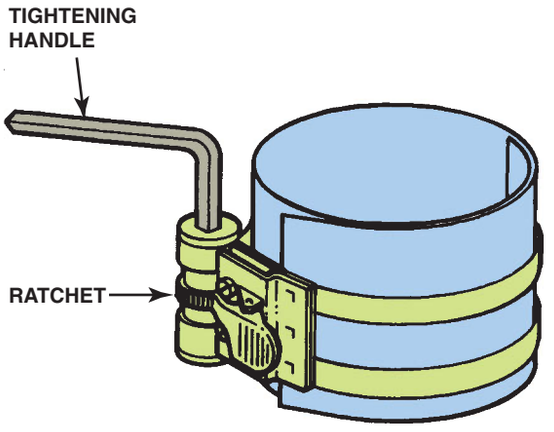


FIGURE 37–34 This style of ring compressor uses a ratchet to contract the spring band and compress the rings into their grooves.

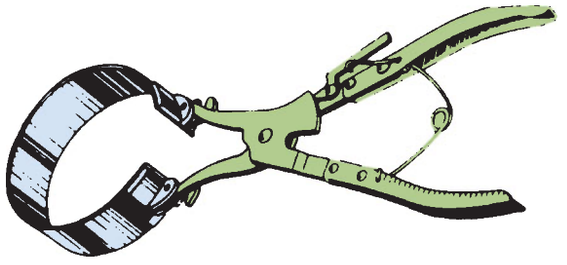


FIGURE 37–35 This pliers-like tool is used to close the metal band around the piston to compress the rings. An assortment of bands is available to service different size pistons.

STEP 4 Using a squirt-type oil can, squirt oil over the rings and the skirt of the piston.

NOTE: Special types of piston rings (overlapping or gapless) are installed dry, without oil. ● SEE FIGURE 37–33. Some manufacturers recommend oiling only the oil control ring. Always check the piston ring instruction sheet for the exact procedure.

STEP 5 The **piston ring compressor** is then put on the piston to hold the rings in their grooves. ● **SEE FIGURES 37–34 AND 37–35.**

STEP 6 Rotate the crankshaft so the crankshaft journal is at the bottom (BDC) to help prevent the rod from touching the crankshaft when the piston is installed.

STEP 7 Remove the bearing cap from the rod, and install the bearings.

STEP 8 Install protectors over the rod bolts. These help prevent damage to the crankshaft journal when the piston/rod assembly is installed. ● **SEE FIGURE 37–36.**

STEP 9 The upper rod bearing should be in the rod and the piston should be turned so that the notch on the piston head is facing the front of the engine.

STEP 10 The piston and rod assembly is placed in the cylinder through the block deck. The ring compressor must be kept tightly against the block deck as the piston is pushed into the cylinder.

The ring compressor holds the rings in their grooves so that they will enter the cylinder. ● **SEE FIGURE 37–37.**

STEP 11 The piston is pushed into the cylinder until the rod bearing is fully seated on the journal.

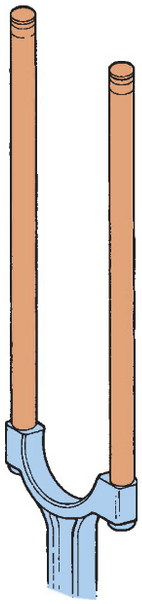


FIGURE 37–36 When threaded onto the rod bolts, these guides not only help align the rod but also protect the threads and holds the bearing shell in place. The soft ends also will not damage the crankshaft journals.



FIGURE 37–37 Installing a piston using a ring compressor to hold the rings into the ring grooves of the piston and then using a hammer handle to drive the piston into the bore. Connecting rod bolt protectors have been installed to help prevent possible damage to the crankshaft during piston installation.

CONNECTING ROD SIDE CLEARANCE

The connecting rods should be checked to ensure that they still have the correct side clearance. This is measured by fitting the correct thickness of feeler gauge between the connecting rod and the crankshaft cheek of the bearing journal. ● **SEE FIGURE 37–38**.

- *If the side clearance is too great,* excessive amounts of oil may escape that can cause lower-than-normal oil pressure. To correct excessive clearance:
  1. Weld and regrind or replace the crankshaft.
  2. Carefully measure all connecting rods and replace those that are too thin or mismatched.

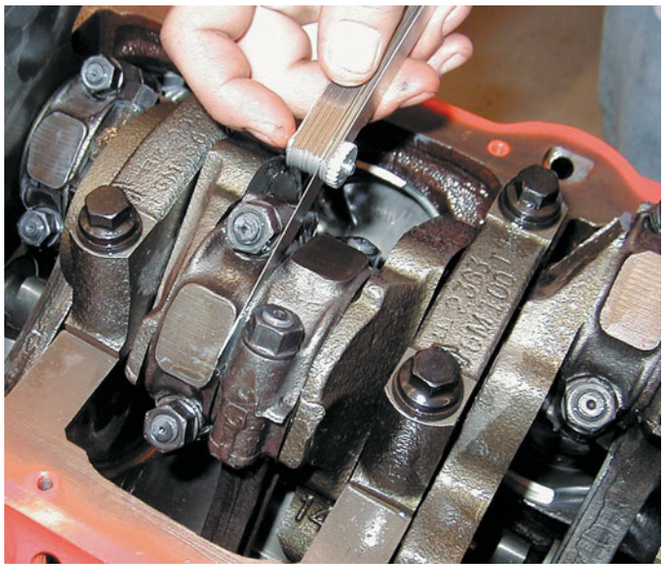


FIGURE 37–38 The connecting rod side clearance is measured with a feeler gauge.

TECH TIP

Tightening Tip for Rod Bearings

Even though the bearing clearances are checked, it is still a good idea to check and record the torque required to rotate the crankshaft with all piston rings dragging on the cylinder walls. The retaining nuts on one bearing should be torqued, and then the torque that is required to rotate the crankshaft should be rechecked and recorded. Follow the same procedure on all rod bearings. If tightening any one of the rod bearing caps causes a large increase in the torque required to rotate the crankshaft, immediately stop the tightening process. Determine the cause of the increased rotating torque using the same method as used on the main bearings. Rotate the crankshaft for several revolutions to ensure that the assembly is turning freely and that there are no tight spots.

The rotating torque of the crankshaft with all connecting rod cap bolts fully torqued should be as follows:

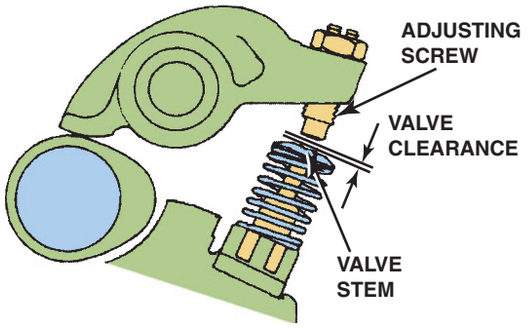
- 4-cylinder engine: 20 lb-ft maximum (88 N-m)
- 6-cylinder engine: 25 lb-ft maximum (110 N-m)
- 8-cylinder engine: 30 lb-ft maximum (132 N-m)

- *If the side clearance is too small,* there may not be enough room for heat expansion. To correct a side clearance that is too small:
  1. Regrind the crankshaft.
  2. Replace the rods.

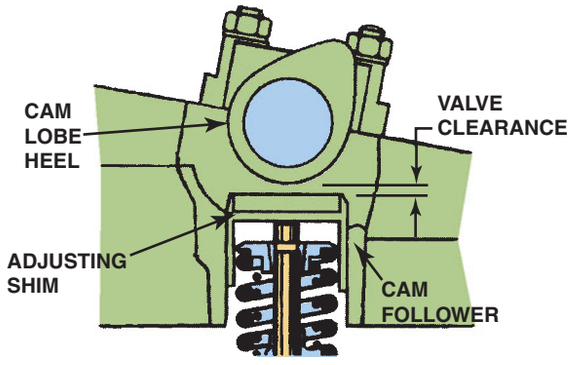
CYLINDER HEAD INSTALLATION

INSTALLING THE CAMSHAFT FOR OHC ENGINES

On some overhead camshaft engines, the camshaft is installed before the head is fastened to the block deck. Some engines have the



(a)



(b)

FIGURE 37–39 Valve clearance allows the metal parts to expand and maintain proper operation, both when the engine is cold and at normal operating temperature. (a) Adjustment is achieved by turning the adjusting screw. (b) Adjustment is achieved by changing the thickness of the adjusting shim.

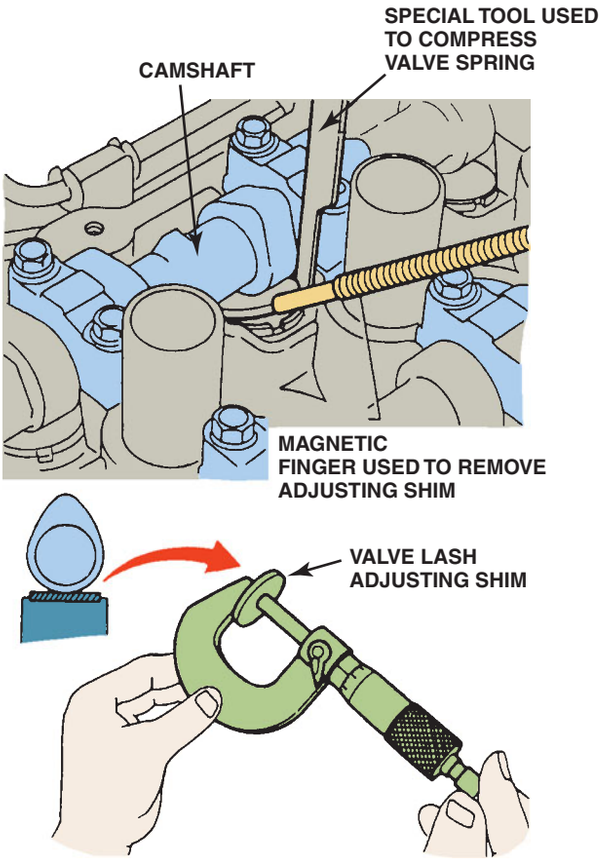


FIGURE 37–40 Some overhead camshaft engines use valve lash adjusting shims to adjust the valve lash. A special tool is usually required to compress the valve spring so that a magnet can remove the shim.

camshaft located directly over the valves. The cam bearings on these engines can be either one piece or split. In other engine types, the camshaft bearings are split to allow the camshaft to be installed without the valves being depressed. The cam bearings and journals are lubricated before assembly. The cam bearing caps must be tightened evenly to avoid bending the camshaft. The valve clearance or lash is checked with the overhead camshaft in place. Some engines use shims under a follower disk, as shown in ● **FIGURE 37–39.**

On these engine types, the camshaft is turned so that the follower is on the base circle of the cam. The clearance of each bucket follower can then be checked with a feeler gauge. The amount of clearance is recorded and compared with the specified clearance, and then a shim of the required thickness is put in the top of the bucket followers, as shown in ● **FIGURE 37–40**.

Always follow the vehicle manufacturer's recommended procedures.

HEAD BOLT TORQUE SEQUENCE

The torque put on the bolts is used to control the clamping force that is applied to the gasket. The clamping force is correct only when the threads are clean and properly lubricated.

CAUTION: Always use the specified lubricant on the threads. If SAE 30 engine oil is specified, do not use SAE 10W-30 or any other viscosity, because using the incorrect viscosity oil can affect the clamping force exerted on the head gaskets.

In general, the head bolts are tightened in a specified torque sequence in three steps. The procedure starts with the head bolts in the center and then moves to those farther and farther from the center. This procedure helps spread the forces toward the ends of the cylinder.

TECH TIP

Watch Out for Wet and Dry Holes

Many engines, such as the small block Chevrolet V-8, use head bolts that extend through the top deck of the block and end in a coolant passage. These bolt holes are called *wet holes.* When installing head bolts into holes that end up in the coolant passage, always use sealer on the threads of the head bolt. Some engines have head bolts that are "wet," whereas others are "dry" because they end in solid cast-iron material. Dry hole bolts do not require sealant, but they still require some oil on the threads of the bolts for lubrication. Do not put oil into a dry hole because the bolt may bottom out in the oil. The liquid oil cannot compress, so the force of the bolt being tightened is transferred to the block by hydraulic force, which can crack the block.

HINT: Apply oil to a shop cloth and rotate the bolt in the cloth to lubricate the threads. This procedure lubricates the threads without applying too much oil.

By tightening the head bolts in three steps, the head gasket has time to compress and conform to the block deck and cylinder head gasket surfaces. Follow that sequence and tighten the bolts in the following manner.

1. Tighten to *one-third* the specified torque.
2. Tighten them a second time following the torque sequence to *two-thirds* the specified torque.

3. Follow the sequence with a final tightening to the specified torque. ● **SEE FIGURES 37–41 AND 37–42.**

CLAMPING FORCE **Clamping force** is the amount of force exerted on a gasket. The clamping force is not the same as the torque applied to the fastener. When tightening a bolt or nut, about 80% of the applied torque is used to overcome friction between the threads. Therefore, it is very important that the threads be clean and lubricated with the proper (specified) lubricant.

FASTENER CONSIDERATION Because most of the torque applied to a fastener is absorbed by friction, it is extremely important that the following steps be performed.

STEP 1 Clean the threads of all fasteners before using.

STEP 2 Check service information for the specified thread lubricant.

THREAD LUBRICANT If using aftermarket bolts or studs, such as ARP (American Racing Products®), use the lubricant and torque that the company specifies. Do not use ARP lubricant and the factory torque specifications or the fasteners will be greatly overtightened. The same applies if using thread sealant to the threads of fasteners being installed in wet holes (holes that extend into the cooling passages). Many vehicle manufacturers recommend the use of 30 weight engine oil (SAE 30).

CAUTION: SAE 5W-30 or SAE 10W-30 is not the same as SAE 30 engine oil. Multiviscosity oil such as SAE 5W-30 is actually SAE 5W oil with additives to provide the protection of SAE 30 oil when it gets hot. Always use the exact oil specified by the vehicle manufacturer.

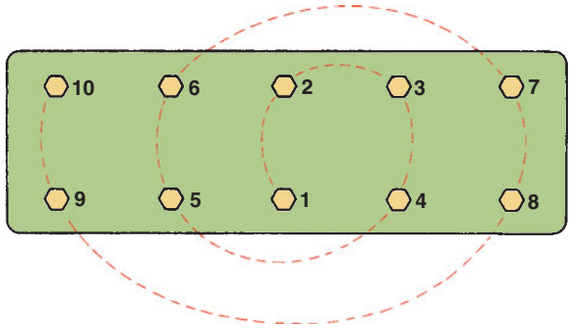


FIGURE 37–41 Typical cylinder head tightening sequence.

TECH TIP

The Piece of Paper Demonstration

Some students and beginning technicians forget the correct order to tighten head bolts or other fasteners of a component. Try the following demonstration:

- Place a single sheet of paper on a table.
- Place both hands on the paper in the center and then move your hands outward.
- Nothing should have happened and the paper should have not moved.
- Now place your hands on the paper at the ends and move them toward the center.
- The paper will wrinkle as the hands move toward the center.

This demonstration shows that the forces are moved away toward the ends the cylinder head if the fasteners are tightened from the inside toward the outside. However, if the cylinder head bolts were tightened incorrectly, the head would likely crack due to the forces exerted during the tightening.

TECH TIP

Always "Exercise" New Bolts

New bolts and studs are manufactured by rolling the threads and heat treating. Due to this operation, the threads usually have some rough areas, which affect the clamping force on the gasket. Many engine building experts recommend that all new bolts be installed in the engine using a new or used gasket and torqued to specifications at least five times, except for torque-to-yield bolts. This process burnishes the ramps of the threads and makes the fastener provide a more even clamping force. Using the recommended lubricant, the bolts should be torqued and removed and then torqued again.

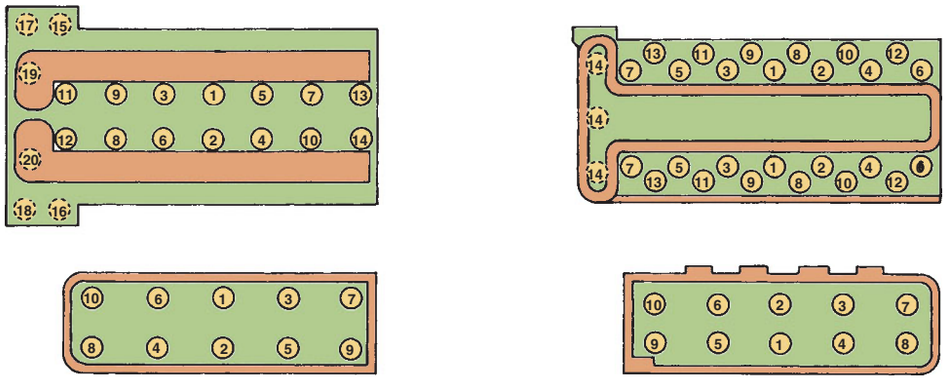


FIGURE 37–42 Examples of cylinder head bolt torquing sequences.



FIGURE 37–43 Typical head gasket markings. The front means that the gasket should be at the accessory drive belt end of the block.

FREQUENTLY ASKED QUESTION

Why Do Both Head Gaskets Have "Front" Marked?

A common question asked by beginning technicians or students include how to install head gaskets on a V-6 engine that is mounted transversely (sideways) in the vehicle. The technician usually notices that "front" is marked on one gasket and therefore installs that gasket on the block, on top of the forward-facing cylinder bank. Then, the technician notices that the other gasket is also marked with "front." How could both be marked "front"? There must be some mistake. The mistake is in the terminology used. In the case of head gaskets, the "front" means toward the accessory drive belt end of the engine and *not* on the cylinder bank toward the front of the vehicle. ● **SEE FIGURE 37–43.**

TORQUE-TO-YIELD HEAD BOLTS

DEFINITION AND TERMINOLOGY Many engines use a tightening procedure called the **torque-to-yield (TTY)** method. The purpose of the TTY procedure is to have a more constant clamping load from bolt to bolt. This aids in head gasket sealing performance and eliminates the need for retorquing.

BOLT CONSTRUCTION Many torque-to-yield head bolts are made with a narrow section between the head and threads. As the bolts are tightened past their elastic limit, they yield and begin to stretch in this narrow section.

Torque-to-yield head bolts will not become any tighter once they reach this elastic limit, as seen on the graph in ● **FIGURE 37–44.**

The torque angle method also decreases the differences in clamping force that can occur depending on the condition or lubrication of the threads. ● **SEE FIGURE 37–45.**

As a result, many engine manufacturers specify *new* head bolts each time the head is installed. If these bolts are reused, they are likely to break during assembly or fail prematurely as the engine runs. If there is any doubt about the head bolts, replace them.

TORQUE-TO-YIELD PROCEDURE Torque-to-yield bolts are tightened to a specific initial torque, from 18 to 50 lb-ft (25 to 68 N-m). The bolts are then tightened an additional specified number of degrees, following the tightening sequence. In some cases they are turned a specified number of degrees two or three times. Some specifications limit the maximum torque that can be applied to the bolt while the degree turn is being made. Torque tables in a service manual will show how much initial torque should be applied to the bolt and how many degrees the bolt should be rotated after torquing. Torque-to-yield head bolts should be tightened as per specified in service information.

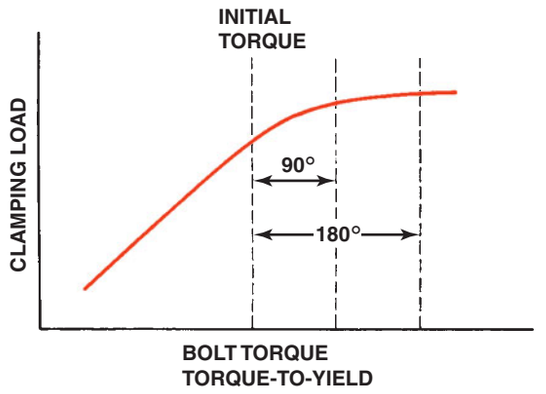


FIGURE 37–44 Due to variations in clamping force with turning force (torque) of head bolts, some engines are specifying the torque-to-yield procedure. The first step is to torque the bolts by an even amount called the initial torque. Final clamping load is achieved by turning the bolt a specified number of degrees. Bolt stretch provides the proper clamping force.

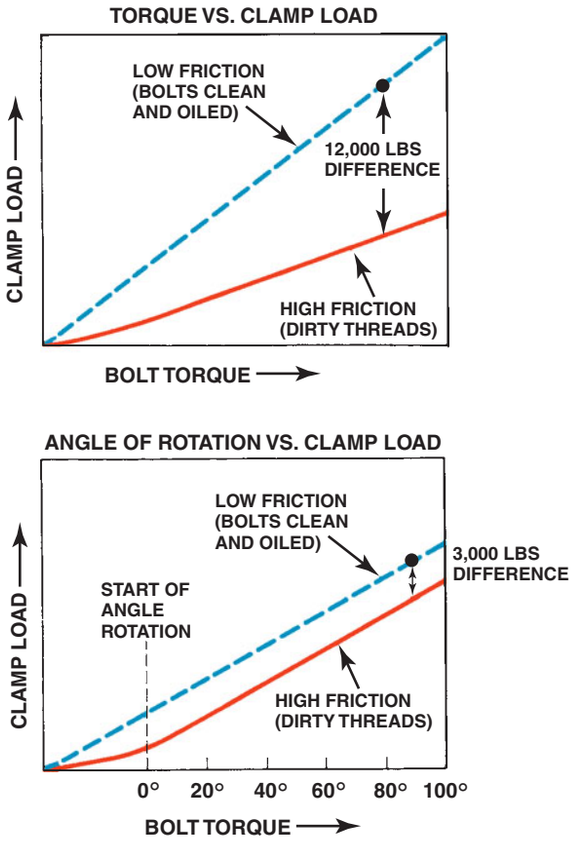


FIGURE 37–45 To ensure consistent clamp force (load), many manufacturers are recommending the torque-angle or torque-to-yield method of tightening head bolts. The torque-angle method specifies tightening fasteners to a low-torque setting and then giving an additional angle of rotation. Notice that the difference in clamping force is much smaller than it would be if just a torque wrench with dirty threads were used.

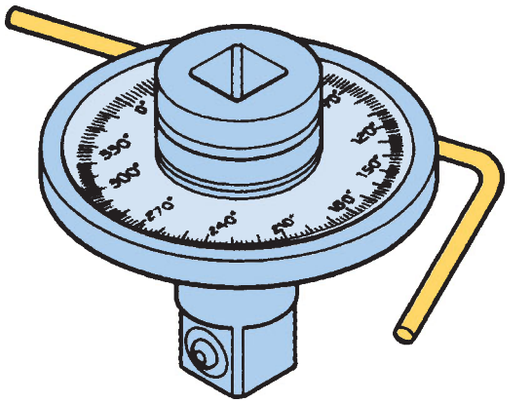


FIGURE 37–46 Torque angle can be measured using a special adaptor.

TECH TIP

Creep Up on the Torque Value

Do not jerk or rapidly rotate a torque wrench. For best results and more even torque, slowly apply force to the torque wrench until it reaches the preset value or the designated torque. Jerky or rapidly moving the torque wrench will often cause the torque to be uneven and not accurate.

The procedure includes the following steps.

STEP 1 Tighten the fasteners to an initial torque in the specified sequence.

STEP 2 Turn the fasteners a specific number of degrees using an angle gauge again following the same sequence.

STEP 3 Turn the fasteners another specific number of degrees again following the designated sequence.

For example, a specified head bolt tightening specification may include:

- Initial torque, such as 44 lb-ft
- Rotate 90 degrees
- Rotate head bolts an additional 90 degrees

● **SEE FIGURES 37–46 AND 37–47**.

TORQUE ANGLE METHOD The *torque angle method,* also called the *torque-turn method,* does not necessarily mean torque-to-yield. Some engine specifications call for a beginning torque and then a specified angle, but the fastener is not designed to yield. These head bolts can often be reused. Always follow the manufacturer's recommended procedures.

VALVE TRAIN ASSEMBLY

TIMING DRIVES FOR OHC ENGINES After the head bolts have been torqued, the cam drive can be installed on overhead cam (OHC) engines. This is done by aligning the timing marks of the crankshaft and camshaft drive sprockets with their respective timing marks. The location of these marks differs between engines, but the marks can be identified by looking carefully at the sprockets. ● **SEE FIGURES 37–48 AND 37–49**.



FIGURE 37–47 An electronic torque wrench showing the number of degrees of rotation. These very accurate and expensive torque wrenches can be programmed to display torque or number of degrees of rotation.

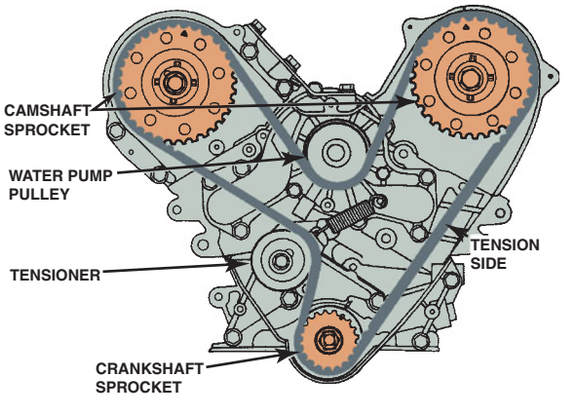


FIGURE 37–48 Both crankshafts have to be timed on this engine and the timing belt also drives the water pump.

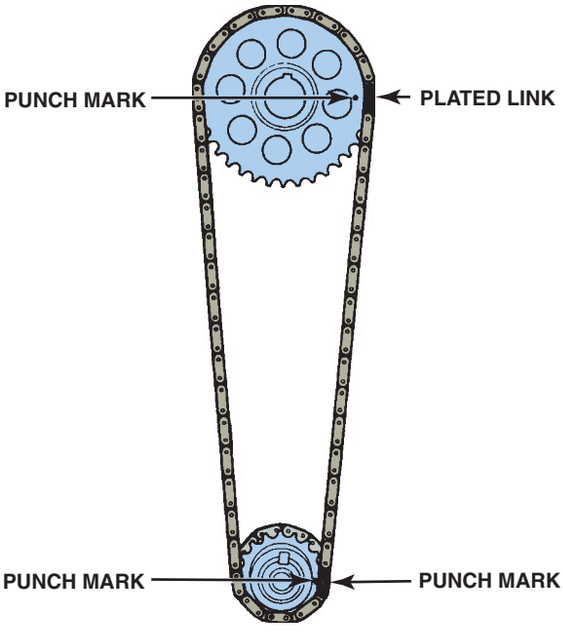


FIGURE 37–49 Some timing chains have plated links that are used to correctly position the chain on the sprockets.

TECH TIP

Soak the Timing Chain

Many experts recommend that a new timing chain be soaked in engine oil prior to engine assembly to help ensure full lubrication at engine start-up. The timing chain is one of the last places in the engine to get lubrication when the engine first starts. This procedure may even extend the life of the chain.

The tensioner may be on either or both sides of the timing belt or chain. After the camshaft drive is engaged, rotate the crankshaft through two full revolutions. On the first full revolution, the exhaust valve will be almost closed and the intake valve will just be starting to open when the *crankshaft* timing mark aligns. At the end of the second revolution, both valves should be closed, and all the timing marks should align on most engines. This is the position the crankshaft should have when cylinder 1 is to fire.

NOTE: Always check the manufacturer's recommended timing chain installation procedure. Engines that use primary and secondary timing chains often require an exact detailed procedure for proper installation.

HYDRAULIC VALVE LIFTER INSTALLATION

Most vehicle manufacturers recommend installing lifters *without* filling or pumping the lifter full of oil. If the lifter is filled with oil during engine start-up, the lifter may not be able to bleed down quickly enough and the valves may be kept open. Not only will the engine not operate correctly with the valves held open, but the piston also could hit the open valves, causing serious engine damage. Most manufacturers usually specify that the lifter be lubricated. Roller hydraulic lifters can be lubricated with engine oil, whereas flat lifters require that engine assembly lube or extreme pressure (EP) grease be applied to the base.

BLEEDING HYDRAULIC LIFTERS

Air trapped inside a hydraulic valve lifter can be easily bled by simply operating the engine at a fast idle (2500 RPM). Normal oil flow through the lifters will allow all of the air inside the lifter to be bled out.

NOTE: Some engines, such as many Nissan overhead camshaft engines, *must* have the air removed from the lifter before installation. This is accomplished by submerging the lifter in a container of engine oil and using a straightened paper clip to depress the oil passage check ball.

Check service information if in doubt about the bleeding procedure for the vehicle being serviced. ● **SEE FIGURE 37–50**.

TIMING CHAINS AND GEARS INSTALLATION

On cam-in-block (OHV) engines, the timing gears or chain and sprocket can be installed after the crankshaft and camshaft. The timing marks should be aligned according to the factory specified marks. ● **SEE FIGURE 37–51**.

When used, the replaceable fuel pump eccentric is installed as the cam sprocket is fastened to the cam. The crankshaft should be rotated several times to see that the camshaft and timing gears or chain rotate freely. The timing mark alignment should be rechecked at this time. If the engine is equipped with a slinger ring, it should also be installed on the crankshaft, in front of the crankshaft gear.

OHV ENGINE LIFTER AND PUSHROD INSTALLATION

The outside of the lifters and the lifter bores in the block should be cleaned and coated with assembly lubricant. The lifters are installed in the lifter bores and the pushrods put in place. There are different length pushrods on some engines. Make sure that the pushrods

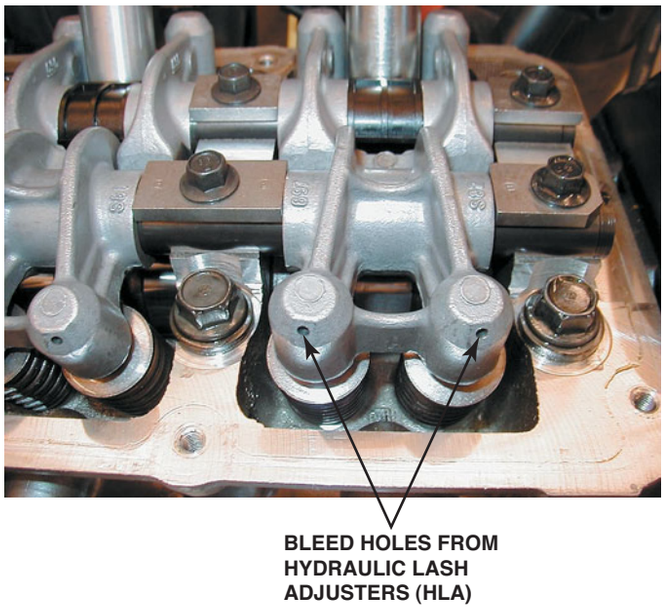


FIGURE 37–50 A special tool may be needed to bleed air from the hydraulic lash adjusters (HLA) through the bleed hole. These lash adjusters are part of the valve end of the rocker arms in this example.



FIGURE 37–51 Timing chain and gears can be installed after the crankshaft and camshaft have been installed and the timing marks are aligned with cylinder 1 at top dead center (TDC).

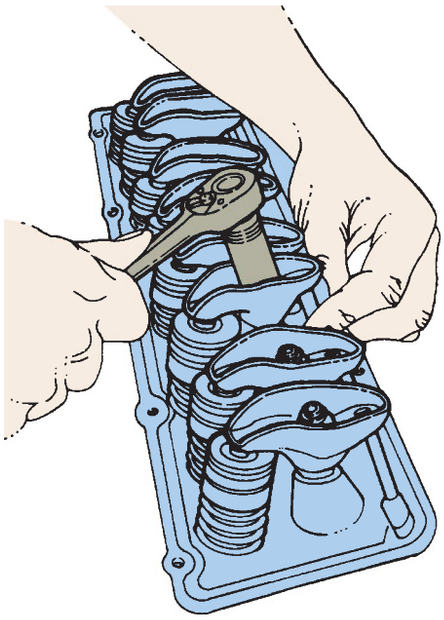


FIGURE 37–52 With the lifter resting on the base circle of the cam, zero lash is achieved by tightening the rocker arm lock nut until the pushrod no longer rotates freely.

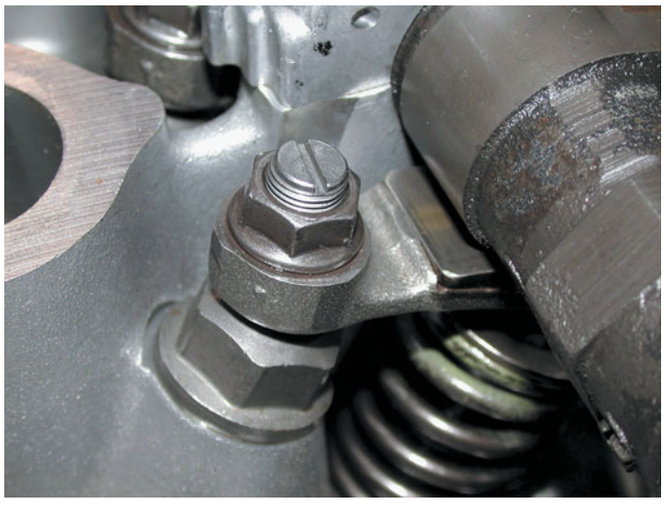


FIGURE 37–53 Most adjustable valves use a nut to keep the adjustment from changing. Therefore, to adjust the valves, the nut has to be loosened and the screw rotated until the proper valve clearance is achieved. Then the screw should be held while tightening the lock nut to keep the adjustment from changing. Double-check the valve clearance after tightening the nut.

TECH TIP

Watch Out for Different Length Pushrods

The very popular General Motors family of engines, including 2.8 liter, 3.1 liter, 3100, 3.4 liter, 3400, and 3.5 liter, each use different pushrod lengths for intake and exhaust valves. If the wrong pushrods are used, two things can occur.

1. The pushrod(s) can be bent.
2. The engine will run rough because the longer pushrod prevents the valve from closing all the way.

Always check service information for the exact location of the pushrods.

are installed in the proper location. The rocker arms are then put in place, aligning with the valves and pushrods. Rocker arm shafts should have their retaining bolts tightened a little at a time, alternating between the retaining bolts. This keeps the shaft from bending as the rocker arm pushes some of the valves open.

HYDRAULIC LIFTER ADJUSTMENT The retaining nut on some rocker arms mounted on studs can be tightened to a specified torque. The rocker arm stud will have a shoulder on this type of rocker assembly. The rocker arm will be adjusted correctly at this torque when the valve tip has the correct height. Other types of rocker arms require tightening the nut to a position that will center the hydraulic lifter. The general procedure includes the following steps.

STEP 1 Rotate the engine until cylinder 1 is at TDC on the compression stroke to be assured that both the intake and exhaust valves are on the base circle of the cam lobes.

STEP 2 Tighten the retaining nut to the point that all free lash is gone and the pushrod cannot be easily rotated. ● **SEE FIGURE 37–52.**

STEP 3 From this point, the retaining nut is tightened by a specified amount, such as three-fourths of a turn or one and one-half turns.

HINT: This method usually results in about three threads showing above the adjusting nut on a *stock* small block Chevrolet V-8 equipped with flat-bottom hydraulic lifters.

STEP 4 Rotate the engine until the next cylinder in the firing order is at top dead center on the compression stroke. The valves on this next cylinder are adjusted in the same manner as those on cylinder 1. This procedure is repeated on each cylinder *following the engine firing order* until all the valves have been adjusted. Always follow the specified procedure found in service information.

SOLID LIFTER ADJUSTMENT The valve clearance or **lash** must be set on a solid lifter engine, so that the valves can positively seat. Check service information for the specified adjustment sequence to follow to set the lash. If this is not available, then the following procedure can be used on all engines requiring valve lash adjustment. The valve lash is adjusted with the valves completely closed. ● **SEE FIGURE 37–53.**

The procedure is similar to that used to adjust hydraulic lifters that are adjustable except that a feeler gauge is used to check the lash. The same valve lash adjustment sequence is used on overhead cam engines. Those engines with rocker arms or with adjustable finger follower pivots are adjusted in the same way as pushrod engines with rocker arms.

FINAL ASSEMBLY

MANIFOLD INSTALLATION The intake manifold gasket for a V-type engine may be a one-piece gasket or it may have several pieces. V-type engines with open-type manifolds have a cover over the lifter valley. The cover may be a separate part or it may be part

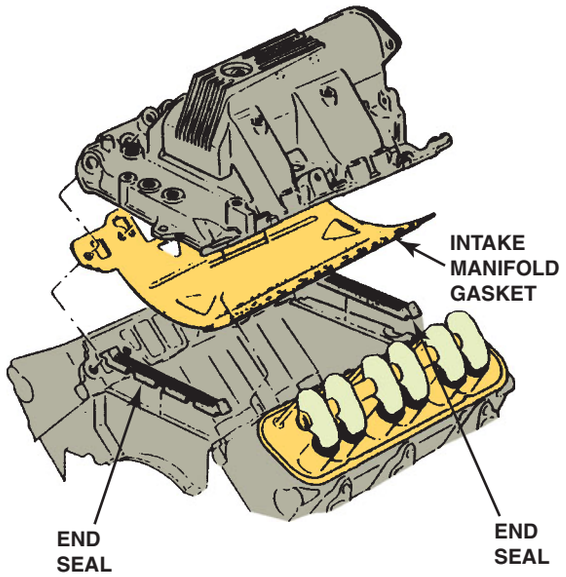


FIGURE 37–54 This intake manifold gasket includes end seals and a full shield cover for the valley to keep hot engine oil from heating the intake manifold.

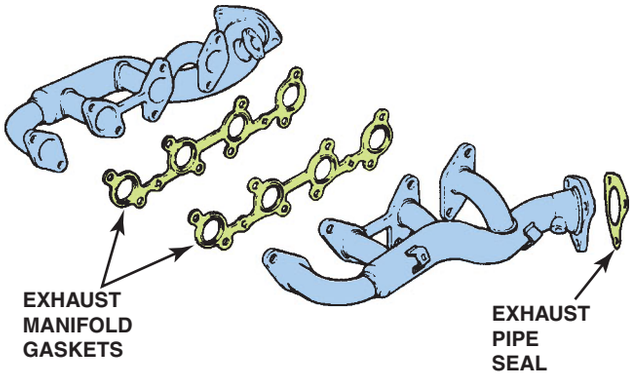


FIGURE 37–55 An exhaust manifold gasket is used on some engines. It seals the exhaust manifold to the cylinder head.

of a one-piece intake manifold gasket. Closed-type intake manifolds on V-type engines require gasket pieces (end seals) at the front and rear of the intake manifold. ● **SEE FIGURE 37–54**.

Inline engines usually have a one-piece intake manifold gasket. The intake manifold is put in place over the gaskets. Use a contact adhesive to hold the gasket and end seal if there is a chance they might slip out of place. Install the bolts and tighten to the specified torque following the correct tightening sequence.

Only some exhaust manifolds use gaskets. The exhaust manifold operates at very high temperatures, so there is usually some expansion and contraction movement in the manifold-to-head joint. It is very important to use attachment bolts, cap screws, and clamps of the correct type and length. ● **SEE FIGURE 37–55**.

They must be properly torqued to avoid both leakage and cracks.

NOTE: If the exhaust manifold gasket has a metal facing on one side, place the metal facing toward the head.

TIMING COVER INSTALLATION

The timing cover with seal installed and gasket are placed over the timing gears and/or chain and sprockets. The attaching bolts are loosely installed to allow the damper hub to align with the cover as it fits in the seal. The damper is installed on the crankshaft. On some engines, it is a press-fit and on others it is held with a large center bolt. After the damper is secured, the attaching bolts on the timing cover can be tightened to the specified torque.



FIGURE 37–56 A 1/8 to 3/16 in. (3 to 5 mm) bead of RTV silicon on a parting surface with silicon going around the bolt hole.

Most timing covers are installed with a gasket, but some use RTV sealer in place of the gasket. A bead of RTV silicon 1/8 to 3/16 in. in diameter is put on the clean sealing surface. ● **SEE FIGURE 37–56**.

Sealing a cover using RTV silicon usually includes the following steps.

STEP 1 Encircle the bolt holes with the sealant.

STEP 2 Install the cover before the silicon begins to cure so that the uncured silicon bonds to both surfaces.

STEP 3 While installing the cover, do not touch the silicon bead, otherwise the bead might be displaced and cause a leak.

STEP 4 Carefully press the cover into place. Do not slide the cover after it is in place.

STEP 5 Install the assembly bolts finger tight, and let the silicon cure for about 30 minutes before tightening the cover bolts.

When installing *cast covers,* anaerobic compound (such as Loctite®) is often used as a gasket substitute.

VIBRATION DAMPER INSTALLATION

Vibration dampers are seated in place by one of three methods.

- The damper hub of some engines is pulled into place using the hub attaching bolt.
- The second method uses a special installation tool that screws into the attaching bolt hole to pull the hub into place. The tool is removed and the attaching bolt is installed and torqued.
- The last method is used on engines that have no attaching bolt. These hubs depend on a press-fit to hold the hub on the crankshaft. The hub is seated using a special tube-type driver. Check service information for the exact procedure and tool to use.

OIL PUMP INSTALLATION

When an engine is rebuilt, the oil pump should be replaced with a new pump and oil pickup screen. Most vehicle manufacturers recommend that the oil pump and screen be replaced rather than cleaned. This ensures positive lubrication and long pump life. Oil pump gears should be coated with assembly lubricant before the cover is put on the pump. This provides initial lubrication, and it primes the pump so that it will draw the oil from the pan when the lubrication system is first operated. Torque the oil pump fasteners to factory specifications. ● **SEE FIGURE 37–57**.



FIGURE 37–57 A beam-type torque wrench being used to tighten the oil pump pickup assembly to factory specification.

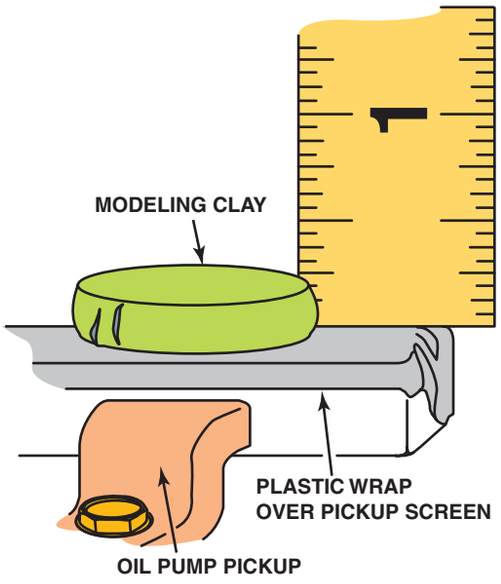


FIGURE 37–58 Using clay to determine the oil pan to oil pickup clearance, which should be about 1/4 in.

TECH TIP

Check the Oil Pump Pickup to Oil Pan Clearance

Whenever installing the oil pan on a rebuilt engine, it is wise to check the clearance between the oil pump pickup and the bottom of the oil pan. This distance should be 3/16 to 3/8 in. (5 to 9 mm). To check the clearance, two methods can be used.

METHOD 1 With the engine upside down and the oil pump and pickup installed, measure the distance from the oil pan rail to the top (actually the bottom) of the oil pump pickup. Then measure the distance from the oil pan rail to the bottom of the oil pan and subtract the two measurements to get the clearance.

METHOD 2 Place about 1/2 in. (13 mm) of modeling clay on the pickup of the oil pump. Then temporarily install the oil pan with a gasket. Press down on the oil pan to compress the modeling clay. Remove the oil pan and measure the thickness of the clay. This thickness is the oil pan to oil pump pickup clearance. ● **SEE FIGURE 37–58.**

OIL PAN INSTALLATION The oil pan should be checked and straightened as necessary. ● **SEE FIGURE 37–59**.

With the oil pump in place, the oil pan gaskets are properly positioned. The oil pan is carefully placed over the gaskets. All oil pan bolts should be started into their holes before any are tightened. The bolts should be alternately snugged up and then they should be properly tightened to factory specifications. Always follow the instructions that come with the gasket for best results.

WATER PUMP INSTALLATION A reconditioned, rebuilt, or new water pump should be used. Once gaskets are fitted in place, the pump is secured with assembly bolts tightened to the correct torque.



FIGURE 37–59 Using a hammer to straighten the gasket rail surface of the oil pan before installing a new gasket. When the retaining bolts are tightened, some distortion of sheet metal covers occurs. If the area around the bolt holes is not straightened, leaks can occur with the new gasket.

REAL WORLD FIX

The New Oil Pump That Failed

A technician replaced the oil pump and screen on a V-8 with low oil pressure. After the repair, the oil pressure returned to normal for two weeks, but then the oil pressure light came on and the valve train started making noise. The vehicle owner returned to the service garage where the oil pump had been replaced. The technician removed the oil pan and pump. The screen was almost completely clogged with the RTV sealant that the technician had used to “seal” the oil pan gasket. The technician had failed to read the instructions that came with the oil pan gasket. Failure to follow directions, and using too much of the wrong sealer, cost the repair shop an expensive comeback repair.

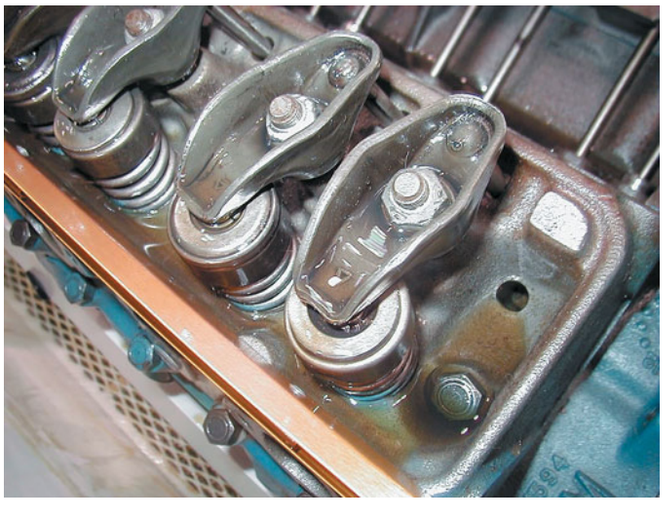


FIGURE 37–60 Oil should be seen flowing to each rocker arm as shown.

A new thermostat should be installed being careful to check that the wax pellet side of the thermostat faces toward the engine. The thermostat housing with the proper gasket is installed, and the retaining bolts are tightened to the proper torque.

ENGINE PAINTING Painting an engine helps prevent rust and corrosion and makes the engine look new. Standard engine paints with original colors are usually available at automotive parts stores. Engine paints should be used rather than other types of paints. Engine paints are compounded to stay on the metal as the engine temperatures change. Normal engine fluids will not dissolve or remove them. These paints are usually purchased in pressure cans so that they can be sprayed from the can directly onto the engine.

All parts that should not be painted must be covered before spray painting. This can be done with old parts, such as old spark plugs and old gaskets. This can also be done by taping paper over the areas to be covered. If the intake manifold of an inline engine is to be painted, it can be painted separately. Engine assembly can continue after the paint has dried.

PRELUBRICATING THE ENGINE With oil in the engine and the distributor, if equipped, out of the engine, oil pressure should be established before the engine is started. This can be done on most engines by rotating the oil pump using an electric drive. This ensures that oil is delivered to all parts of the engine before the engine is started. Adapters are available that allow an electric drill motor to rotate the oil pump.

Engines that do not drive the oil pump with the distributor will have to be cranked with the spark plugs removed to establish oil pressure. The load on the starter and battery is reduced with the spark plugs out so that the engine will have a higher cranking speed. Rotate the engine as the oil pump is being turned and then look for oil being delivered to each rocker arm which ensures that all of the oil passages are clear. ● **SEE FIGURE 37–60**.

SETTING IGNITION TIMING After oil pressure is established, the distributor, if equipped, can be installed. Rotate the crankshaft in its normal direction of rotation until there is compression on cylinder 1. This can be done with the starter or by using a wrench on the damper bolt. The compression stroke can be determined by covering the opening of spark plug 1 with a finger as the crankshaft is rotated. Continue to rotate the crankshaft slowly as compression is felt, until the timing marks on the damper align with the timing indicator on the timing cover.

The angle of the distributor gear drive will cause the distributor rotor to turn a few degrees when installed. Before the distributor is installed, the shaft must be positioned to compensate for the gear angle. After installation, the rotor should be pointing to tower 1 of the distributor cap.

The distributor position should be close enough to the basic timing position to start the engine. If the distributor holddown clamp is slightly loose, the distributor housing can be adjusted to make the engine run smoothly after the engine has been started.

REAL WORLD FIX

"Oops"

After overhauling a big block Ford V-8 engine, the technician used an electric drill to rotate the oil pump with a pressure gauge connected to the oil pressure sending unit hole. When the electric drill was turned on, oil pressure would start to increase (to about 10 PSI), then drop to zero. In addition, the oil was very aerated (full of air). Replacing the oil pump did not solve the problem. After hours of troubleshooting and disassembly, it was discovered that an oil gallery plug had been left out underneath the intake manifold. The oil pump was working correctly and pumped oil throughout the engine and out of the end of the unplugged oil gallery. It did not take long for the oil pan to empty and the oil pump began drawing in air that aerated the oil which caused the oil pressure to drop. Installing the gallery plug solved the problem. It was smart of the technician to check the oil pressure before starting the engine. This oversight of leaving out one gallery plug could have resulted in a ruined engine shortly after the engine was started.

NOTE: Many overhead camshaft engines use an oil passage check valve in the block near the deck. The purpose of this valve is to hold oil in the cylinder head around the camshaft and lifters when the engine is stopped. Failure to reinstall this check valve can cause the valve train to be noisy after engine start-up.

TECH TIP

Install Heat Tabs

The wise engine builder should install a heat tab to the back of the cylinder head(s). A heat tab uses a special heat-sensitive metal in the center of a mild steel disc. If the temperature of the cylinder head exceeds 250°F (121°C), the center of the tab will melt and flow out indicating that the engine was overheated. ● **SEE FIGURE 37–61**.



FIGURE 37–61 Heat tabs can be purchased from engine supply companies.

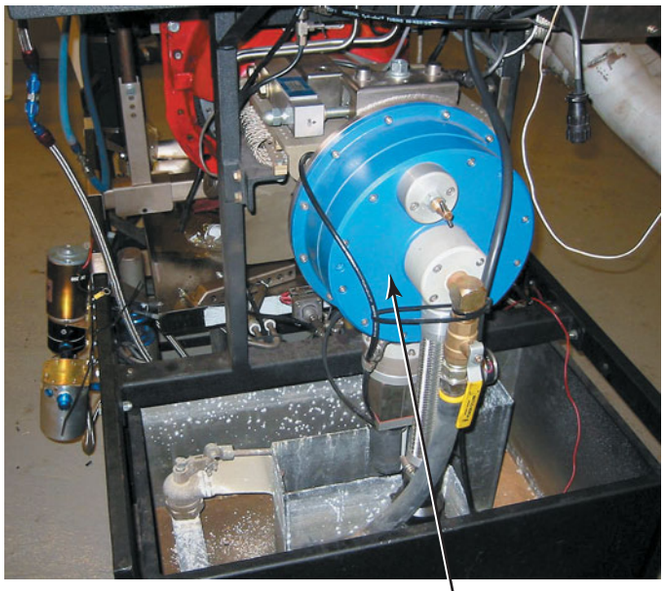


FIGURE 37–62 A dynamometer measures engine torque by applying a resistive force to the engine and measuring the force applied. Water is being used as the resistive load on this dynamometer.

DYNAMOMETER TESTING

PURPOSES The purposes for using an engine dynamometer after an engine is assembled are varied. The testing:

1. Allows the completed engine to be started and run to operating temperature
2. Permits checking for possible problems or leaks before the engine is installed in a vehicle
3. Allow the piston rings to seat and the engine to be partially broken in before being installed in a vehicle
4. Permits the technician to determine the output of the engine
5. Allows the opportunity to maximize the engine output by changing air-fuel ratios and valve or ignition timing until the best performance has been achieved

TYPES OF DYNAMOMETERS Basic types of dynamometers include:

- A *brake type,* where a variable load is applied to the engine and the computer calculates the power output based on the readings taken from the load cell or strain gauge and engine RPM. Most brake types use a water impeller to create the load on the engine. ● **SEE FIGURE 37–62.**
- An *inertia type,* which measures engine power by using the engine to accelerate a known mass load. An inertia type dynamometer is most often used to measure the power of an engine at the drive wheels of the vehicle. ● **SEE FIGURE 37–63.**

TERMINOLOGY Numbers allow values to be assigned to virtually everything being measured or tested. The numbers help identify, quantify, and compare variables and performance.

Two types of data include:

1. **Measured values.** Taken directly from the engine using sensors that read the actual data
2. **Calculated values.** Those found by using basic numbers and a formula to obtain them



FIGURE 37–63 A chassis dynamometer is used to measure torque at the drive wheels. There is a power loss through the drive train so the measured values are about 20% less than when measuring engine output at the flywheel using an engine dynamometer.

MEASURED VALUES Measured units are those that are obtained directly from sensors and include:

- **Torque.** As the name implies, this is the amount of twisting force that the engine puts out at the crank flange. Typically this is measured in foot-pounds.

  NOTE: Dynamometers only measure torque output of an engine. Horsepower is not measured directly but is instead a calculated value.

- **Fuel flow.** Mass flow rate of fuel is calculated by the number of gallons per hour times pounds per gallon and is measured in pounds per hour. To determine this value, the specific

gravity of the fuel has to be measured and entered into the computer prior to the engine tests so the program can calculate the fuel flow. Make sure there is enough fuel delivery for the engine by checking the gallons per hour prior to running each engine. Proper pressure (PSI) does not mean that there is enough volume being delivered to the engine especially under load conditions.

- **Manifold pressure.** Measured in inches of mercury (in. Hg), this value is called *manifold vacuum* in a normally aspirated engine.
- **Oil pressure.** This should be about 10 PSI per 1000 RPM.
- **Air inlet pressure.** Core value used to calculate the correction factor during the run, also referred to as dry bulb (DB) temperature. **Dry bulb temperature** is the temperature of a room where the thermometer is shielded from moisture. This reduces the effect of evaporation of moisture from the thermometer which could affect the temperature reading.
- **Fuel temperature.** Used to calculate the density of fuel for fuel flow values.
- **Oil temperature.** Very important in run-to-run comparisons. Typically, the hotter the oil, the more horsepower an engine makes (up to a point). Oil that is too hot loses its cooling capability as well as some of its lubricating properties.
- **Engine coolant temperature.** This reading is important to monitor as a safety limit to help prevent possible engine damage if it goes too high.

Transducers are needed to measure the basic values. A transducer is a device that is able to convert various input signals such as pressures and temperature into an electrical signal that a computer can recognize. Typical dynamometer transducers include:

- Magnetic pickups ● **SEE FIGURE 37–64**.
- Load cells
- Strain gauge flow meters
- Rotary potentiometers or rheostats
- Thermocouples
- Linear variable displacement transducers (LVDT)

CALCULATED VALUES

Calculated values are those that are obtained by using the measured values and processing them through software to obtain the following:

- **Corrected torque.** This is a calculated number determined by the actual torque multiplied by the correction factor. This is an important number and the reading should show a wide and flat band of torque over a broad engine speed range.
- **Corrected horsepower.** This is a calculated number showing the corrected observed horsepower.
- **Frictional horsepower.** This can best be thought of as the power required to rotate the engine over without firing and without pumping losses.
- **Volumetric efficiency.** This is a measure of the engine's cylinder filling efficiency; 100% represents filling a cylinder to its total swept volume. On a race engine, it is quite normal to see over 100% volumetric efficiency.
- **Mechanical efficiency.** This is the ratio of the engine's frictional torque divided by its corrected output torque. A value of 100% would indicate that the engine had no frictional losses.

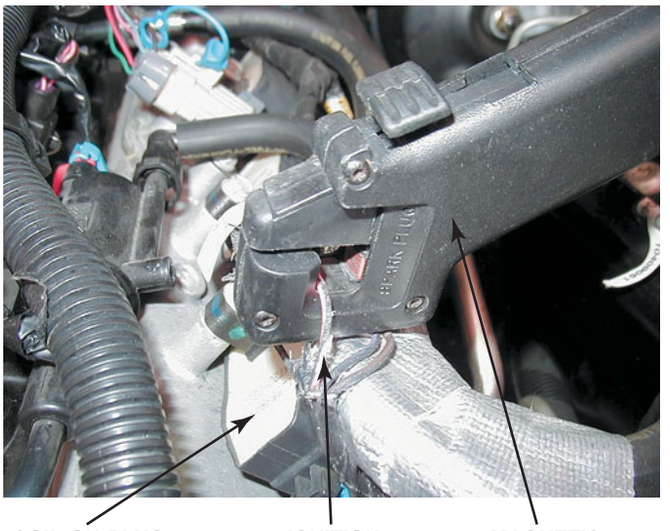


FIGURE 37–64 A magnetic pickup being used to monitor engine speed when the vehicle is being tested on a chassis dynamometer.

TECH TIP

Look at the Crossing Point

All dynamometers measure torque of an engine, then calculate the horsepower. Horsepower is torque multiplied by engine speed (RPM) divided by 5,252 (a constant). Therefore, all graphs should show that the two curves for horsepower and torque should be the same at 5,252 RPM. ● **SEE FIGURE 37–65**.

STANDARDS

For best results, perform testing on nice days with low relative humidity and high atmospheric pressure. These factors have a huge effect on the amount of air that the engine can "breathe" in which in turn can dramatically affect horsepower readings. Testing on nice days is not always possible, so using corrected data allows the technician to compare test results from day to day and dynamometer to dynamometer. A **correction factor** is a value that is multiplied to the data values so that engine performance can be compared regardless of weather conditions. Over the years there have been many different correction factors specified by the Society of Automotive Engineers (SAE) including:

- SAE J606
- SAE J607 (Using this correction factor results in higher numbers than if using other correction factors mainly due to the higher barometric pressure standard used.)
- SAE J1349
- SAE J1739

There are subtle differences between each of the testing standards. The result after the correction factor has been applied is called **corrected torque.** From the corrected torque values the other units such as horsepower can then be calculated.

FINAL NOTES

- Corrected numbers are to be applied to wide open throttle (WOT) runs only.

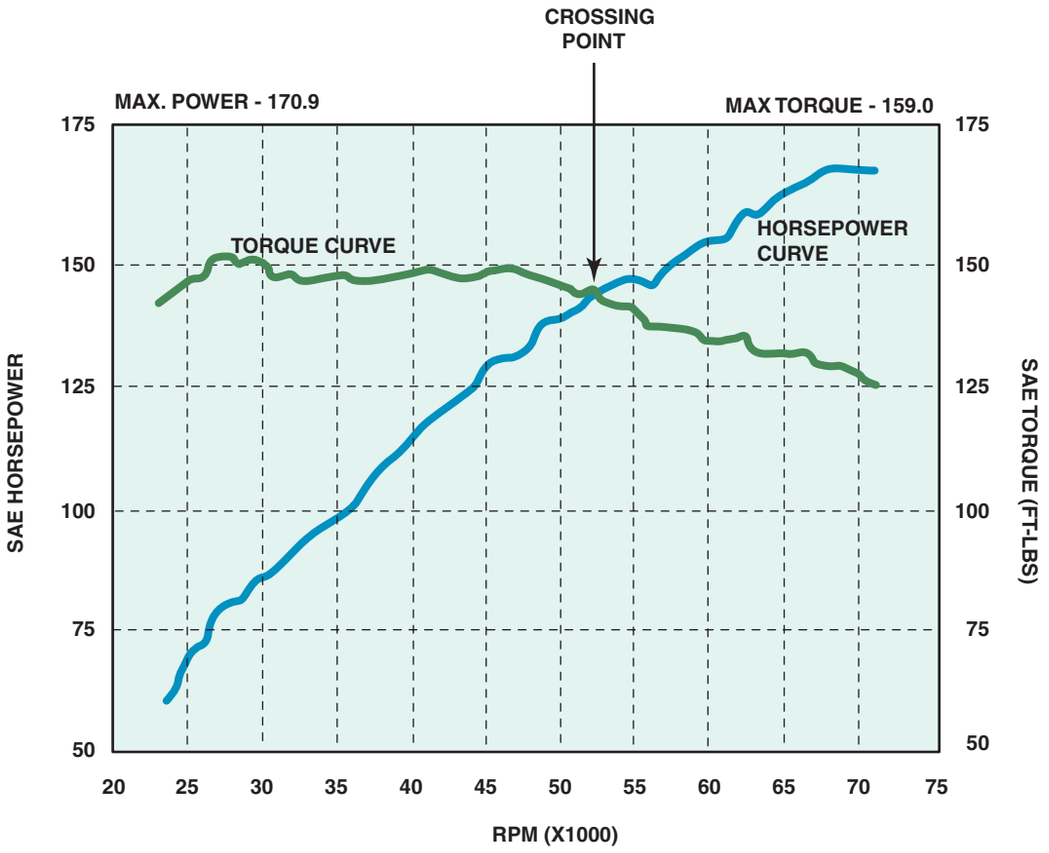


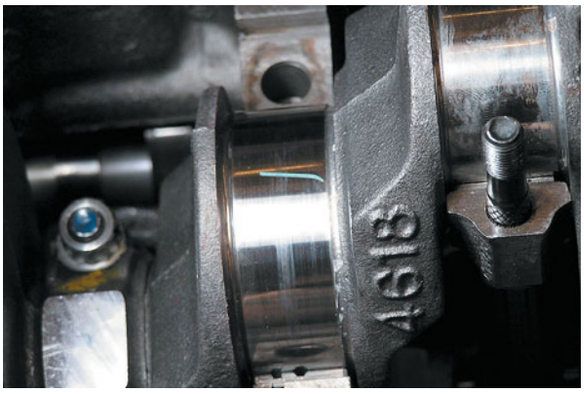
FIGURE 37–65 Because horsepower is calculated from measured torque, the horsepower and torque curves should always cross at exactly 5,252 RPM.

- Corrected numbers only apply to *normally aspirated* engines and are not to be used for turbocharged or supercharged engines.
- Double-check that the spark timing is set relative to top dead center (TDC).
- Double-check that the engine has good electrical grounds and adequate voltage.
- Be sure to have enough *good* fuel before starting to test an engine. Do not use any gasoline older than 90 days.

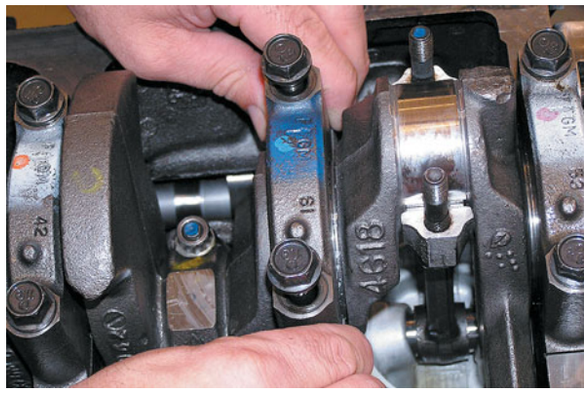
TECH TIP

Compare Dyno Results from the Same Dyno Only

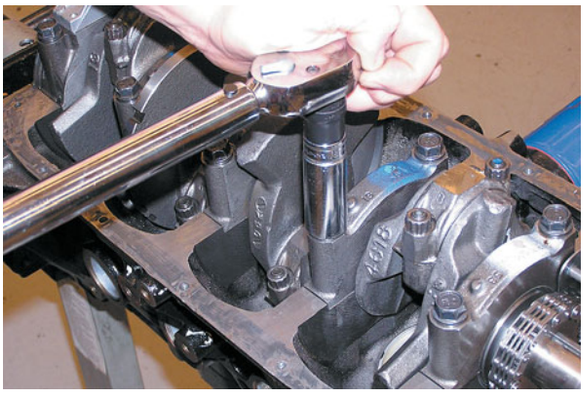
There are too many variables between dynamometers to allow a fair comparison when testing an engine. If changes are made to the engine, try to use the same dynamometer and use the same correction factors. Using another dynamometer can result in readings that may not be equivalent when testing on the original tester.



1 Clean the main bearing journal and then place a strip of Plastigage material across the entire width of the journal.



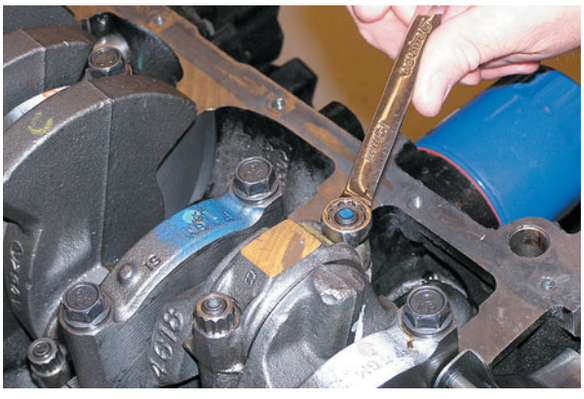
2 Carefully install the main bearing cap with the bearing installed.



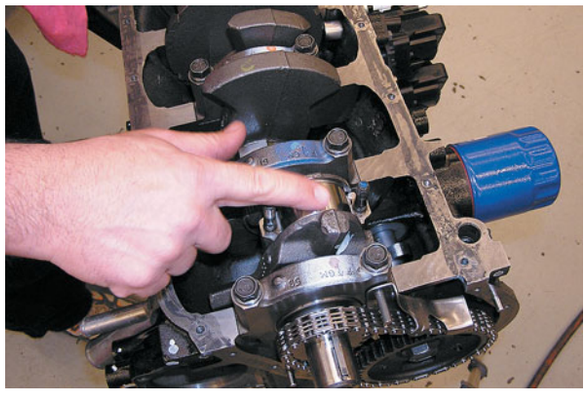
3 Torque main bearing cap bolts to factory specifications.



4 Carefully remove the bearing cap and, using the package that contained the Plastigage strips, measure the width of the compressed material. The gauge is calibrated in thousandths of the inch. Repeat for each main bearing.



5 To measure rod bearing oil clearance, start by removing the rod cap.

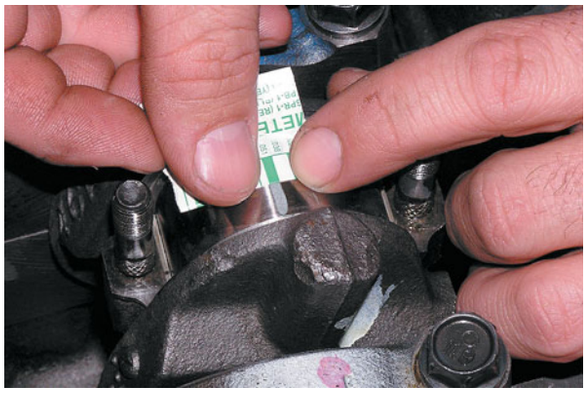


6 Clean the rod bearing journal and then place a strip of Plastigage across the entire width of the journal.

CONTINUED ▶



7 Torque the rod bearing cap nuts to factory specifications.



8 Remove the rod cap and measure the oil clearance using the markings on the Plastigage package. The wider the compressed gauge material, the narrower the bearing oil clearance. Repeat for all rod bearings.

REVIEW QUESTIONS

1. List the items that need to be installed as part of the short block assembly.
2. How is crankshaft end play measured?
3. Why should Teflon seals not be oiled prior to being installed?
4. List the measured and the calculated values as a result of testing an engine on a dynamometer.

CHAPTER QUIZ

1. About how much of the turning torque applied to a head bolt is lost to friction?
   a. 20% **c.** 60%
   b. 40% **d.** 80%
2. Service information states that SAE 30 engine oil should be used on the threads of the head bolts before installation and torquing. Technician A says that SAE 5W-30 will work. Technician B says that SAE 10W-30 will work. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
3. Technician A says that the torque applied to the head bolts is the same as the clamping force on the gasket. Technician B says that the clamping force is the force actually applied to the surfaces of the gasket. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
4. A coating often used to keep an engine from rusting during assembly is called _____.
   a. Engine oil **c.** Fogging oil
   b. Assembly lube **d.** Penetrating oil
5. Head gasket installation is being discussed. Technician A says that the surface finish of the cylinder head or block deck is very important for proper sealing to occur. Technician B says that if "front" is marked on a head gasket, the mark should be installed near the accessory drive belt end of the engine. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
6. Technician A says that studs should be installed finger tight. Technician B says that studs must be installed using a thread locker such as Loctite®. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. What can be used to check that heads are at the correct angle for the intake manifold on a V-type engine?
   a. Metal rule **c.** Tape measure
   b. Angle gauge **d.** Dial indicator
8. What is true about checking bearing clearance using Plastigage?
   a. The journal should be clean and oil free
   b. The cap should be torqued to factory specifications
   c. The wider the strip means the narrower the oil clearance
   d. all of the above
9. An engine dynamometer measures _____.
   a. Torque
   b. Horsepower
   c. Both horsepower and torque
   d. Fuel economy
10. If the torque and horsepower readings are graphed, where do the curves cross (equal each other)?
    a. Never
    b. At peak horsepower which can vary from engine to engine
    c. At peak torque which can vary from engine to engine
    d. At 5,252 RPM

chapter 38

ENGINE INSTALLATION AND BREAK-IN

OBJECTIVES: **After studying Chapter 38, the reader should be able to:** • Prepare for ASE Engine Repair (A1) certification test content area "E" (Fuel, Electrical, Ignition, and Exhaust System Inspection and Service). • List the steps necessary to install and start up a rebuilt engine. • Discuss the importance of torquing all bolts or fasteners that connect accessories to the engine block. • Describe what precautions must be taken to prevent damage to the engine when it is first started. • Explain how to break in a newly rebuilt engine.

KEY TERMS: Lugging 419 • Normal operating temperature 418

PREINSTALLATION CHECKLIST

NEED FOR A CHECKLIST Engine installation must be thoroughly checked to ensure that it is in proper condition to give the customer dependable operation for a long time. Using a checklist guarantees that all accessories are correctly reinstalled on the engine.

ENGINE INSTALLATION CHECKLIST Before installing or starting a new or rebuilt engine in a vehicle, be sure all of the following items have been checked.

1. Be sure the battery is fully charged.
2. Prelube the engine and check for proper oil pressure.
3. Check that all electrical wiring connecters and harnesses are properly installed. ● **SEE FIGURE 38–1**.
4. Check that all of the vacuum lines are correctly installed and routed.
5. Check that all fuel lines are properly connected and free from leaks.
6. Make sure all engine fluids are at the proper operating level such as coolant, engine oil, and power steering fluid.
7. Know the ignition timing specification and procedure.
8. Check that fresh fuel is in the fuel tank.
9. Be sure that the radiator has been tested, is free from leaks, and flows correctly.
10. Check that all accessory drive belts are routed and tensioned correctly.

CAUTION: Be sure to have a fire extinguisher nearby when the engine is first started.



FIGURE 38–1 A partially melted electrical connector indicates that excessive current flow was present. The cause of the excessive current should be located and corrected before the engine is started.

TRANSMISSION INSTALLATION

MANUAL TRANSMISSION INSTALLATION If the engine was removed with the transmission attached, the transmission should be reinstalled on the engine before other accessories are added. The flywheel is installed on the back of the crankshaft. Often, the attaching bolt holes are unevenly spaced so that the flywheel will fit in only one way to maintain engine balance. The pilot bearing or bushing in the rear of the crankshaft is usually replaced with a new one to minimize the possibility of premature failure of this part.

The clutch is installed next and the installation usually includes the following steps.

STEP 1 Most experts recommend that a new clutch assembly or, at the least, a new clutch friction disc be installed.

STEP 2 The clutch friction disc must be held in position using an alignment tool (sometimes called a dummy shaft) that is secured in the pilot bearing. This holds the disc in position while the pressure plate is being installed.

STEP 3 The engine bell housing is put on the engine, if it was not installed before. The alignment of this type of bell housing is then checked. ● **SEE FIGURE 38–2**.

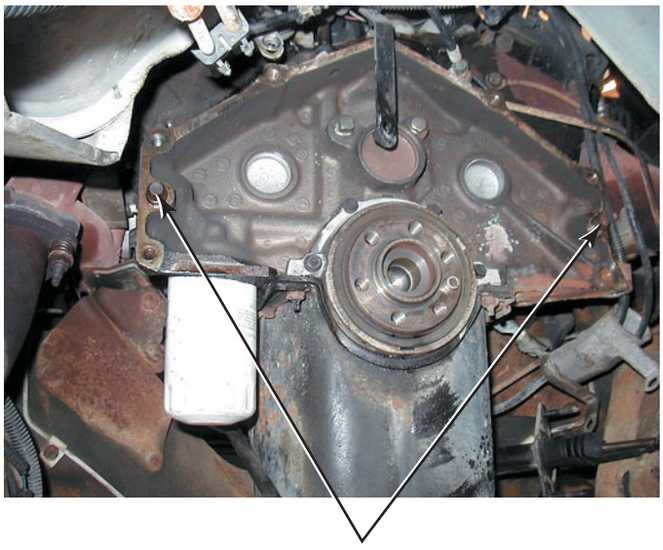


FIGURE 38–2 Bell housing alignment dowel pins are used to ensure proper alignment between the engine block and the transmission.

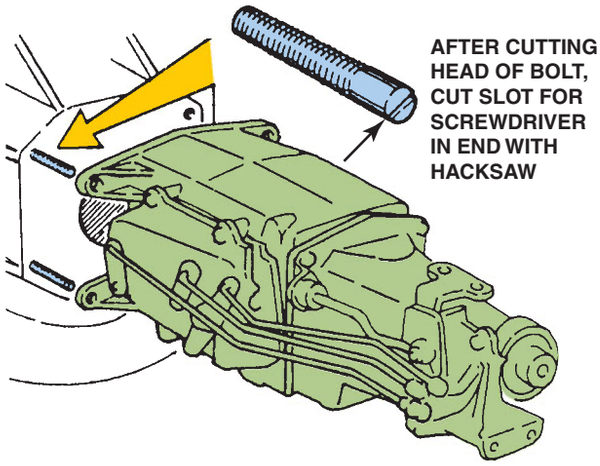


FIGURE 38–3 Headless long bolts can be used to help install a transmission to the engine.

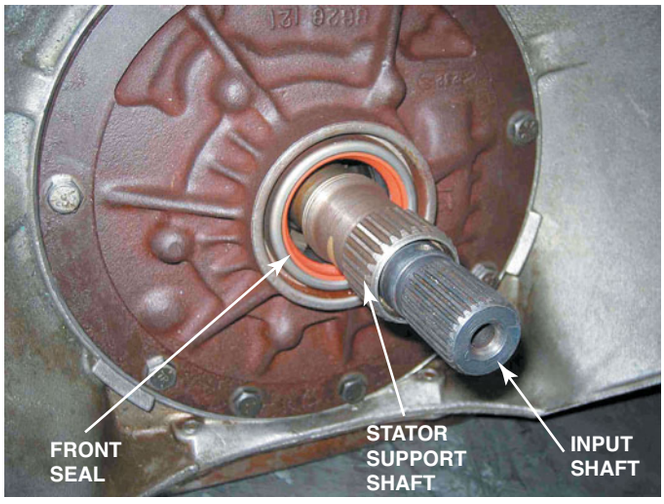


FIGURE 38–4 The internal splines inside the torque converter must be properly aligned with all of the splines of the automatic transmission.

TECH TIP

The Headless Bolt Trick

Sometimes parts do not seem to line up correctly. Try this tip the next time. Cut the head off of extra-long bolts that are of the same diameter and thread as those being used to retain the part, such as a transmission. ● **SEE FIGURE 38–3**.

Use a hacksaw to cut a slot in this end of the guide bolts for a screwdriver slot. Install the guide bolts; then install the transmission. Use a straight-blade screwdriver to remove the guide bolts after securing the transmission with the retaining bolts.

CAUTION: Perfectly round cylinders can be distorted whenever another part of the engine is bolted and torqued to the engine block. For example, it has been determined that after the cylinders are machined, the rear cylinder bore can be distorted to be as much as 0.006 in. (0.15 mm) out-of-round after the bell housing is bolted onto the block! To help prevent this distortion, always apply the specified torque to all fasteners going into the engine block and tighten in the recommended sequence.

STEP 4 The clutch release yoke should be checked for free movement. Usually, the clutch release bearing is replaced to ensure that the new bearing is securely attached to the clutch release yoke.

STEP 5 The transmission is installed by carefully guiding the transmission input (clutch) shaft straight into the clutch disc and pilot bearing. See the Tech Tip, "The Headless Bolt Trick." Rotate the transmission output shaft as needed to engage the splines of the clutch disc. The assembly bolts are secured when the transmission fully mates with the bell housing.

CAUTION: Always adjust the clutch free play *before* starting the engine to help prevent engine thrust bearing or clutch release bearing damage.

AUTOMATIC TRANSMISSION INSTALLATION On engines equipped with an automatic transmission, the drive (flex) plate is attached to the back of the crankshaft. Its assembly bolts are tightened to the specified torque. The bell housing is part of the transmission case on most automatic transmissions. Installing an automatic transmission usually includes the following steps.

STEP 1 The torque converter should be installed on the transmission before the transmission is put on the engine.

STEP 2 Rotate the torque converter while it is pushed onto the transmission shafts until the splines of all shafts are engaged in the torque converter. ● **SEE FIGURE 38–4**.

STEP 3 The torque converter is held against the transmission as the transmission is fitted on the back of the engine. The transmission mounting bolts are attached finger tight.

STEP 4 The torque converter should be rotated to make sure that there is no binding. The bell housing is secured to the block and then the torque converter is fastened to the drive plate.

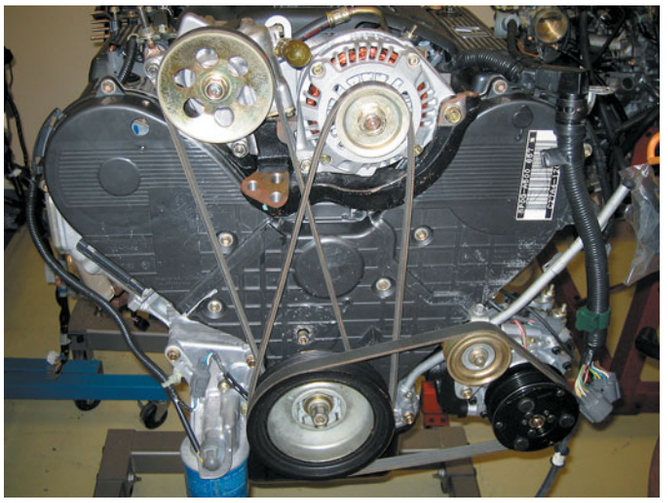


FIGURE 38–5 It is often easier to install all of the accessory drive belts before the engine is installed in the vehicle.

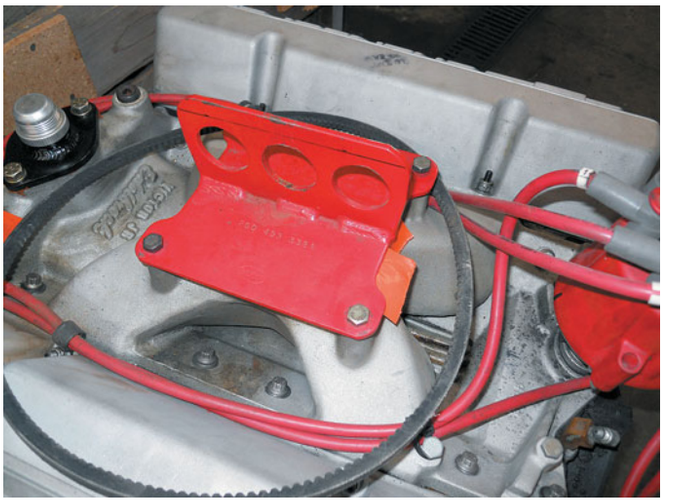


FIGURE 38–6 A fixture installed that is used as a place to attach the hosting chains.

DRESSING THE ENGINE

"Dressing the engine" is a term used to describe the process of attaching all of the auxiliary items to the engine. The items include:

- Starter motor
- Fuel rail and related fuel system components
- New oxygen sensor(s), to ensure that the engine will be operating at the correct air-fuel ratio
- Engine/transmission wiring harness
- Ignition components, such the ignition coil(s) and spark plug wires, if equipped
- All belt-driven engine accessories, mounted on the front of the engine (Some engines drive all these accessories with one belt. Other engines use as many as four belts. Check service information or decals under the hood to determine the specific belt routing for the accessories used on the engine.) ● **SEE FIGURE 38–5**.
- Front accessories, such as the power steering pump, alternator, and air-conditioning compressor (These accessories may be installed before the engine is installed in the vehicle. On some vehicles it is easier to put the engine in the chassis before installing the front accessories.)

Always check service information for the exact procedure to follow.

ENGINE INSTALLATION

SECURING THE ENGINE

A sling, either a chain or lift cable, is attached to the manifold or head bolts or lifting brackets on the top of the engine. A hoist is attached to the sling and snugged up to take the weight and to make sure that the engine is supported and balanced properly. ● **SEE FIGURE 38–6**.

INSTALLING THE ENGINE

- **Rear-wheel drive.** The engine must be tipped as it was during removal to let the transmission go into the engine compartment first. The transmission is worked under the floor pan on rear-wheel-drive vehicles as the engine is lowered into the engine compartment. The front engine mounts are aligned and the rear cross-member and rear engine mount are installed. The engine mount bolts are installed, and the nuts are torqued. Then the hoist is removed.
- **Front-wheel drive.** Many engines for front-wheel-drive vehicles are installed from underneath the vehicle. Often the entire drivetrain package is placed back in the vehicle while it is attached to the cradle. The vehicle is positioned on a hoist and is lowered onto the engine cradle assembly to install. Always check the recommended procedure for the vehicle being serviced.

RECONNECTING COMPONENTS AND CONNECTORS

The following items should be connected to the engine assembly.

- Throttle and cruise control linkages or cables
- Exhaust system to the exhaust manifolds
- If any of the steering linkage was previously disconnected, it can be reattached while work is being done under the vehicle.
- After the engine is in place, the front engine accessories can all be installed, if they were not installed before the engine was put in the chassis.
- The air-conditioning compressor is reattached to the engine, with care being taken to avoid damaging the air-conditioning hoses and lines.

COOLING SYSTEM

The radiator is installed and secured in place, followed by the cooling fan and shroud. The fan and new drive belts are then installed and adjusted. New radiator hoses, including new heater hoses, and new coolant should be installed.

ELECTRICAL SYSTEM

Under the hood the following electrical components will need to be mounted and connected.

- Connect all wiring to the starter and alternator as required.
- Connect the instrument and computer sensor wires to the sensors on the engine.
- Double-check the condition and routing of all wiring, being certain that wires have not been pinched or broken, before installing a fully charged battery.
- Attach the positive cable first and then the ground cable.

FREQUENTLY ASKED QUESTION

What Is Break-In Engine Oil?

Many years ago, vehicle manufacturers used straight weight such as SAE 30 nondetergent engine oil as break-in oil. Today, the engine oil recommended for break-in (running in) is the same type of oil that is recommended for use in the engine. No special break-in oil is recommended or used by the factory in new vehicles. Always use the specified viscosity oil as recommended by the vehicle manufacturer.

- Ensure that the starter will crank the engine.
- Install and time the distributor (if equipped), then connect the ignition cables to the spark plugs, again being sure that they are routed according to service information.

ENGINE START

PRECAUTIONS The engine installation should be given one last inspection to ensure that everything has been put together correctly before the engine is started. If the engine overhaul and installation are done properly, the engine should crank and start on its own fully charged battery without the use of a fast charger or jumper battery. As soon as the engine starts and shows oil pressure, it should be brought up to a fast idle speed and *kept there* to ensure that the engine gets proper lubrication. The fast-running oil pump develops full pressure, and the fast-turning crankshaft throws plenty of oil on the cam and cylinder walls.

NOTE: In camshaft-in-block engines, the only lubrication sent to the contact point between the camshaft lobes and the lifters (tappets) is from the splash off the crankshaft and connecting rods. At idle, engine oil does not splash enough for proper break-in lubrication of the camshaft.

Maintaining engine speed above 1,500 RPM for the first 10 minutes of engine operation must be performed to break in a flat-bottom lifter camshaft. If the engine speed is decreased to idle (about 600 RPM), the lifter (tappet) will be in contact with and exerting force *on* the lobe of the cam for a longer period of time than occurs at higher engine speeds. The pressure and volume of oil supplied to the camshaft area are also increased at the higher engine speeds. Therefore, to ensure long camshaft and lifter life, make certain that the engine will start quickly after reassembly to prevent long cranking periods and subsequent low engine speeds after a new camshaft and lifters have been installed.

NOTE: Many molydisulfide greases used during assembly can start to clog oil filters within 20 minutes after starting the engine. Most engine rebuilders recommend changing the oil and filter after 30 minutes of running time.

After the engine has started, the following items should be checked.

1. Is the valve train quiet? Some engines will require several minutes to quiet down.
2. Record the engine vacuum. It should be 17 to 21 in. Hg (sea level).
3. Check for any gasoline, coolant, or oil leaks. Stop the engine and repair the leaks as soon as possible.
4. Check the charging system for proper operation. The charging voltage should be 13.5 to 15 volts.

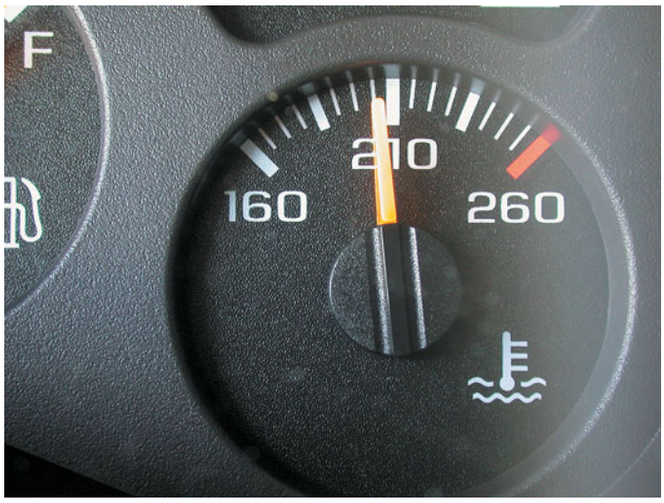


FIGURE 38–7 Even though the dash gauge may show normal operating temperature, a scan tool or an infrared pyrometer can also be used to verify proper coolant temperature.

As soon the engine is at operating temperature and running well, the vehicle should be driven to a road having minimum traffic. Perform the following during the test drive.

- The vehicle should be accelerated, full throttle, from 30 to 50 mph (48 to 80 km/h).
- Then the throttle is fully closed while the vehicle is allowed to return to 30 mph (48 km/h). This sequence is repeated 10 to 12 times.
- The acceleration sequence puts a high load on the piston rings to properly seat them against the cylinder walls. The piston rings are the only part of the modern engine that needs to be broken in. Good ring seating is indicated by a dry coating inside the tailpipe at the completion of the ring seating drive.

The vehicle is returned to the service area, where the engine is again checked for visible fluid leaks. If the engine is dry, it is ready to be turned over to the customer.

The customer should be instructed to drive the vehicle in a normal fashion, neither babying it at slow speeds nor beating it at high speeds for the first 100 miles (160 km). The oil and filter should be changed at 500 miles (800 km) to remove any dirt that may have been trapped in the engine during assembly and to remove the material that has worn from the surfaces during the break-in period.

A well-designed engine that has been correctly reconditioned and assembled using the techniques described should give reliable service for many miles.

NORMAL OPERATING TEMPERATURE **Normal operating temperature** is the temperature at which the upper radiator hose is hot and pressurized. Another standard method used to determine when normal operating temperature is reached is to observe the operation of the electric cooling fan, when the vehicle is so equipped. Many manufacturers define normal operating temperature as being reached when the cooling fan has cycled on and off at least once after the engine has been started. Some vehicle manufacturers specify that the cooling fan should cycle twice. This method also helps assure the technician that the engine is not being overheated. ● **SEE FIGURE 38–7**.

HOW TO WARM UP A COLD ENGINE The greatest amount of engine wear occurs during start-up. The oil in a cold engine is thick, and it requires several seconds to reach all the moving parts of an engine. After the engine starts, allow the engine to idle until the oil pressure peaks. This will take from 15 to 60 seconds, depending on the outside

temperature. *Do not allow the engine to idle for longer than five minutes.* Because an engine warms up faster under load, drive the vehicle in a normal manner until the engine is fully warm. Avoid full-throttle acceleration until the engine is completely up to normal operating temperature. This method of engine warm-up also warms the rest of the powertrain, including transmission and final drive component lubricants.

BREAK-IN PRECAUTIONS

Any engine overhaul represents many hours of work and a large financial investment. Precautions should be taken to protect the investment, including the following:

1. Never add cold water to the cooling system while the engine is running.
2. Never lug any engine. **Lugging** means increasing the throttle opening without increasing engine speed (RPM). An example where lugging an engine can occur is when the vehicle is driven at a low speed, such as 15 mph, with the manual transmission in third or fourth gear instead of in second gear as per the recommended speed for that gear as published in the owner manual.
3. Applying loads to an engine for *short periods* of time creates higher piston ring pressure against the cylinder walls and assists the breaking-in process by helping to seat the rings.
4. Change the oil and filter at 500 miles (800 km) or after 20 hours of operation.
5. Check for leaks after the engine has gone through several warm-up and cooling down periods.

REVIEW QUESTIONS

1. How are the clutch and bell housing installed?
2. What should be done to help prevent rear cylinder distortion when the bell housing is being installed on the engine?
3. Describe the engine break-in procedure.

CHAPTER QUIZ

1. "Dressing the engine" means _____.
   a. Installing all of the exterior engine components
   b. Cleaning the engine
   c. Changing the oil and oil filter
   d. Both b and c
2. If the bell housing is not properly torqued to the engine block, _____.
   a. The bell housing will distort
   b. The engine block will crack
   c. The rear cylinder can be distorted (become out-of-round)
   d. The crankshaft will crack
3. Break-in engine oil is _____.
   a. Of the same viscosity and grade as that specified for normal engine operation
   b. SAE 40
   c. SAE 30
   d. SAE 20W-50
4. Normal operating temperature is reached when _____.
   a. The radiator cap releases coolant into the overflow
   b. The upper radiator hose is hot and pressurized
   c. The electric cooling fan has cycled at least once (if the vehicle is so equipped)
   d. Both b and c
5. Lugging an engine means _____.
   a. Wide-open throttle in low gear above 25 mph
   b. That engine speed does not increase when the throttle is opened wider
   c. Starting a cold engine and allowing it to idle for longer than five minutes
   d. Both b and c
6. Which computer sensor should be replaced to help ensure that the engine will be operating at the correct air-fuel ratio?
   a. Throttle position sensor
   b. Oxygen sensor
   c. Manifold absolute pressure sensor
   d. Engine coolant temperature sensor
7. How should the vehicle be driven to best break in a newly overhauled engine?
   a. At a steady low speed
   b. At varying speeds and loads
   c. At high speed and loads
   d. At idle speed and little or no load
8. Which type of vehicle is the engine most likely to be installed from underneath the vehicle?
   a. Rear-wheel drive (RWD)
   b. Front-wheel drive (FWD)
   c. Four-wheel drive (4WD)
   d. Both a and c
9. Engine vacuum on a normal stock rebuilt engine should be _____.
   a. 10 to 15 in. Hg
   b. 12 to 16 in. Hg
   c. 17 to 21 in. Hg
   d. 19 to 23 in. Hg
10. Why must flat-bottom camshafts be broken in at a fast idle?
    a. Cam in a cam-in-block engine is only lubricated by splash oil.
    b. The flat-bottom of the lifters must become slightly concave in order to rotate.
    c. Both a and b are correct
    d. Neither a nor b are correct

SECTION VII

Electrical and Electronic Systems

39 Electrical Fundamentals
40 Electrical Circuits and Ohm's Law
41 Series, Parallel, and Series-Parallel Circuits
42 Circuit Testers and Digital Meters
43 Oscilloscopes and Graphing Multimeters
44 Automotive Wiring and Wire Repair
45 Wiring Schematics and Circuit Testing
46 Capacitance and Capacitors
47 Magnetism and Electromagnetism
48 Electronic Fundamentals
49 CAN and Network Communications
50 Batteries
51 Battery Testing and Service
52 Cranking Systems
53 Cranking System Diagnosis and Service
54 Charging Systems
55 Charging System Diagnosis and Service
56 Lighting and Signaling Circuits
57 Driver Information and Navigation Systems
58 Horn, Wiper, and Blower Motor Circuits
59 Accessory Circuits
60 Restraint Systems and Airbags
61 Audio System Operation and Diagnosis

chapter 39

ELECTRICAL FUNDAMENTALS

OBJECTIVES: **After studying Chapter 39, the reader should be able to:** • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "A" (General Electrical/Electronic System Diagnosis). • Define electricity. • Explain the units of electrical measurement. • Discuss the relationship among volts, amperes, and ohms. • Explain how magnetism is used in automotive applications.

KEY TERMS: Ammeter 424 • Ampere 424 • Atom 421 • Bound electrons 422 • Conductors 422 • Conventional theory 424 • Coulomb 424 • Electrical potential 424 • Electricity 421 • Electrochemistry 426 • Electromotive force (EMF) 424 • Electron theory 424 • Free electrons 422 • Insulators 423 • Ion 422 • Neutral charge 421 • Ohmmeter 425 • Ohms 425 • Peltier effect 425 • Photoelectricity 426 • Piezoelectricity 426 • Positive temperature coefficient (PTC) 426 • Potentiometer 427 • Resistance 425 • Rheostat 427 • Semiconductor 423 • Static electricity 425 • Thermocouple 425 • Thermoelectricity 425 • Valence ring 422 • Volt 424 • Voltmeter 425 • Watt 425

INTRODUCTION

The electrical system is one of the most important systems in a vehicle today. Every year more and more components and systems use electricity. Those technicians who really know and understand automotive electrical and electronic systems will be in great demand.

Electricity may be difficult for some people to learn for the following reasons.

- It cannot be seen.
- Only the results of electricity can be seen.
- It has to be detected and measured.
- The test results have to be interpreted.

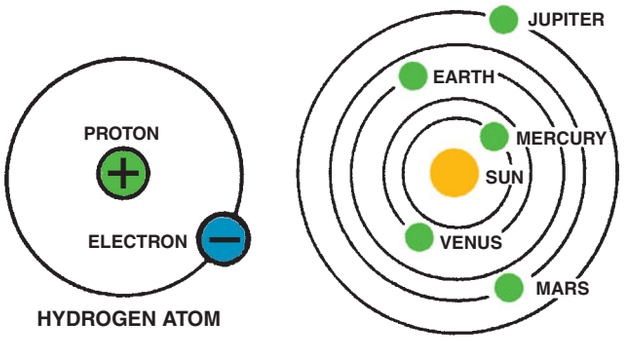


FIGURE 39–1 In an atom (left), electrons orbit protons in the nucleus just as planets orbit the sun in our solar system (right).

ELECTRICITY

BACKGROUND Our universe is composed of matter, which is *anything* that has mass and occupies space. All matter is made from slightly over 100 individual components called *elements*. The smallest particle that an element can be broken into and still retain the properties of that element is known as an **atom**. ● **SEE FIGURE 39–1**.

DEFINITION **Electricity** is the movement of electrons from one atom to another. The dense center of each atom is called the nucleus. The nucleus contains:

- *Protons*, which have a positive charge
- *Neutrons*, which are electrically neutral (have no charge)

Electrons, which have a negative charge, surround the nucleus in orbits. Each atom contains an equal number of electrons and protons. The physical aspect of all protons, electrons, and neutrons are the same for all atoms. It is the *number* of electrons and protons in the atom that determines the material and how electricity is conducted. Because the number of negative-charged electrons is balanced with the same number of positive-charged protons, an atom has a **neutral charge** (no charge).

NOTE: As an example of the relative sizes of the parts of an atom, consider that if an atom were magnified so that the nucleus were the size of the period at the end of this sentence, the whole atom would be bigger than a house.

POSITIVE AND NEGATIVE CHARGES The parts of the atom have different charges. The orbiting electrons are negatively charged, while the protons are positively charged. Positive charges are indicated by the "plus" sign (+), and negative charges by the "minus" sign (−), as shown in ● **FIGURE 39–2**.

These same + and − signs are used to identify parts of an electrical circuit. Neutrons have no charge at all. They are neutral. In a normal, or balanced, atom, the number of negative particles equals the number of positive particles. That is, there are as many electrons as there are protons. ● **SEE FIGURE 39–3**.

MAGNETS AND ELECTRICAL CHARGES An ordinary magnet has two ends, or poles. One end is called the south pole, and the other is called the north pole. If two magnets are brought close to each other with like poles together (south to south or north to north), the magnets will push each other apart, because like poles repel each other. If the opposite poles of the magnets are brought close to each other, south to north, the magnets will snap together, because unlike poles attract each other.

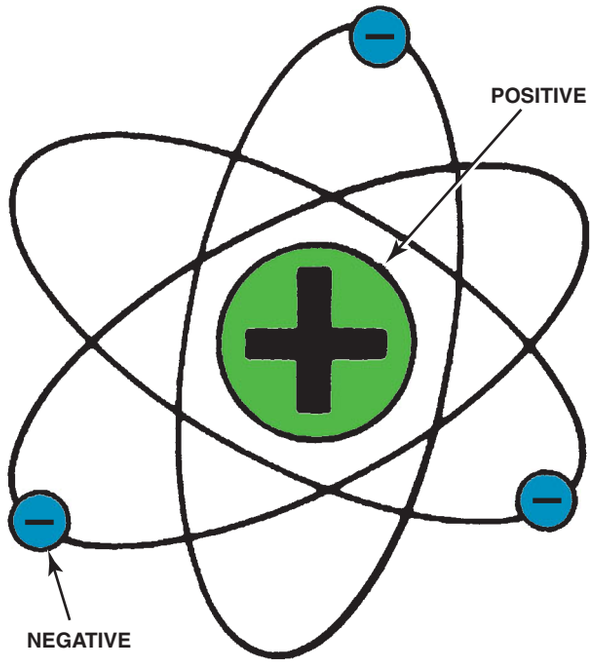


FIGURE 39–2 The nucleus of an atom has a positive (+) charge and the surrounding electrons have a negative (−) charge.

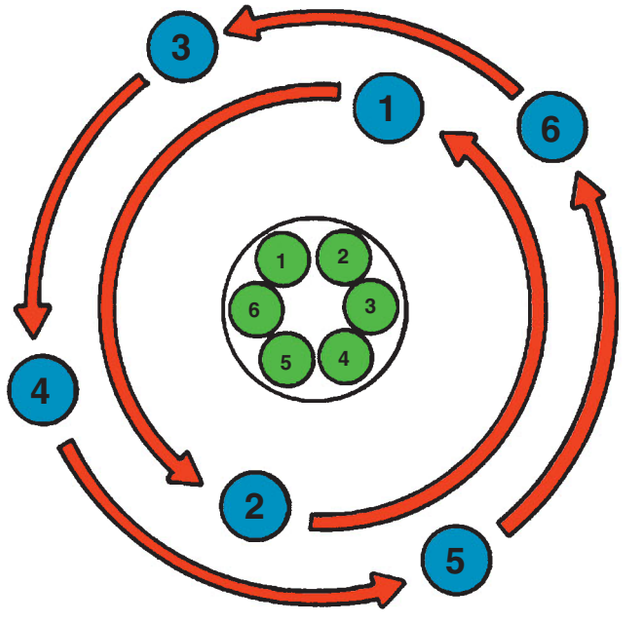


FIGURE 39–3 This figure shows a balanced atom. The number of electrons is the same as the number of protons in the nucleus.



FIGURE 39–4 Unlike charges attract and like charges repel.

The positive and negative charges within an atom are like the north and south poles of a magnet. Charges that are alike will repel each other, similar to the poles of a magnet. ● **SEE FIGURE 39–4**.

That is why the negative electrons continue to orbit around the positive protons. They are attracted and held by the opposite charge of the protons. The electrons keep moving in orbit because they repel each other.

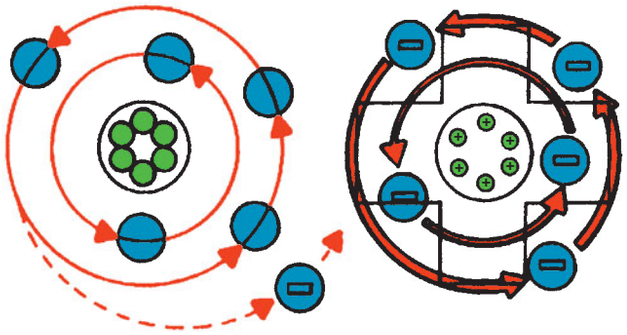


FIGURE 39–5 An unbalanced, positively charged atom (ion) will attract electrons from neighboring atoms.

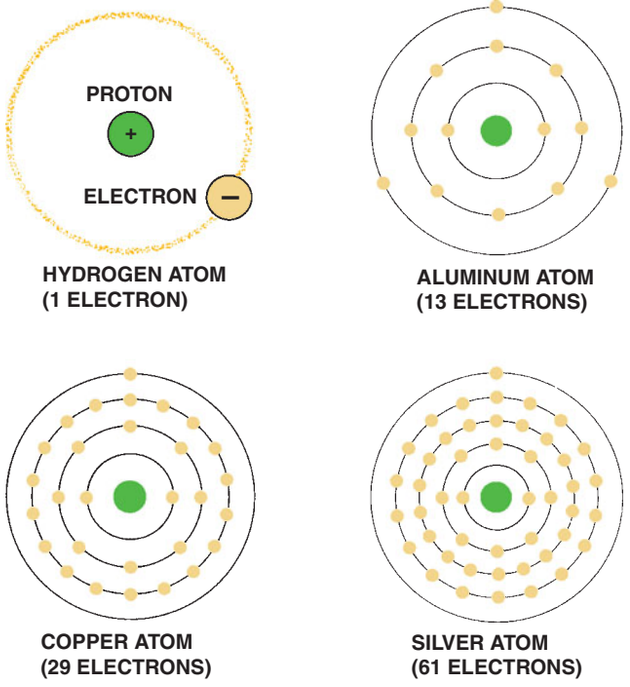


FIGURE 39–6 The hydrogen atom is the simplest atom, with only one proton, one neutron, and one electron. More complex elements contain higher numbers of protons, neutrons, and electrons.

IONS When an atom loses any electrons, it becomes unbalanced. It will have more protons than electrons, and therefore will have a positive charge. If it gains more electrons than protons, the atom will be negatively charged. When an atom is not balanced, it becomes a charged particle called an **ion**. Ions try to regain their balance of equal protons and electrons by exchanging electrons with neighboring atoms. The flow of electrons during the "equalization" process is defined as the flow of electricity. ● **SEE FIGURE 39–5**.

ELECTRON SHELLS Electrons orbit around the nucleus in definite paths. These paths form shells, like concentric rings, around the nucleus. Only a specific number of electrons can orbit within each shell. If there are too many electrons for the first and closest shell to the nucleus, the others will orbit in additional shells until all electrons have an orbit within a shell. There can be as many as seven shells around a single nucleus. ● **SEE FIGURE 39–6**.

FREE AND BOUND ELECTRONS The outermost electron shell or ring, called the **valence ring**, is the most important part of understanding electricity. The number of electrons in this outer ring determines the valence of the atom, and indicates its capacity to combine with other atoms.

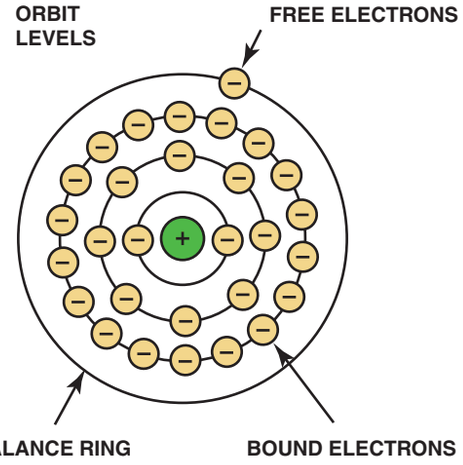


FIGURE 39–7 As the number of electrons increases, they occupy increasing energy levels that are farther from the center of the atom.

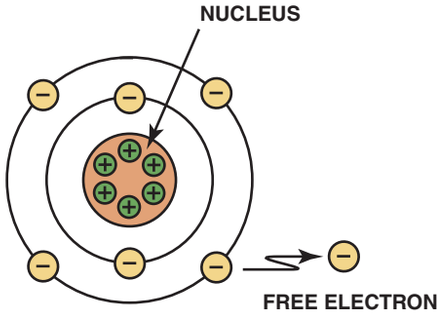


FIGURE 39–8 Electrons in the outer orbit, or shell, can often be drawn away from the atom and become free electrons.

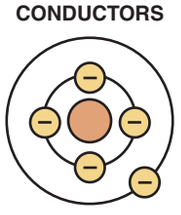


FIGURE 39–9 A conductor is any element that has one to three electrons in its outer orbit.

If the valence ring of an atom has three or fewer electrons in it, the ring has room for more. The electrons there are held very loosely, and it is easy for a drifting electron to join the valence ring and push another electron away. These loosely held electrons are called **free electrons**. When the valence ring has five or more electrons in it, it is fairly full. The electrons are held tightly, and it is hard for a drifting electron to push its way into the valence ring. These tightly held electrons are called **bound electrons**. ● **SEE FIGURES 39–7 AND 39–8**.

The movement of these drifting electrons is called current. Current can be small, with only a few electrons moving, or it can be large, with a tremendous number of electrons moving. Electric current is the controlled, directed movement of electrons from atom to atom within a conductor.

CONDUCTORS **Conductors** are materials with fewer than four electrons in their atom's outer orbit. ● **SEE FIGURE 39–9**.

Copper is an excellent conductor because it has only one electron in its outer orbit. This orbit is far enough away from the nucleus of the copper atom that the pull or force holding the outermost electron in orbit is relatively weak. ● **SEE FIGURE 39–10**.

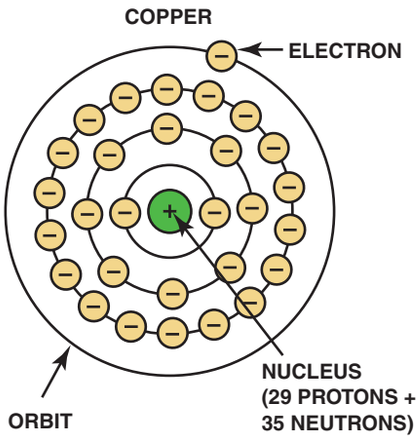


FIGURE 39–10 Copper is an excellent conductor of electricity because it has just one electron in its outer orbit, making it easy to be knocked out of its orbit and flow to other nearby atoms. This causes electron flow, which is the definition of electricity.

FREQUENTLY ASKED QUESTION

Is Water a Conductor?

Pure water is an insulator; however, if anything is in the water, such as salt or dirt, then the water becomes conductive. Because it is difficult to keep it from becoming contaminated, water is usually thought of as being capable of conducting electricity, especially high-voltage household 110 or 220 volt outlets.

Copper is the conductor most used in vehicles because the price of copper is reasonable compared to the relative cost of other conductors with similar properties. Examples of other commonly used conductors include:

- Silver
- Gold
- Aluminum
- Steel
- Cast iron

INSULATORS Some materials hold their electrons very tightly; therefore, electrons do not move through them very well. These materials are called insulators. **Insulators** are materials with more than four electrons in their atom's outer orbit. Because they have more than four electrons in their outer orbit, it becomes easier for these materials to acquire (gain) electrons than to release electrons. ● **SEE FIGURE 39–11**.

Examples of insulators include:

- Rubber
- Plastic
- Nylon
- Porcelain
- Ceramic
- Fiberglass

Examples of insulators include plastics, wood, glass, rubber, ceramics (spark plugs), and varnish for covering (insulating) copper wires in alternators and starters.

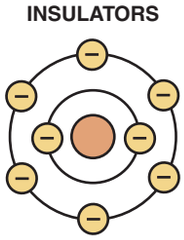


FIGURE 39–11 Insulators are elements with five to eight electrons in the outer orbit.

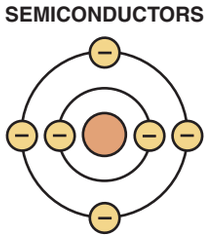


FIGURE 39–12 Semiconductor elements contain exactly four electrons in the outer orbit.

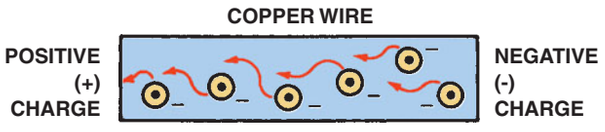


FIGURE 39–13 Current electricity is the movement of electrons through a conductor.

SEMICONDUCTORS Materials with exactly four electrons in their outer orbit are neither conductors nor insulators, but are called **semiconductors**. Semiconductors can be either an insulator or a conductor in different design applications. ● **SEE FIGURE 39–12**.

Examples of semiconductors include:

- Silicon
- Germanium
- Carbon

Semiconductors are used mostly in transistors, computers, and other electronic devices.

HOW ELECTRONS MOVE THROUGH A CONDUCTOR

CURRENT FLOW The following events occur if a source of power, such as a battery, is connected to the ends of a conductor—a positive charge (lack of electrons) is placed on one end of the conductor and a negative charge (excess of electrons) is placed on the opposite end of the conductor. For current to flow, there *must* be an imbalance of excess electrons at one end of the circuit and a deficiency of electrons at the opposite end of the circuit.

- The negative charge will repel the free electrons from the atoms of the conductor, whereas the positive charge on the opposite end of the conductor will attract electrons.
- As a result of this attraction of opposite charges and repulsion of like charges, electrons will flow through the conductor. ● **SEE FIGURE 39–13**.

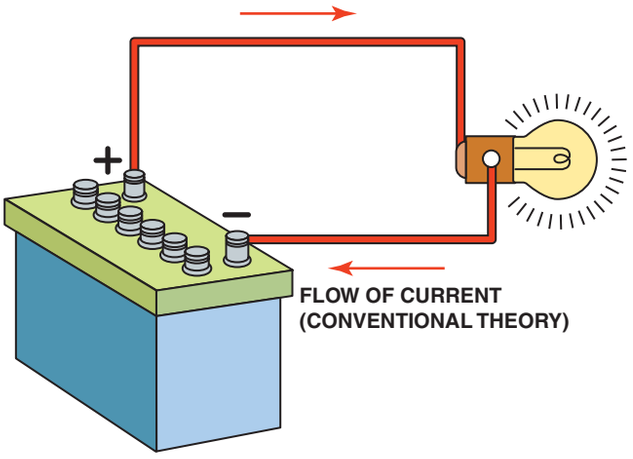


FIGURE 39–14 Conventional theory states that current flows through a circuit from positive (+) to negative (–). Automotive electricity uses the conventional theory in all electrical diagrams and schematics.

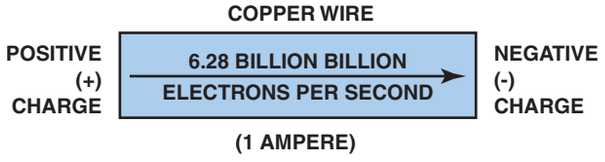


FIGURE 39–15 One ampere is the movement of 1 coulomb (6.28 billion billion electrons) past a point in 1 second.

CONVENTIONAL THEORY VERSUS ELECTRON THEORY

- **Conventional theory.** It was once thought that electricity had only one charge and moved from positive to negative. This theory of the flow of electricity through a conductor is called the **conventional theory** of current flow. ● **SEE FIGURE 39–14**.
- **Electron theory.** The discovery of the electron and its negative charge led to the **electron theory**, which states that there is electron flow from negative to positive. Most automotive applications use the conventional theory. This book will use the conventional theory (positive to negative) unless stated otherwise.

UNITS OF ELECTRICITY

Electricity is measured using meters or other test equipment. The three fundamentals of electricity-related units include the ampere, volt, and ohm.

AMPERES The **ampere** is the unit used throughout the world to measure current flow. When 6.28 billion billion electrons (the name for this large number of electrons is a **coulomb**) move past a certain point in 1 second, this represents 1 ampere of current. ● **SEE FIGURE 39–15**.

The ampere is the electrical unit for the amount of electron flow, just as "gallons per minute" is the unit that can be used to measure the quantity of water flow. It is named for the French electrician, Andrè Marie Ampére (1775–1836). The conventional abbreviations and measurement for amperes are as follows:

1. The ampere is the unit of measurement for the amount of current flow.
2. *A* and *amps* are acceptable abbreviations for *amperes*.

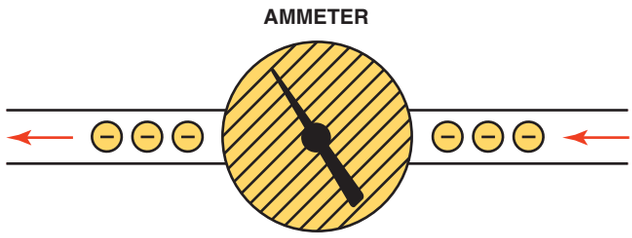


FIGURE 39–16 An ammeter is installed in the path of the electrons similar to a water meter used to measure the flow of water in gallons per minute. The ammeter displays current flow in amperes.

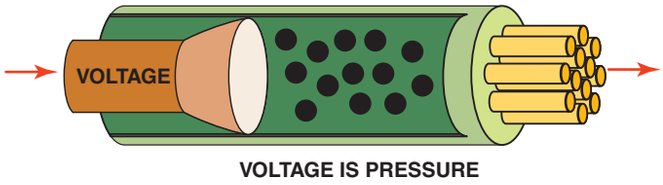


FIGURE 39–17 Voltage is the electrical pressure that causes the electrons to flow through a conductor.

3. The capital letter *I*, for *intensity*, is used in mathematical calculations to represent amperes.
4. Amperes do the actual work in the circuit. It is the actual movement of the electrons through a light bulb or motor that actually makes the electrical device work. Without amperage through a device it will not work at all.
5. Amperes are measured by an **ammeter** (not ampmeter). ● **SEE FIGURE 39–16**.

VOLTS The **volt** is the unit of measurement for electrical pressure. It is named for an Italian physicist, Alessandro Volta (1745–1827). The comparable unit using water pressure as an example would be pounds per square inch (psi). It is possible to have very high pressures (volts) and low water flow (amperes). It is also possible to have high water flow (amperes) and low pressures (volts). Voltage is also called **electrical potential**, because if there is voltage present in a conductor, there is a potential (possibility) for current flow. This electrical pressure is a result of the following:

- Excess electrons remain at one end of the wire or circuit.
- There is a lack of electrons at the other end of the wire or circuit.
- The natural effect is to equalize this imbalance, creating a pressure to allow the movement of electrons through a conductor.
- It is possible to have pressure (volts) without any flow (amperes). For example, a fully charged 12 volt battery sitting on a workbench has 12 volts of pressure potential, but because there is not a conductor (circuit) connected between the positive and negative posts of the battery, there is no flow (amperes). Current will only flow when there is pressure and a circuit for the electrons to flow in order to "equalize" to a balanced state.

Voltage does *not* flow through conductors, but voltage does cause current (in amperes) to flow through conductors. ● **SEE FIGURE 39–17**.

The conventional abbreviations and measurement for voltage are as follows:

1. The volt is the unit of measurement for the amount of electrical pressure.
2. **Electromotive force**, abbreviated **EMF**, is another way of indicating voltage.



FIGURE 39–18 This digital multimeter set to read DC volts is being used to test the voltage of a vehicle battery. Most multimeters can also measure resistance (ohms) and current flow (amperes).

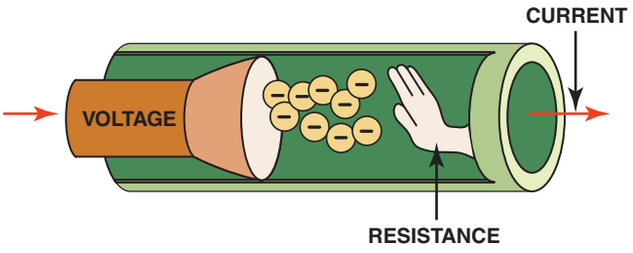


FIGURE 39–19 Resistance to the flow of electrons through a conductor is measured in ohms.

3. *V* is the generally accepted abbreviation for *volts*.
4. The symbol used in calculations is *E*, for *electromotive force*.
5. Volts are measured by a **voltmeter**. ● **SEE FIGURE 39–18**.

OHMS **Resistance** to the flow of current through a conductor is measured in units called **ohms**, named after the German physicist, George Simon Ohm (1787–1854). The resistance to the flow of free electrons through a conductor results from the countless collisions the electrons cause within the atoms of the conductor. ● **SEE FIGURE 39–19**.

The conventional abbreviations and measurement for resistance are as follows:

1. The ohm is the unit of measurement for electrical resistance.
2. The symbol for ohms is Ω (Greek capital letter omega), the last letter of the Greek alphabet.
3. The symbol used in calculations is *R*, for *resistance*.
4. Ohms are measured by an **ohmmeter**.
5. Resistance to electron flow depends on the material used as a conductor.

WATTS A **watt** is the electrical unit for *power,* the capacity to do work. It is named after a Scottish inventor, James Watt (1736–1819). The symbol for power is *P*. Electrical power is calculated as amperes times volts:

$$P \text{ (power)} = I \text{ (amperes)} \times E \text{ (volts)}$$

The formula can also be used to calculate the amperage if the wattage and the voltage are known. For example, a 100 watt light bulb powered by 120 volts AC in the shop requires how many amperes?

A (amperes) = *P* (watts) divided by *E* (volts)

A = 0.83 amperes

● **SEE FIGURE 39–20**.



FIGURE 39–20 A display at the Henry Ford Museum in Dearborn, Michigan, which includes a hand-cranked generator and a series of light bulbs. This figure shows a young man attempting to light as many bulbs as possible. The crank gets harder to turn as more bulbs light because it requires more power to produce the necessary watts of electricity.

SOURCES OF ELECTRICITY

FRICTION When certain different materials are rubbed together, the friction causes electrons to be transformed from one to the other. Both materials become electrically charged. These charges are not in motion, but stay on the surface where they were deposited. Because the charges are stationary, or static, this type of voltage is called **static electricity**. Walking across a carpeted floor creates a buildup of a static charge in your body which is an insulator and then the charge is discharged when you touch a metal conductor. Vehicle tires rolling on pavement often create static electricity that interferes with radio reception.

HEAT When pieces of two different metals are joined together at both ends and one junction is heated, current passes through the metals. The current is very small, only millionths of an ampere, but this is enough to use in a temperature-measuring device called a **thermocouple**. ● **SEE FIGURE 39–21**.

Some engine temperature sensors operate in this manner. This form of voltage is called **thermoelectricity**.

Thermoelectricity was discovered and has been known for over a century. In 1823, a German physicist, Thomas Johann Seebeck, discovered that a voltage was developed in a loop containing two dissimilar metals, provided the two junctions were maintained at different temperatures. A decade later, a French scientist, Jean Charles Athanase Peltier, found that electrons moving through a solid can carry heat from one side of the material to the other side. This effect is called the **Peltier effect**. A Peltier effect device is often used in

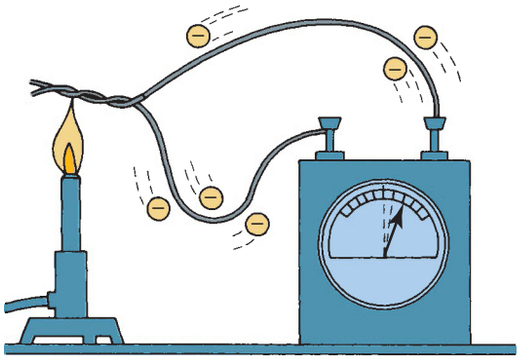


FIGURE 39–21 Electron flow is produced by heating the connection of two different metals.

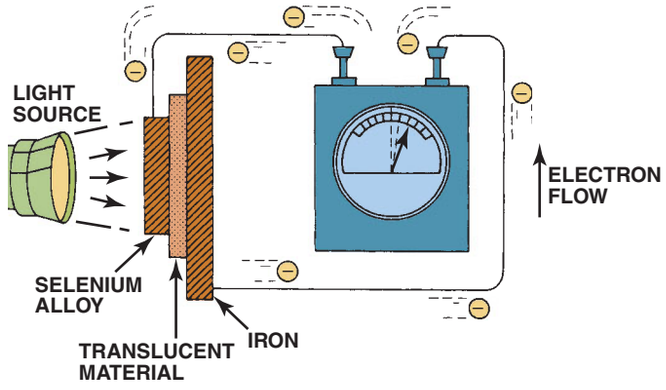


FIGURE 39–22 Electron flow is produced by light striking a light-sensitive material.

portable coolers to keep food items cool if the current flows in one direction and keep items warm if the current flows in reverse.

LIGHT In 1839, Edmond Becquerel noticed that by shining a beam of sunlight over two different liquids, he could develop an electric current. When certain metals are exposed to light, some of the light energy is transferred to the free electrons of the metal. This excess energy breaks the electrons loose from the surface of the metal. They can then be collected and made to flow in a conductor. ● **SEE FIGURE 39–22**.

This **photoelectricity** is widely used in light-measuring devices such as photographic exposure meters and automatic headlamp dimmers.

PRESSURE The first experimental demonstration of a connection between the generation of a voltage due to pressure applied to a crystal was published in 1880 by Pierre and Jacques Curie. Their experiment consisted of voltage being produced when prepared crystals, such as quartz, topaz, and Rochelle salt, had a force applied. ● **SEE FIGURE 39–23**.

This current is used in crystal microphones, underwater hydrophones, and certain stethoscopes. The voltage created is called **piezoelectricity**. A gas grille igniter uses the principle of piezoelectricity to produce a spark, and engine knock sensor (KS) use piezoelectricity to create a voltage signal for use as an input as an engine computer input signal.

CHEMICAL Two different materials (usually metals) placed in a conducting and reactive chemical solution create a difference in potential, or voltage, between them. This principle is called **electrochemistry** and is the basis of the automotive battery.

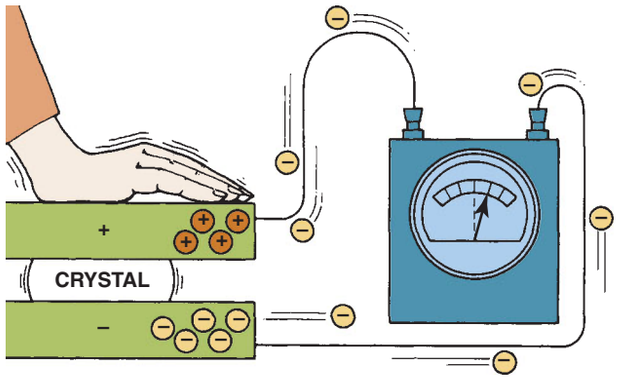


FIGURE 39–23 Electron flow is produced by pressure on certain crystals.

? FREQUENTLY ASKED QUESTION

Why Is Gold Used if Copper Has Lower Resistance?

Copper is used for most automotive electrical components and wiring because it has low resistance and is reasonably priced. Gold is used in airbag connections and sensors because it does not corrode. Gold can be buried for hundreds of years and when dug up it is just as shiny as ever.

MAGNETISM Electricity can be produced if a conductor is moved through a magnetic field or a moving magnetic field is moved near a conductor. This is the principle of how many automotive devices work, including:

- Starter motor
- Alternator
- Ignition coils
- Solenoids and relays

CONDUCTORS AND RESISTANCE

All conductors have some resistance to current flow. The following are principles of conductors and their resistance.

- **If the conductor length is doubled, its resistance doubles.** This is the reason why battery cables are designed to be as short as possible.
- **If the conductor diameter is increased, its resistance is reduced.** This is the reason starter motor cables are larger in diameter than other wiring in the vehicle.
- **As the temperature increases, the resistance of the conductor also increases.** This is the reason for installing heat shields on some starter motors. The heat shield helps to protect the conductors (copper wiring inside the starter) from excessive engine heat and so reduces the resistance of starter circuits. Because a conductor increases in resistance with increased temperature, the conductor is called a **positive temperature coefficient (PTC)** resistor.

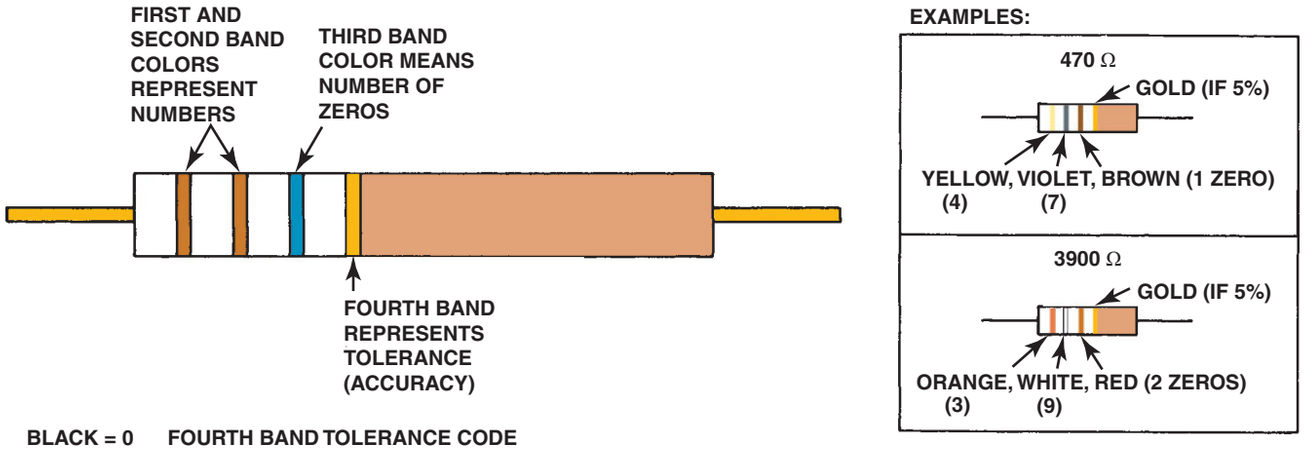


FIGURE 39–24 This figure shows a resistor color-code interpretation.

1	Silver
2	Copper
3	Gold
4	Aluminum
5	Tungsten
6	Zinc
7	Brass (copper and zinc)
8	Platinum
9	Iron
10	Nickel
11	Tin
12	Steel
13	Lead

CHART 39–1

Conductor ratings (starting with the best).

- **Materials used in the conductor have an impact on its resistance.** Silver has the lowest resistance of any conductor, but is expensive. Copper is the next lowest in resistance and is reasonably priced. ● **SEE CHART 39–1** for a comparison of materials.

RESISTORS

FIXED RESISTORS

Resistance is the opposition to current flow. Resistors represent an electrical load, or resistance, to current flow. Most electrical and electronic devices use resistors of specific values to limit and control the flow of current. Resistors can be made from carbon or from other materials that restrict the flow of electricity and are available in various sizes and resistance values. Most resistors have a series of painted color bands around them. These color bands are coded to indicate the degree of resistance. ● **SEE FIGURES 39–24 AND 39–25.**



FIGURE 39–25 A typical carbon resistor.

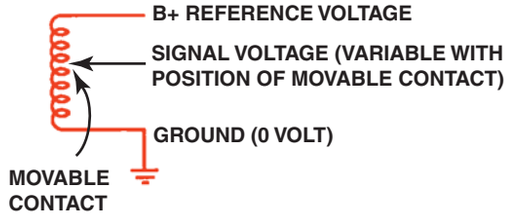


FIGURE 39–26 A three-wire variable resistor is called a potentiometer.

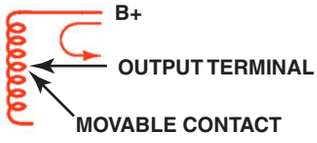


FIGURE 39–27 A two-wire variable resistor is called a rheostat.

VARIABLE RESISTORS

Two basic types of mechanically operated variable resistors are used in automotive applications.

- A **potentiometer** is a three-terminal variable resistor where a wiper contact provides a variable voltage output. ● **SEE FIGURE 39–26.** Potentiometers are most commonly used as throttle position (TP) sensors on computer-equipped engines. A potentiometer is also used to control audio volume, bass, treble, balance, and fade.
- Another type of mechanically operated variable resistor is the **rheostat**. A rheostat is a *two*-terminal unit in which all of the current flows through the movable arm. ● **SEE FIGURE 39–27.** A rheostat is commonly used for a dash light dimmer control.

REVIEW QUESTIONS

1. What is electricity?
2. What are the ampere, volt, and ohm?
3. What are three examples of conductors and three examples of insulators?
4. What are the four sources of electricity?

CHAPTER QUIZ

1. An electrical conductor is an element with _____ electrons in its outer orbit.
   a. Less than 2 **c.** Exactly 4
   b. Less than 4 **d.** More than 4
2. Like charges _____.
   a. Attract **c.** Neutralize each other
   b. Repel **d.** Add
3. Carbon and silicon are examples of _____.
   a. Semiconductors **c.** Conductors
   b. Insulators **d.** Photoelectric materials
4. Which unit of electricity does the work in a circuit?
   a. Volt **c.** Ohm
   b. Ampere **d.** Coulomb
5. As temperature increases, _____.
   a. The resistance of a conductor decreases
   b. The resistance of a conductor increases
   c. The resistance of a conductor remains the same
   d. The voltage of the conductor decreases
6. The _____ is a unit of electrical pressure.
   a. Coulomb **c.** Ampere
   b. Volt **d.** Ohm
7. Technician A says that a two-wire variable resistor is called a rheostat. Technician B says that a three-wire variable resistor is called a potentiometer. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
8. Creating electricity by exerting a force on a crystal is called _____.
   a. Electrochemistry **c.** Thermoelectricity
   b. Piezoelectricity **d.** Photoelectricity
9. The fact that a voltage can be created by exerting force on a crystal is used in which type of sensor?
   a. Throttle position (TP)
   b. Manifold absolute pressure (MAP)
   c. Barometric pressure (BARO)
   d. Knock sensor (KS)
10. A potentiometer, a three-wire variable resistance, is used in which type of sensor?
    a. Throttle position (TP)
    b. Manifold absolute pressure (MAP)
    c. Barometric pressure (BARO)
    d. Knock sensor (KS)

chapter 40

ELECTRICAL CIRCUITS AND OHM'S LAW

OBJECTIVES: **After studying Chapter 40, the reader should be able to:** • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "A" (General Electrical/Electronic Systems Diagnosis). • Explain Ohm's law. • Identify the parts of a complete circuit. • Explain Watt's law. • Describe the characteristics of an open, a short-to-ground, and a short-to-voltage.

KEY TERMS: Circuit 428 • Complete circuit 428 • Continuity 428 • Electrical load 429 • Grounded 431 • High resistance 431 • Load 428 • Ohm's law 431 • Open circuit 429 • Power path 429 • Power source 429 • Protection 429 • Return path (ground) 429 • Shorted 430 • Short-to-ground 430 • Short-to-voltage 430 • Watt 432 • Watt's law 432

CIRCUITS

DEFINITION A **circuit** is a complete path that electrons travel from a power source (such as a battery) through a **load** such as a light bulb and back to the power source. It is called a *circuit* because the current must start and finish at the same place (power source).

For *any* electrical circuit to work at all, it must be continuous from the battery (power), through all the wires and components, and back to the battery (ground). A circuit that is continuous throughout is said to have **continuity**.

PARTS OF A COMPLETE CIRCUIT Every **complete circuit** contains the following parts. ● **SEE FIGURE 40–1**.

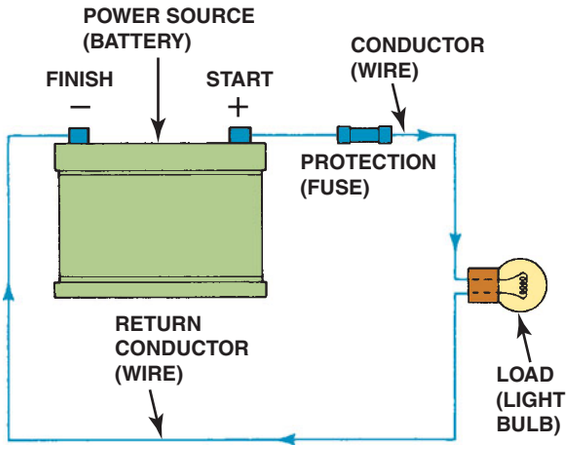


FIGURE 40–1 All complete circuits must have a power source, a power path, protection (fuse), an electrical load (light bulb in this case), and a return path back to the power source.

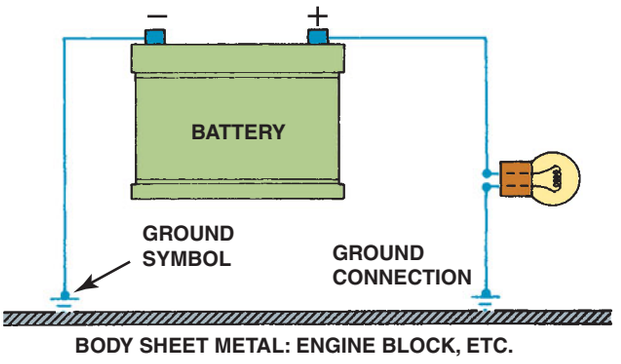


FIGURE 40–2 The return path back to the battery can be any electrical conductor, such as a copper wire or the metal frame or body of the vehicle.

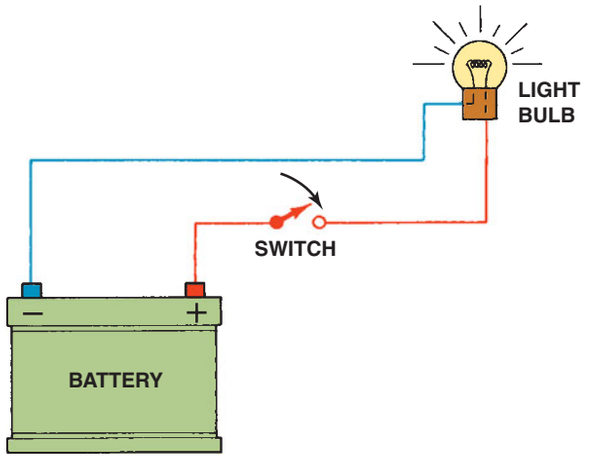


FIGURE 40–3 An electrical switch opens the circuit and no current flows. The switch could also be on the return (ground) path wire.

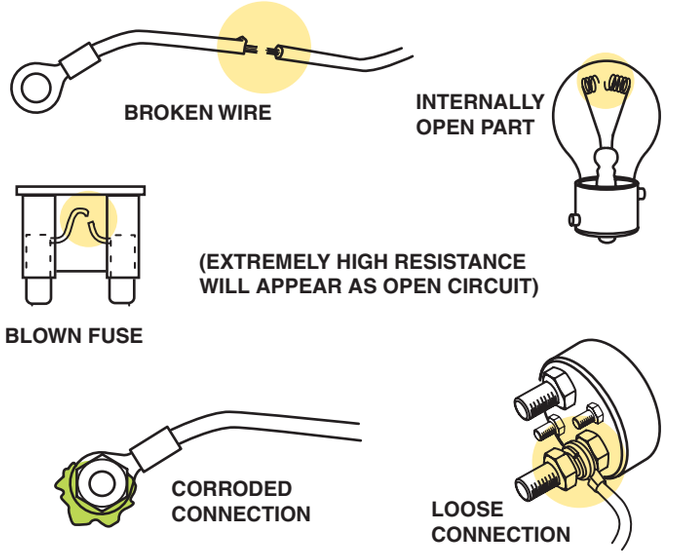


FIGURE 40–4 Examples of common causes of open circuits. Some of these causes are often difficult to find.

1. A **power source**, such as a vehicle's battery
2. **Protection** from harmful overloads (excessive current flow) (Fuses, circuit breakers, and fusible links are examples of electrical circuit protection devices.)
3. The **power path** for the current to flow through from the power source to the resistance (This path from a power source to the load—a light bulb in this example—is usually an insulated copper wire.)
4. The **electrical load** or resistance which converts electrical energy into heat, light, or motion
5. A **return path (ground)** for the electrical current from the load back to the power source so that there is a *complete* circuit (This return, or ground, path is usually the metal body, frame, ground wires, and engine block of the vehicle. ● **SEE FIGURE 40–2**).
6. Switches and controls that turn the circuit on and off (● **SEE FIGURE 40–3**).

CIRCUIT FAULT TYPES

OPEN CIRCUITS

An **open circuit** is any circuit that is *not* complete, or that lacks continuity, such as a broken wire. ● **SEE FIGURE 40–4**.

TECH TIP

"Open" Is a Four-Letter Word

An open in a circuit breaks the path of current flow. The open can be any break in the power side, load, or ground side of a circuit. A switch is often used to close and open a circuit to turn it on and off. Just remember,

Open = no current flow
Closed = current flow

Trying to locate an open circuit in a vehicle is often difficult and may cause the technician to use other four-letter words, such as "HELP"!

Open circuits have the following features:

1. *No current at all* will flow through an open circuit.
2. An open circuit may be created by a break in the circuit or by a switch that opens (turns off) the circuit and prevents the flow of current.
3. In any circuit containing a power load and ground, an opening anywhere in the circuit will cause the circuit not to work.

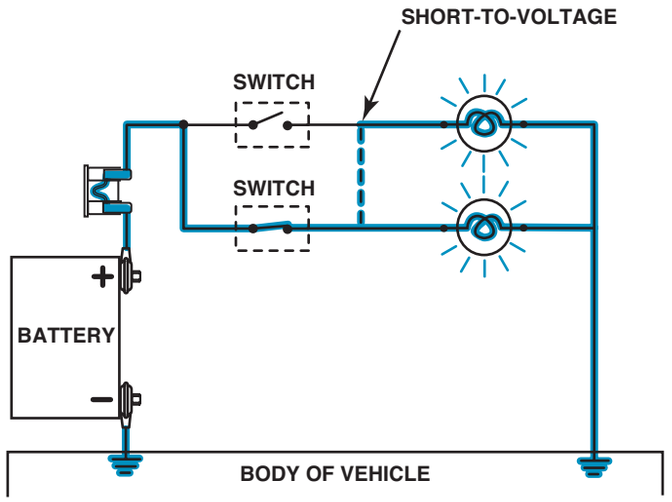


FIGURE 40–5 A short circuit permits electrical current to bypass some or all of the resistance in the circuit.

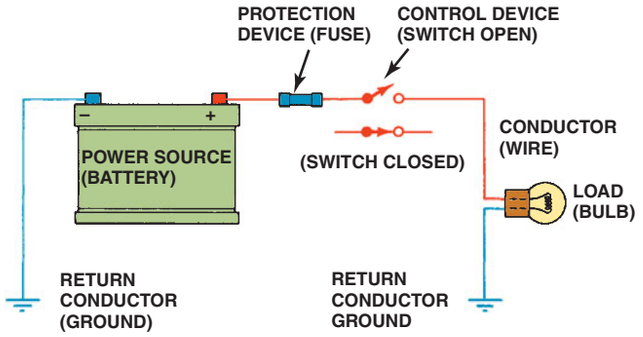


FIGURE 40–6 A fuse or circuit breaker opens the circuit to prevent possible overheating damage in the event of a short circuit.

4. A light switch in a home and the headlight switch in a vehicle are examples of devices that open a circuit to control its operation.
5. A fuse will blow (open) when the current in the circuit exceeds the fuse rating. This stops the current flow to prevent any harm to the components or wiring as a result of the fault.

SHORT-TO-VOLTAGE *If a wire (conductor) or component is shorted to voltage*, it is commonly referred to as being **shorted**. A **short-to-voltage** occurs when the power side of one circuit is electrically connected to the power side of another circuit. ● **SEE FIGURE 40–5**.

A short circuit has the following features:

1. It is a complete circuit in which the current usually bypasses *some* or *all* of the resistance in the circuit.
2. It involves the power side of the circuit.
3. It involves a copper-to-copper connection (two power-side wires touching together).
4. It is also called a *short-to-voltage*.
5. It usually affects more than one circuit. In this case if one circuit is electrically connected to another circuit, one of the circuits may operate when it is not supposed to because it is being supplied power from another circuit.
6. It *may* or *may not* blow a fuse. ● **SEE FIGURE 40–6**.

SHORT-TO-GROUND A **short-to-ground** is a type of short circuit that occurs when the current bypasses part of the normal circuit and flows directly to ground. A short-to-ground has the following features.

1. Because the ground return circuit is metal (vehicle frame, engine, or body), it is often identified as having current flowing from copper to steel.
2. It occurs any place where a power path wire accidentally touches a return path wire or conductor. ● **SEE FIGURE 40–7**.

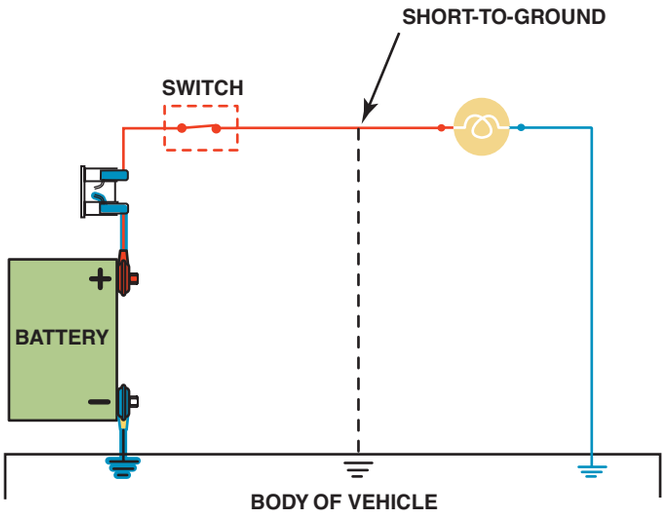


FIGURE 40–7 A short-to-ground affects the power side of the circuit. Current flows directly to the ground return, bypassing some or all of the electrical loads in the circuit. There is no current in the circuit past the short. A short-to ground will also cause the fuse to blow.

REAL WORLD FIX

The Short-to-Voltage Story

A technician was working on a Chevrolet pickup truck with the following unusual electrical problems.

1. When the brake pedal was depressed, the dash light and the side marker lights would light.
2. The turn signals caused all lights to blink and the fuel gauge needle to bounce up and down.
3. When the brake lights were on, the front parking lights also came on.

The technician tested all fuses using a conventional test light and found them to be okay. All body-to-engine block ground wires were clean and tight. All bulbs were of the correct trade number as specified in the owner's manual.

NOTE: Using a single-filament bulb (such as a #1156) in the place of a dual-filament bulb (such as a #1157) could also cause many of these same problems.

Because most of the trouble occurred when the brake pedal was depressed, the technician decided to trace all the wires in the brake light circuit. The technician discovered the problem near the exhaust system. A small hole in the tailpipe (after the muffler) directed hot exhaust gases to the wiring harness containing all of the wires for circuits at the rear of the truck. The heat had melted the insulation and caused most of the wires to touch. Whenever one circuit was activated (such as when the brake pedal was applied), the current had a complete path to several other circuits. A fuse did not blow because there was enough resistance in the circuits being energized, so the current (in amperes) was too low to blow any fuses.

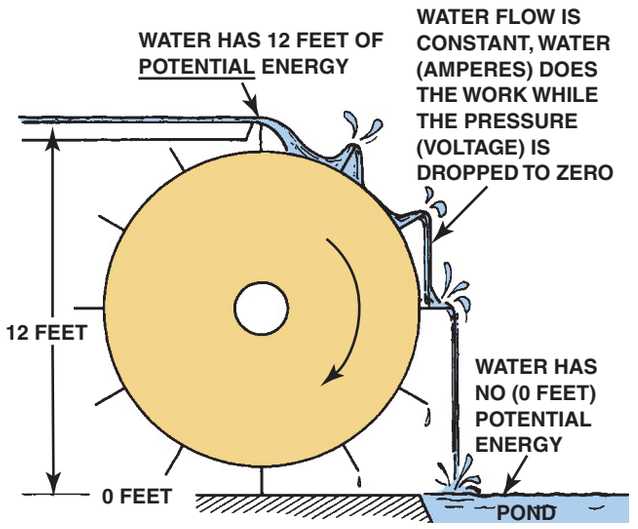


FIGURE 40–8 Electrical flow through a circuit is similar to water flowing over a waterwheel. The more water (amperes in electricity), the greater the amount of work (waterwheel). The amount of water remains constant, yet the pressure (voltage in electricity) drops as the current flows through the circuit.

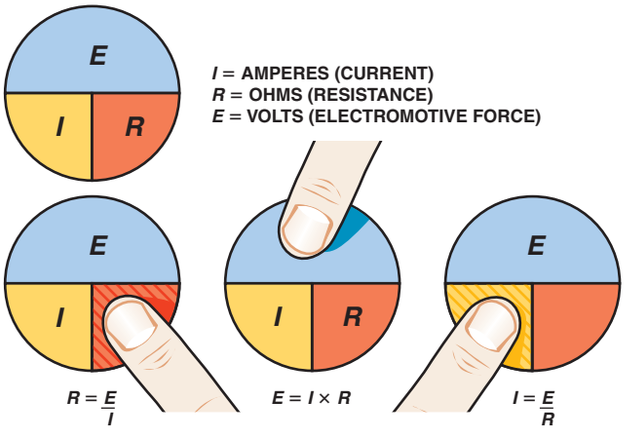


FIGURE 40–9 To calculate one unit of electricity when the other two are known, simply use your finger and cover the unit you do not know. For example, if both voltage (*E*) and resistance (*R*) are known, cover the letter *I* (amperes). Notice that the letter *E* is above the letter *R,* so divide the resistor's value into the voltage to determine the current in the circuit.

TECH TIP

Think of a Waterwheel

A beginner technician cleaned the positive terminal of the battery when the starter was cranking the engine slowly. When questioned by the shop foreman as to why only the positive post had been cleaned, the technician responded that the negative terminal was "only a ground." The foreman reminded the technician that the current, in amperes, is constant throughout a series circuit (such as the cranking motor circuit). If 200 amperes leave the positive post of the battery, then 200 amperes must return to the battery through the negative post.

The technician could not understand how electricity can do work (crank an engine), yet return the same amount of current, in amperes, as left the battery. The shop foreman explained that even though the current is constant throughout the circuit, the voltage (electrical pressure or potential) drops to zero in the circuit. To explain further, the shop foreman drew a waterwheel. ● **SEE FIGURE 40–8**.

As water drops from a higher level to a lower level, high potential energy (or voltage) is used to turn the waterwheel and results in low potential energy (or lower voltage). The same amount of water (or amperes) reaches the pond under the waterwheel as started the fall above the waterwheel. As current (amperes) flows through a conductor, it performs work in the circuit (turns the waterwheel) while its voltage (potential) drops.

3. A defective component or circuit that is shorted to ground is commonly called **grounded**.
4. A short-to-ground almost always results in a blown fuse, damaged connectors, or melted wires.

HIGH RESISTANCE **High resistance** can be caused by any of the following:

- Corroded connections or sockets
- Loose terminals in a connector
- Loose ground connections

If there is high resistance anywhere in a circuit, it may cause the following problems.

1. Slow operation of a motor-driven unit, such as the windshield wipers or blower motor
2. Dim lights
3. "Clicking" of relays or solenoids
4. No operation of a circuit or electrical component

OHM'S LAW

DEFINITION The German physicist, George Simon Ohm, established that electric pressure (EMF) in volts, electrical resistance in ohms, and the amount of current in amperes flowing through any circuit are all related. **Ohm's law** states:

It requires 1 volt to push 1 ampere through 1 ohm of resistance.

This means that if the voltage is doubled, then the number of amperes of current flowing through a circuit will also double if the resistance of the circuit remains the same.

FORMULAS Ohm's law can also be stated as a simple formula used to calculate one value of an electrical circuit if the other two are known. ● **SEE FIGURE 40–9**.

If, for example, the current (*I*) is unknown but the voltage (*E*) and resistance (*R*) are known, then Ohm's Law can be used to find the answer.

$$I = \frac{E}{R}$$

where

I = Current in amperes (A)

E = Electromotive force (EMF) in volts (V)

R = Resistance in ohms (Ω)

VOLTAGE	RESISTANCE	AMPERAGE
Up	Down	Up
Up	Same	Up
Up	Up	Same
Same	Down	Up
Same	Same	Same
Same	Up	Down
Down	Up	Down
Down	Same	Down

CHART 40–1

Ohm's law relationship with the three units of electricity.

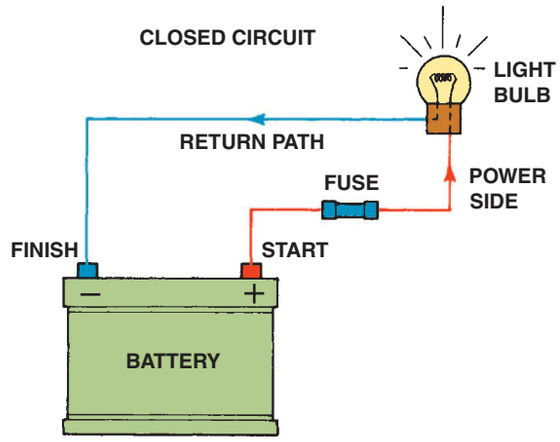


FIGURE 40–10 This closed circuit includes a power source, power-side wire, circuit protection (fuse), resistance (bulb), and return path wire. In this circuit, if the battery has 12 volts and the electrical load has 4 ohms, then the current through the circuit is 4 amperes.

1. Ohm's law can determine the resistance if the volts and amperes are known: $R = \frac{E}{I}$
2. Ohm's law can determine the *voltage* if the resistance (ohms) and amperes are known: $E = I \times R$
3. Ohm's law can determine the amperes if the resistance and voltage are known: $I = \frac{E}{R}$

NOTE: Before applying Ohm's law, be sure that each unit of electricity is converted into base units. For example, 10 KΩ should be converted to 10,000 ohms and 10 mA should be converted into 0.010 A.

● **SEE CHART 40–1**.

OHM'S LAW APPLIED TO SIMPLE CIRCUITS If a battery with 12 volts is connected to a resistor of 4 ohms, as shown in ● **FIGURE 40–10**, how many amperes will flow through the circuit?

Using Ohm's law, we can calculate the number of amperes that will flow through the wires and the resistor. Remember, if two factors are known (volts and ohms in this example), the remaining factor (amperes) can be calculated using Ohm's law.

$$I = \frac{E}{R} = \frac{12\text{ V}}{4\ \Omega}\ A$$

TECH TIP

Wattage Increases by the Square of the Voltage

The brightness of a light bulb, such as an automotive headlight or courtesy light, depends on the number of watts available. The watt is the unit by which electrical power is measured. If the battery voltage drops, even slightly, the light becomes noticeably dimmer. The formula for calculating power (P) in watts is $P = I \times E$. This can also be expressed as Watts = Amps × Volts.

According to Ohm's law, $I = \frac{E}{R}$. Therefore, $\frac{E}{R}$ can be substituted for I in the previous formula resulting in $P = \frac{E}{R} \times E$ or $P = \frac{E^2}{R}$.

E^2 means E multiplied by itself. A small change in the voltage (E) has a big effect on the total brightness of the bulb. (Remember, household light bulbs are sold according to their wattage.) Therefore, if the voltage to an automotive bulb is reduced, such as by a poor electrical connection, the brightness of the bulb is *greatly* affected. A poor electrical ground causes a voltage drop. The voltage at the bulb is reduced and the bulb's brightness is reduced.

The values for the voltage (12) and the resistance (4) were substituted for the variables E and R, and I is thus 3 amperes

$$\left(\frac{12}{4} = 3\right)$$

If we want to connect a resistor to a 12 volt battery, we now know that this simple circuit requires 3 amperes to operate. This may help us for two reasons.

1. We can now determine the wire diameter that we will need based on the number of amperes flowing through the circuit.
2. The correct fuse rating can be selected to protect the circuit.

WATT'S LAW

BACKGROUND James Watt (1736–1819), a Scottish inventor, first determined the power of a typical horse while measuring the amount of coal being lifted out of a mine. The power of one horse was determined to be 33,000 foot-pounds per minute. Electricity can also be expressed in a unit of power called a watt and the relationship is known as **Watt's law**, which states:

A watt is a unit of electrical power represented by a current of 1 ampere through a circuit with a potential difference of 1 volt.

FORMULAS A **watt** is a unit of electrical power represented by a current of 1 ampere through a circuit with a potential difference of 1 volt.

The symbol for a watt is the capital letter W. The formula for watts is:

$$W = I \times E$$

Another way to express this formula is to use the letter P to represent the unit of power. The formula then becomes:

$$P = I \times E$$

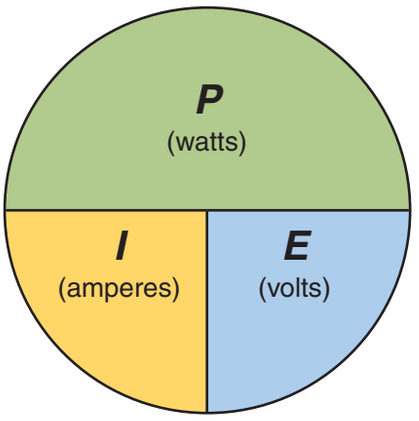


FIGURE 40–11 To calculate one unit when the other two are known, simply cover the unknown unit to see what unit needs to be divided or multiplied to arrive at the solution.

HINT: An easy way to remember this equation is that it spells "pie."

Engine power is commonly rated in watts or kilowatts (1,000 watts equal 1 kilowatt), because 1 horsepower is equal to 746 watts. For example, a 200 horsepower engine can be rated as having the power equal to 149,200 watts or 149.2 kilowatts (kW).

To calculate watts, both the current in amperes and the voltage in the circuit must be known. If any two of these factors are known, then the other remaining factor can be determined by the following equations:

$P = I \times E$ **(watts equal amperes times voltage)**

$I = \frac{P}{E}$ **(amperes equal watts divided by voltage)**

$E = \frac{P}{I}$ **(voltage equals watts divided by amperes)**

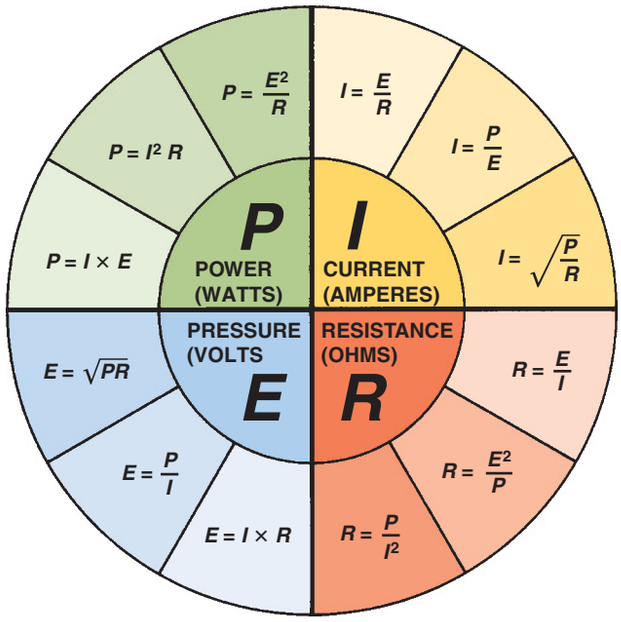


FIGURE 40–12 "Magic circle" of most formulas for problems involving Ohm's law. Each quarter of the "pie" has formulas used to solve for a particular unknown value: current (amperes), in the upper right segment; resistance (ohms), in the lower right; voltage (*E*), in the lower left; and power (watts), in the upper left.

A Watt's circle can be drawn and used like the Ohm's law circle diagram. ● **SEE FIGURE 40–11**.

MAGIC CIRCLE The formulas for calculating any combination of electrical units are shown in ● **FIGURE 40–12**.

It is almost impossible to remember all of these formulas, so this one circle showing all of the formulas is nice to have available if needed.

REVIEW QUESTIONS

1. What is included in a complete electrical circuit?
2. What is the difference between a short-to-voltage and a short-to-ground?
3. What is the difference between an electrical open and a short?
4. What is Ohm's law?
5. What occurs to current flow (amperes) and wattage if the resistance of a circuit is increased because of a corroded connection?

CHAPTER QUIZ

1. If an insulated wire rubbed through a part of the insulation and the wire conductor touched the steel body of a vehicle, the type of failure would be called a(n) _____.
   a. Short-to-voltage **c.** Open
   b. Short-to-ground **d.** Chassis ground
2. If two insulated wires were to melt together where the copper conductors touched each other, the type of failure would be called a(n) _____.
   a. Short-to-voltage **c.** Open
   b. Short-to-ground **d.** Floating ground
3. If 12 volts are being applied to a resistance of 3 ohms, _____ amperes will flow.
   a. 12 **c.** 4
   b. 3 **d.** 36
4. How many watts are consumed by a light bulb if 1.2 amperes are measured when 12 volts are applied?
   a. 14.4 watts **c.** 10 watts
   b. 144 watts **d.** 0.10 watt
5. How many watts are consumed by a starter motor if it draws 150 amperes at 10 volts?
   a. 15 watts **c.** 1,500 watts
   b. 150 watts **d.** 15,000 watts
6. High resistance in an electrical circuit can cause _____.
   a. Dim lights
   b. Slow motor operation
   c. Clicking of relays or solenoids
   d. All of the above

7. If the voltage increases in a circuit, what happens to the current (amperes) if the resistance remains the same?
   a. Increases
   b. Decreases
   c. Remains the same
   d. Cannot be determined

8. If 200 amperes flow from the positive terminal of a battery and operate the starter motor, how many amperes will flow back to the negative terminal of the battery?
   a. Cannot be determined
   b. Zero
   c. One half (about 100 amperes)
   d. 200 amperes

9. What is the symbol for voltage used in calculations?
   a. *R*
   b. *E*
   c. EMF
   d. *I*

10. Which circuit failure is most likely to cause the fuse to blow?
    a. Open
    b. Short-to-ground
    c. Short-to-voltage
    d. High resistance

chapter 41

SERIES, PARALLEL, AND SERIES-PARALLEL CIRCUITS

OBJECTIVES: **After studying Chapter 41, the reader should be able to:** • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "A" (General Electrical/Electronic System Diagnosis). • Identify a series circuit. • Identify a parallel circuit. • Identify a series-parallel circuit. • Calculate the total resistance in a parallel circuit. • State Kirchhoff's voltage law. • Calculate voltage drops in a series circuit. • Explain series and parallel circuit laws. • State Kirchhoff's current law. • Identify where faults in a series-parallel circuit can be detected or determined.

KEY TERMS: Branches 438 • Combination circuit 441 • Compound circuit 441 • Kirchhoff's current law 438 • Kirchhoff's voltage law 435 • Leg 438 • Parallel circuit 438 • Series circuit 434 • Series-parallel circuits 441 • Shunt 438 • Total circuit resistance 439 • Voltage drop 436

SERIES CIRCUITS

A **series circuit** is a complete circuit that has more than one electrical load where all of the current has only one path to flow through all of the loads. Electrical components such as fuses and switches are generally not considered to be included in the determination of a series circuit. The circuit must be continuous or have continuity in order for current to flow through the circuit.

NOTE: Because an electrical load needs both a power and a ground to operate, a break (open) anywhere in a series circuit will cause the current in the circuit to stop.

OHM'S LAW AND SERIES CIRCUITS

As explained earlier, a series circuit is a circuit containing more than one resistance in which all current must flow through all resistances in the circuit. Ohm's law can be used to calculate the value of one unknown (voltage, resistance, or amperes) if the other two values are known.

Because *all* current flows through all resistances, the total resistance is the sum (addition) of all resistances. ● **SEE FIGURE 41–1.**

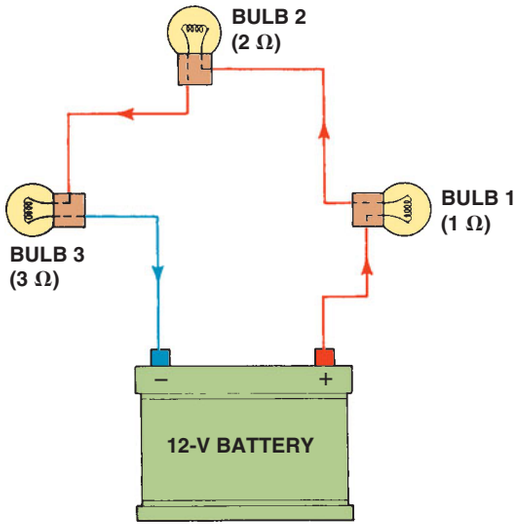


FIGURE 41–1 A series circuit with three bulbs. All current flows through all resistances (bulbs). The total resistance of the circuit is the sum of the total resistance of the bulbs, and the bulbs will light dimly because of the increased resistance and the reduction of current flow (amperes) through the circuit.

The total resistance of the circuit shown here is 6 ohms (1 Ω + 2 Ω + 3 Ω). The formula for total resistance (R_T) for a series circuit is:

$$R_T = R_1 + R_2 + R_3 + \ldots$$

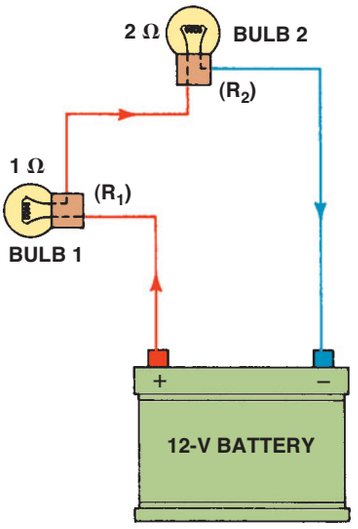


FIGURE 41–2 A series circuit with two bulbs.

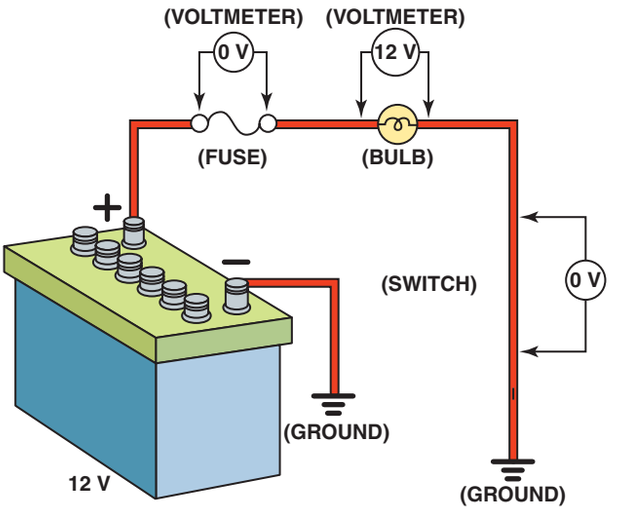


FIGURE 41–3 As current flows through a circuit, the voltage drops in proportion to the amount of resistance in the circuit. Most, if not all, of the resistance should occur across the load such as the bulb in this circuit. All of the other components and wiring should produce little, if any, voltage drop. If a wire or connection did cause a voltage drop, less voltage would be available to light the bulb and the bulb would be dimmer than normal.

TECH TIP

Farsighted Quality of Electricity

Electricity almost seems to act as if it "knows" what resistances are ahead on the long trip through a circuit. If the trip through the circuit has many high-resistance components, very few electrons (amperes) will choose to attempt to make the trip. If a circuit has little or no resistance (for example, a short circuit), then as many electrons (amperes) as possible attempt to flow through the complete circuit. If the flow exceeds the capacity of the fuse or the circuit breaker, then the circuit is opened and all current flow stops.

Using Ohm's law to find the current flow, we have

$$I = E/R + 12\text{ V}/6\ \Omega + 2\text{ A}$$

Therefore, with a total resistance of 6 ohms using a 12-volt battery in the series circuit shown, 2 amperes of current will flow through the entire circuit. If the amount of resistance in a circuit is reduced, more current will flow.

In ● **FIGURE 41–2**, one resistance has been eliminated and now the total resistance is 3 ohms (1 Ω + 2 Ω). Using Ohm's law to calculate current flow yields 4 amperes.

$$I = E/R = 12\text{ V}/3\ \Omega = 4\text{ A}$$

Notice that the current flow was doubled (4 amperes instead of 2 amperes) when the resistance was cut in half (from 6 ohms to 3 ohms).

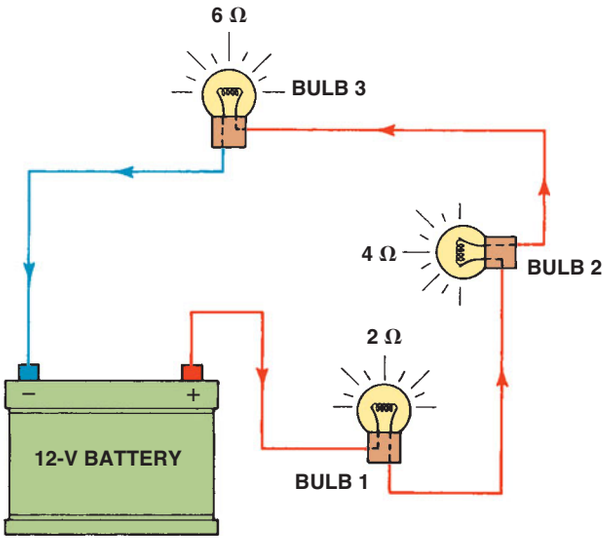


FIGURE 41–4 In a series circuit the voltage is dropped or lowered by each resistance in the circuit. The higher the resistance, the greater the drop in voltage.

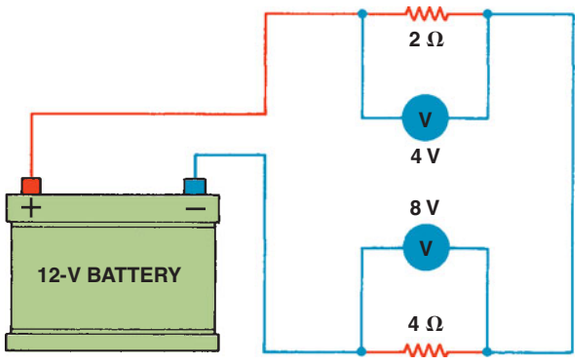
KIRCHHOFF'S VOLTAGE LAW

The voltage that is applied through a series circuit drops with each resistor in a manner similar to that in which the strength of an athlete drops each time a strenuous physical feat is performed. The greater the resistance, the greater the drop in voltage.

A German physicist, Gustav Robert Kirchhoff (1824–1887), developed laws about electrical circuits. His second law, **Kirchhoff's voltage law**, concerns voltage drops. It states: *The voltage around any closed circuit is equal to the sum (total) of the voltage drops across the resistances.*

APPLYING KIRCHHOFF'S VOLTAGE LAW Kirchhoff states in his second law that the voltage will drop in proportion to the resistance and that the total of all voltage drops will equal the applied voltage. ● **SEE FIGURE 41–3**. Using ● **FIGURE 41–4**, the total resistance of the circuit can be determined by adding the individual resistances (2 Ω + 4 Ω + 6 Ω = 12 Ω). The current through the circuit is determined by using Ohm's law, $I = E/R$ = 12 V/12 Ω = 1 A. Therefore, in the circuit shown, the following values are known:

Resistance = 12 Ω
Voltage = 12 V
Current = 1 A



A. $I = E/R$ (TOTAL "R" = 6 Ω)
$= 12\text{ V}/6\ \Omega = 2\text{A}$

B. $E = I/R$ (VOLTAGE DROP)
AT 2 Ω RESISTANCE =
$E = 2 \times 2 = 4\text{ V}$
AT 4 Ω RESISTANCE =
$E = 2 \times 4 = 8\text{ V}$

C. 4 + 8 = 12 V
SUM OF VOLTAGE DROP
EQUALS APPLIED VOLTAGE

FIGURE 41–5 A voltmeter reads the differences of voltage between the test leads. The voltage read across a resistance is the voltage drop that occurs when current flows through a resistance. A voltage drop is also called an "*IR*" drop because it is calculated by multiplying the current (*I*) through the resistance (electrical load) by the value of the resistance (*R*).

Everything is known *except* the voltage drop caused by each resistance. The **voltage drop** can be determined by using Ohm's law and calculating for voltage (*E*) using the value of each resistance individually:

$$E = I \times R$$

where

E = Voltage
I = Current in the circuit (remember, the current is constant in a series circuit; only the voltage varies)
R = Resistance of only one of the resistances

The voltage drops are as follows:

Voltage drop for bulb 1: $E = I \times R = 1\text{ A} \times 2\ \Omega = 2\text{ V}$

Voltage drop for bulb 2: $E = I \times R = 1\text{ A} \times 4\ \Omega = 4\text{ V}$

Voltage drop for bulb 3: $E = I \times R = 1\text{ A} \times 6\ \Omega = 6\text{ V}$

NOTE: Notice that the voltage drop is proportional to the resistance. In other words, the higher the resistance, the greater the voltage drop. A 6-ohm resistance dropped the voltage three times as much as the voltage drop created by the 2-ohm resistance.

According to Kirchhoff, the sum (addition) of the voltage drops should equal the applied voltage (battery voltage):

Total of voltage drops = 2 V + 4 V + 6 V = 12 V = Battery voltage

This illustrates Kirchhoff's second (voltage) law. Another example is illustrated in ● **FIGURE 41–5**.

USE OF VOLTAGE DROPS Voltage drops, due to built-in resistance, are used in automotive electrical systems to drop the voltage in the following examples.

1. **Dash lights.** Most vehicles are equipped with a method of dimming the brightness of the dash lights by turning a variable resistor. This type of resistor can be changed and therefore varies the voltage to the dash light bulbs. A high voltage to the bulbs causes them to be bright, and a low voltage results in a dim light.
2. **Blower motor** (heater or air-conditioning fan). Speeds are usually controlled by a fan switch sending current through high-, medium-, or low-resistance wire resistors. The highest resistance will drop the voltage the most, causing the motor to run at the lowest speed. The highest speed of the motor will occur when *no* resistance is in the circuit and full battery voltage is switched to the blower motor.



FIGURE 41–6 In this series circuit with a 2-ohm resistor and a 4-ohm resistor, current (2 amperes) is the same throughout even though the voltage drops across each resistor.

? FREQUENTLY ASKED QUESTION

Why Check the Voltage Drop Instead of Measuring the Resistance?

Imagine a wire with all strands cut except for one. An ohmmeter can be used to check the resistance of this wire and the resistance would be low, indicating that the wire was okay. But this one small strand cannot properly carry the current (amperes) in the circuit. A voltage drop test is therefore a better test to determine the resistance in components for two reasons:

- An ohmmeter can only test a wire or component that has been disconnected from the circuit and is not carrying current. The resistance can, and does, change when current flows.
- A voltage drop test is a dynamic test because as the current flows through a component, the conductor increases in temperature, which in turn increases resistance. This means that a voltage drop test is testing the circuit during normal operation and is therefore the most accurate way of determining circuit conditions.

A voltage drop test is also easier to perform because the resistance does not have to be known, only that the unwanted loss of voltage in a circuit should be less than 3% or less than about 0.14 volts for any 12-volt circuit.

SERIES CIRCUIT LAWS

LAW 1 The total resistance in a series circuit is the sum total of the individual resistances. The resistance values of each electrical load are simply added together.

LAW 2 The current is constant throughout the entire circuit. ● **SEE FIGURE 41–6**. If 2 amperes of current leave the battery, 2 amperes of current return to the battery.

LAW 3 Although the current (in amperes) is constant, the voltage drops across each resistance in the circuit. The voltage

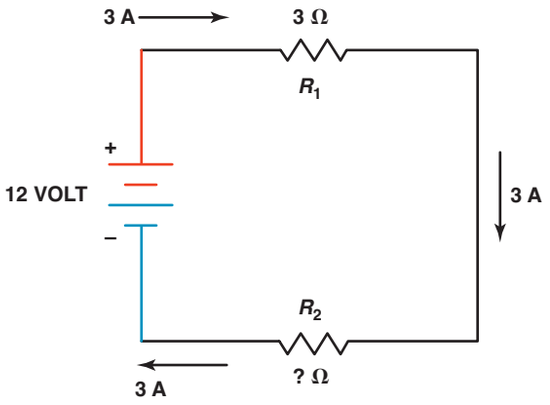


FIGURE 41–7 Example 1.

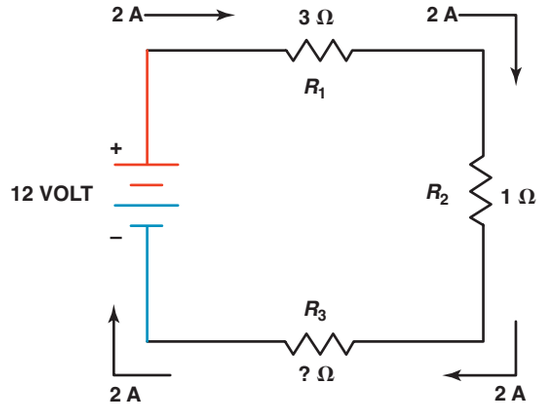


FIGURE 41–8 Example 2.

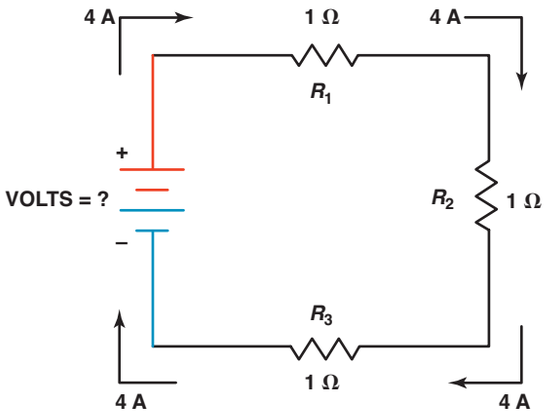


FIGURE 41–9 Example 3.

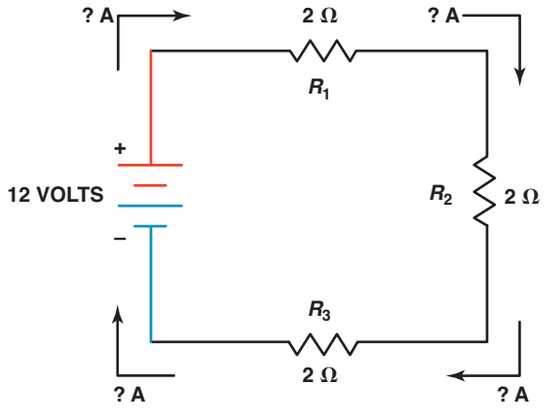


FIGURE 41–10 Example 4.

drop across each load is proportional to the value of the resistance compared to the total resistance. For example, if the resistance is one-half of the total resistance, the voltage drop across that resistance will be one-half of the applied voltage. The sum total of all individual voltage drops equals the applied source voltage.

SERIES CIRCUIT EXAMPLES

Each of the four examples includes solving for the following:

- Total resistance in the circuit
- Current flow (amperes) through the circuit
- Voltage drop across each resistance

Example 1:

● **SEE FIGURE 41–7.**

The unknown in this problem is the value of R_2. The total resistance, however, can be calculated using Ohm's law.

$$R_{Total} = E/I = 12 \text{ volts}/3 \text{ A} = 4 \Omega$$

Because R_1 is 3 ohms and the total resistance is 4 ohms, the value of R_2 is 1 ohm.

Example 2:

● **SEE FIGURE 41–8.**

The unknown in this problem is the value of R_3. The total resistance, however, can be calculated using Ohm's law.

$$R_{Total} = E/I = 12 \text{ volts}/2 \text{ A} = 6 \Omega$$

The total resistance of R_1 (3 ohms) and R_2 (1 ohm) equals 4 ohms so that the value of R_3 is the difference between the total resistance (6 ohms) and the value of the known resistance (4 ohms).

$$6 - 4 = 2 \text{ ohms} = R_3$$

Example 3:

● **SEE FIGURE 41–9.**

The unknown value in this problem is the voltage of the battery. To solve for voltage, use Ohm's law ($E = I \times R$). The "R" in this problem refers to the total resistance (R_T). The total resistance of a series circuit is determined by adding the values of the individual resistors.

$$R_T = 1 \Omega + 1 \Omega + 1 \Omega$$
$$R_T = 3 \Omega$$

Placing the value for the total resistance (3 Ω) into the equation results in a battery voltage of 12 volts.

$$E = 4 \text{ A} \times 3 \Omega$$
$$E = 12 \text{ volts}$$

Example 4:

● **SEE FIGURE 41–10.**

The unknown in this example is the current (amperes) in the circuit. To solve for current, use Ohm's law.

$$I = E/R = 12 \text{ volts}/6 \text{ ohms} = 2 \text{ A}$$

Notice that the total resistance in the circuit (6 ohms) was used in this example, which is the total of the three individual resistors (2 Ω + 2 Ω + 2 Ω = 6 Ω). The current through the circuit is two amperes.

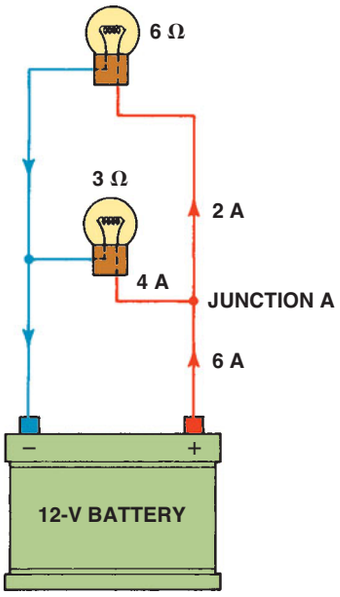


FIGURE 41–11 The amount of current flowing into junction point A equals the total amount of current flowing out of the junction.

PARALLEL CIRCUITS

A **parallel circuit** is a complete circuit that has more than one path for the current. The separate paths which split and meet at junction points are called **branches**, **legs**, or **shunts**. The current flow through each branch or leg varies depending on the resistance in that branch. A break or open in one leg or section of a parallel circuit does not stop the current flow through the remaining legs of the parallel circuit.

KIRCHHOFF'S CURRENT LAW

Kirchhoff's current law (his first law) states: *The current flowing into any junction of an electrical circuit is equal to the current flowing out of that junction.* This first law can be illustrated using Ohm's law, as seen in ● **FIGURE 41–11**. Kirchhoff's law states that the amount of current flowing into junction A will equal the current flowing out of junction A.

Because the 6-ohm leg requires 2 amperes and the 3-ohm resistance leg requires 4 amperes, it is necessary that the wire from the battery to junction A be capable of handling 6 amperes. Also notice that the sum of the current flowing *out* of a junction (2 + 4 = 6 A) is equal to the current flowing *into* the junction (6 A), proving Kirchhoff's current law.

PARALLEL CIRCUIT LAWS

LAW 1 The total resistance of a parallel circuit is always less than that of the smallest-resistance leg. This occurs because not all of the current flows through each leg or branch. With many branches, more current can flow from the battery just as more vehicles can travel on a road with five lanes compared to a road with only one or two lanes.

LAW 2 The voltage is the same for each leg of a parallel circuit.

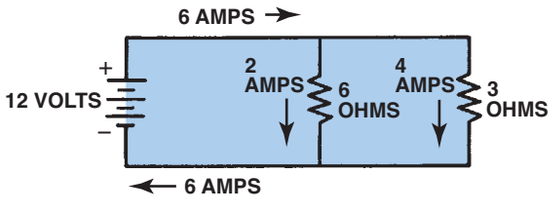


FIGURE 41–12 The current in a parallel circuit splits (divides) according to the resistance in each branch.

TECH TIP

The Path of Least Resistance

There is an old saying that electricity will always take the path of least resistance. This is true, especially if there is a fault such as in the secondary (high-voltage) section of the ignition system. If there is a path to ground that is lower than the path to the spark plug, the high-voltage spark will take the path of least resistance. In a parallel circuit where there is more than one path for the current to flow, most of the current will flow through the branch with the lower resistance. This does not mean that all of the current will flow through the lowest resistance, because the other path does provide a path to ground, and the amount of current flow through the other branches is determined by the resistance and the applied voltage according to Ohm's law.

Therefore, the only place where electricity takes the path of least resistance is in a series circuit where there are not other paths for the current to flow.

LAW 3 The sum of the individual currents in each leg will equal the total current. The amount of current flow through a parallel circuit may vary for each leg depending on the resistance of that leg. The current flowing through each leg results in the same voltage drop (from the power side to the ground side) as for every other leg of the circuit. ● **SEE FIGURE 41–12**.

NOTE: A parallel circuit drops the voltage from source voltage to zero (ground) across the resistance in each leg of the circuit.

DETERMINING TOTAL RESISTANCE IN A PARALLEL CIRCUIT

There are five methods commonly used to determine total resistance in a parallel circuit.

NOTE: Determining the total *resistance* of a parallel circuit is very important in automotive service. Electronic fuel-injector and diesel engine glow plug circuits are two of the most commonly tested circuits where parallel circuit knowledge is required. Also, when installing extra lighting, the technician must determine the proper gauge wire and protection device.

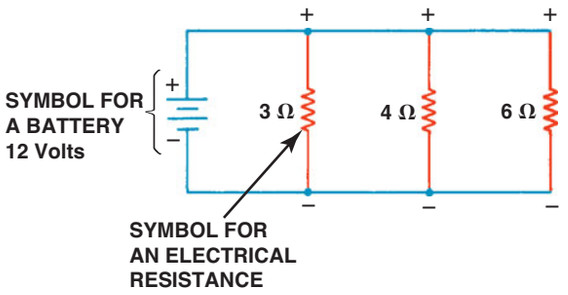


FIGURE 41–13 In a typical parallel circuit, each resistance has power and ground and each leg operates independently of the other legs of the circuit.

METHOD 1 The total *current* (in amperes) can be calculated first by treating each leg of the parallel circuit as a simple circuit. ● **SEE FIGURE 41–13**. Each leg has its own power and ground (−), and therefore, the current through each leg is independent of the current through any other leg.

Current through the 3-Ω resistance =
$$I = E/R = 12\text{ V}/3\ \Omega = 4\text{ A}$$

Current through the 4-Ω resistance =
$$I = E/R = 12\text{ V}/4\ \Omega = 3\text{ A}$$

Current through the 6-Ω resistance =
$$I = E/R = 12\text{ V}/6\ \Omega = 2\text{ A}$$

The total current flowing from the battery is the sum total of the individual currents for each leg. Total current from the battery is, therefore, 9 amperes (4 A + 3 A + 2 A = 9 A).

If **total circuit resistance** (R_T) is needed, Ohm's law can be used to calculate it because voltage (E) and current (I) are now known.

$$R_T = E/I = 12\text{ V}/9\text{ A} = 1.33\ \Omega$$

Note that the total resistance (1.33 Ω) is smaller than that of the smallest-resistance leg of the parallel circuit. This characteristic of a parallel circuit holds true because not all current flows through all resistances as in a series circuit.

Because the current has alternative paths to ground through the various legs of a parallel circuit, as additional resistances (legs) are added to a parallel circuit, the total current from the battery (power source) *increases.*

Additional current can flow when resistances are added in parallel, because each leg of a parallel circuit has its own power and ground and the current flowing through each leg is strictly dependent on the resistance of *that* leg.

METHOD 2 If only two resistors are connected in parallel, the total resistance (R_T) can be found using the formula $R_T = (R_1 \times R_2) / (R_1 + R_2)$. For example, using the circuit in ● **FIGURE 41–14** and substituting 3 ohms for R_1 and 4 amperes for R_2, $R_T = (3 \times 4) / (3 + 4) = 12/7 = 1.7\ \Omega$. Note that the total resistance (1.7 Ω) is smaller than that of the smallest-resistance leg of the circuit.

NOTE: Which resistor is R_1 and which is R_2 is not important. The position in the formula makes no difference in the multiplication and addition of the resistor values.

This formula can be used for more than two resistances in parallel, but only two resistances can be calculated at a time. After solving for R_T for two resistors, use the value of R_T as R_1 and the additional resistance in parallel as R_2.

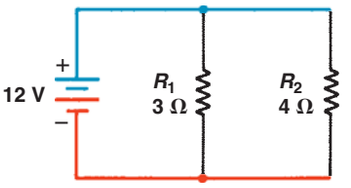


FIGURE 42–14 A schematic showing two resistors in parallel connected to a 12-volt battery.

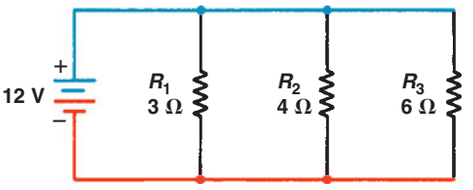


FIGURE 41–15 A parallel circuit with three resistors connected to a 12-volt battery.

Then solve for another R_T. Continue the process for all resistance legs of the parallel circuit. However, note that it might be easier to solve for R_T when there are more than two resistances in parallel by using Method 3 or 4.

METHOD 3 A formula that can be used to find the total resistance for any number of resistances in parallel is $1/R_T = 1/R_1 + 1/R_2 + 1/R_3 + \cdots$

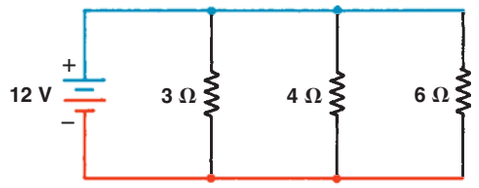
To solve for R_T for the three resistance legs in ● **FIGURE 41–15**, substitute the values of the resistances for R_1, R_2, and R_3: $1/R_T = 1/3 + 1/4 + 1/6$. The fractions cannot be added together unless they all have the same denominator. The lowest common denominator in this example is 12. Therefore, 1/3 becomes 4/12, 1/4 becomes 3/12, and 1/6 becomes 2/12. $1/R_T = 4/12 + 3/12 + 2/12$ or 9/12. Cross multiplying $R_T = 12/9 = 1.33\ \Omega$. Note that the result (1.33 Ω) is the same regardless of the method used (see Method 1). The most difficult part of using this method (besides using fractions) is determining the lowest common denominator, especially for circuits containing a wide range of ohmic values for the various legs. For an easier method using a calculator, see Method 4.

METHOD 4 This method uses an electronic calculator, commonly available at very low cost. Instead of determining the lowest common denominator as in Method 3, one can use the electronic calculator to convert the fractions to decimal equivalents. The memory buttons on most calculators can be used to keep a running total of the fractional values. Use ● **FIGURE 41–16** and calculate the total resistance (R_T) by pushing the indicated buttons on the calculator. Also ● **SEE FIGURE 41–17**.

NOTE: This method can be used to find the total resistance of *any number* of resistances in parallel.

The memory recall (MRC) and equals (=) buttons invert the answer to give the correct value for total resistance (1.33 Ω). The inverse (1/X or X^{-1}) button can be used with the sum (SUM) button on scientific calculators without using the memory button.

METHOD 5 This method can be easily used whenever two or more resistances connected in parallel are of the same value. ● **SEE FIGURE 41–18**. To calculate the total resistance (R_T) of equal-value resistors, divide the number of equal resistors into the value of the resistance. R_T = Value of equal resistance/Number of equal resistances = 12 Ω/4 = 3 Ω.



1 ÷ 3 M+
1 ÷ 4 M+
1 ÷ 6 M+

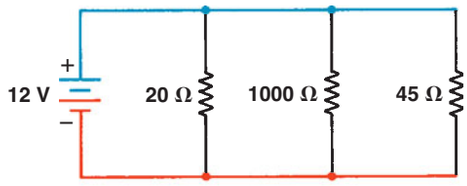
TO SOLVE THIS PARALLEL CIRCUIT PROBLEM FOR R_1 (TOTAL RESISTANCE), PUSH THE EXACT BUTTONS ON AN ELECTRONIC CALCULATOR

NOTE: BE CERTAIN TO PUSH THE = BUTTON. FAILURE TO DO SO WILL RESULT IN INCORRECT ANSWERS WHEN USING MOST CALCULATORS.

÷ M_{RC} =

(ANSWER = 1.3333)

FIGURE 41–16 Using an electronic calculator to determine the total resistance of a parallel circuit.



USE AN ELECTRONIC CALCULATOR TO SOLVE:

R_T = 1 ÷ 20 M+
1 ÷ 1000 M+
1 ÷ 45 M+
1 ÷ M_{RC} =

NOTE:

THE TOTAL RESISTANCE (R_T) MUST BE LESS THAN THE SMALLEST RESISTANCE (LESS THAN 20 Ω IN THIS EXAMPLE).

FIGURE 41–17 Another example of how to use an electronic calculator to determine the total resistance of a parallel circuit. The answer is 13.45 ohms. Notice that the effective resistance of this circuit is less than the resistance of the lowest branch (20 ohms).

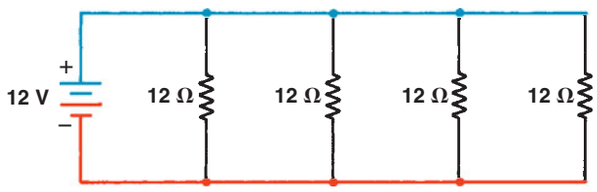


FIGURE 41–18 A parallel circuit containing four 12-ohm resistors. When a circuit has more than one resistor of equal value, the total resistance can be determined by simply dividing the value of the resistance (12 ohms in this example) by the number of equal-value resistors (4 in this example) to get 3 ohms.

NOTE: Since most automotive and light-truck electrical circuits involve multiple use of the same resistance, this method is the most useful. For example, if six additional 12-ohm lights were added to a vehicle, the additional lights would represent just 2 ohms of resistance (12 Ω/6 lights = 2). Therefore, 6 amperes of additional current would be drawn by the additional lights ($I = E/R$ = 12 V/2 Ω = 6 A).

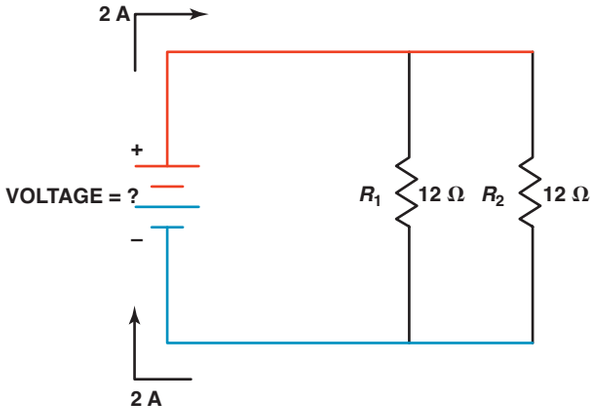


FIGURE 41–19 Example 1.

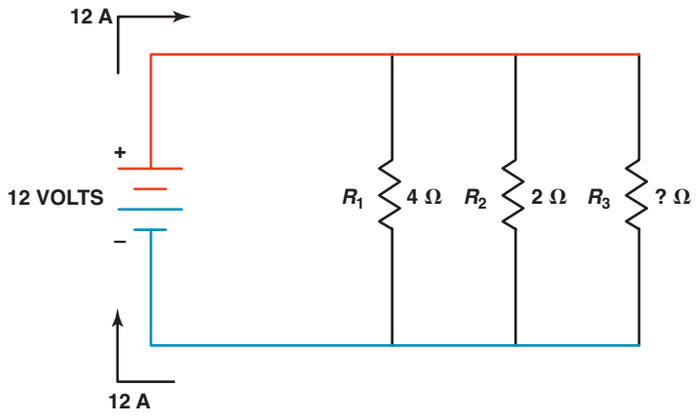


FIGURE 41–20 Example 2.

PARALLEL CIRCUIT EXAMPLES

Each of the four examples includes solving for the following:

- Total resistance
- Current flow (amperes) through each branch as well as total current flow
- Voltage drop across each resistance

Example 1:

● **SEE FIGURE 41–19.**

In this example, the voltage of the battery is unknown and the equation to be used is $E = I \times R$ where R represents the total resistance of the circuit. Using the equation for two resistors in parallel, the total resistance is 6 ohms.

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{12 \times 12}{12 + 12} = \frac{144}{24} = 6\ \Omega$$

Placing the value of the total resistors into the equation results in a value for the battery voltage of 12 volts.

$$E = I \times R$$

$$E = 2\ \text{A} \times 6\ \Omega$$

$$E = 12\ \text{volts}$$

Example 2:

● **SEE FIGURE 41–20.**

In this example, the value of R_3 is unknown. Because the voltage (12 volts) and the current (12 A) are known, it is easier to solve for the unknown resistance by treating each branch or leg as a separate circuit. Using Kirchhoff's law, the total current equals the total current flow

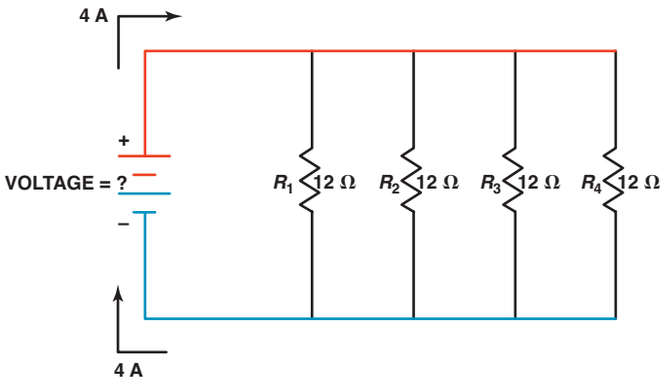


FIGURE 41–21 Example 3.

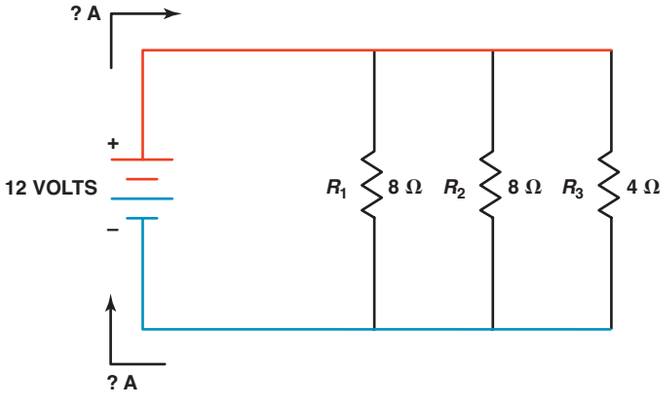


FIGURE 41–22 Example 4.

through each branch. The current flow through R_1 is 3 A ($I = E/R$ = 12 V/4 Ω = 3 A) and the current flow through R_2 is 6 A ($I = E/R$ = 12 V/2 Ω = 6 A). Therefore, the total current through the two known branches equals 9 A (3 A + 6 A = 9 A). Because there are 12 A leaving and returning to the battery, the current flow through R_3 must be 3 A (12 A − 9 A = 3 A). The resistance must therefore be 4 Ω because the current through the unknown resistance is 3 A ($I = E/R$ = 12 V/4 Ω = 3 A).

Example 3:

● **SEE FIGURE 41–21**.

In this example, the voltage of the battery is unknown. The equation to solve for voltage according to Ohm's law is:

$$E = I \times R$$

The *R* in this equation refers to the total resistance. Because there are four resistors of equal value, the total can be determined by the equation:

$$R_{Total} = \text{Value of Resistors/Number of Equal Resistors}$$
$$= 12\ \Omega/4 = 3\ \Omega$$

Inserting the value of the total resistance of the parallel circuit (3 Ω) into Ohm's law results in a battery voltage of 12 V.

$$E = 4\ \text{A} \times 3\ \Omega$$
$$E = 12\ \text{V}$$

Example: 4

● **SEE FIGURE 41–22**.

The unknown is the amount of current in the circuit. The Ohm's law equation for determining current is:

$$I = E/R$$

The *R* represents the total resistance. Because there are two equal resistances (8 Ω), these two can be replaced by one resistance of 4 Ω (R_{Total} = Value/Number = 8 Ω/2 × 4 Ω).

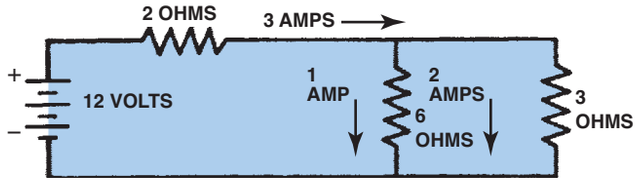


FIGURE 41–23 A series-parallel circuit.

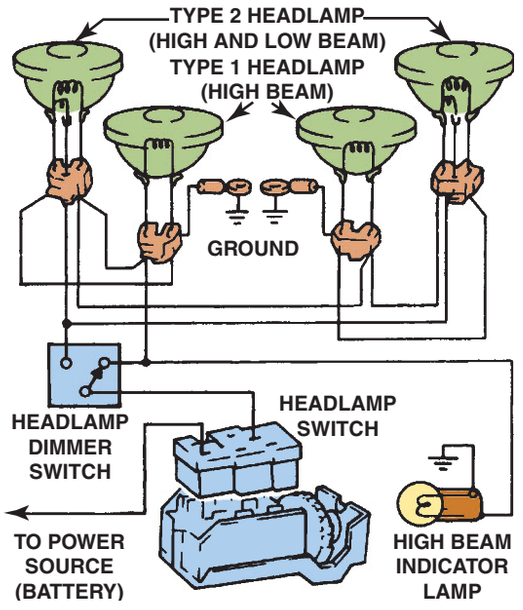


FIGURE 41–24 This complete headlight circuit with all bulbs and switches is a series-parallel circuit.

The total resistance of this parallel circuit containing two 8-ohm resistors and one 4-ohm resistor is 2 ohms. (Two 8 ohm resistors in parallel equals one four ohm. Then you have two four ohm resistors in parallel which equals 2 Ohms) The current flow from the battery is then calculated to be 6 A.

$$I = E/R = 12\ \text{V}/2\ \Omega = 6\ \text{A}$$

SERIES-PARALLEL CIRCUITS

Series-parallel circuits are a combination of series and parallel segments in one complex circuit. A series-parallel circuit is also called a **compound** or a **combination circuit**. Many automotive circuits include sections that are in parallel and in series.

A series-parallel circuit includes both parallel loads or resistances, plus additional loads or resistances that are electrically connected in series. There are two basic types of series-parallel circuits.

- A circuit where the load is in series with other loads in parallel. ● **SEE FIGURE 41–23**. An example of this type of series-parallel circuit is a dash light dimming circuit. The variable resistor is used to limit current flow to the dash light bulbs, which are wired in parallel.
- A circuit where a parallel circuit contains resistors or loads which are in series with one or more branches. A headlight and starter circuit is an example of this type of series-parallel circuit. A headlight switch is usually connected in series with a dimmer switch and in parallel with the dash light dimmer resistors. The headlights are also connected in parallel along with the taillights and side marker lights. ● **SEE FIGURE 41–24**.

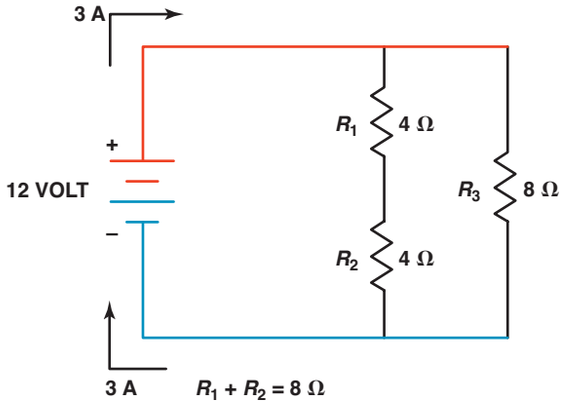


FIGURE 41–25 Solving a series-parallel circuit problem.

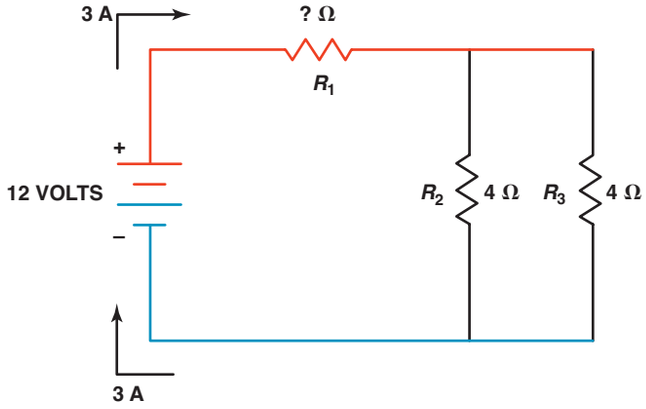


FIGURE 41–26 Example 1.

SERIES-PARALLEL CIRCUIT FAULTS If a conventional parallel circuit, such as a taillight circuit, had an electrical fault that increased the resistance in one branch of the circuit, then the amount of current flow through that one branch will be reduced. The added resistance, due to corrosion or other similar cause, would create a voltage drop. As a result of this drop in voltage, a lower voltage would be applied and the bulb in the taillight would be dimmer than normal. Because the brightness of the bulb depends on the voltage and current applied, the lower voltage and current would cause the bulb to be dimmer than normal. If, however, the added resistance occurred in a part of the circuit that fed both taillights, then both taillights would be dimmer than normal. In this case, the added resistance created a series-parallel circuit that was originally just a simple parallel circuit.

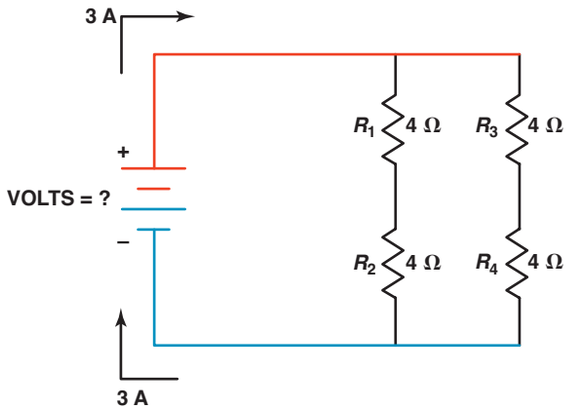


FIGURE 41–27 Example 2.

SOLVING SERIES-PARALLEL CIRCUIT PROBLEMS

The key to solving series-parallel circuit problems is to combine or simplify as much as possible. For example, if there are two loads or resistances in series within a parallel branch or leg, then the circuit can be made simpler if the two are first added together before attempting to solve the parallel section. ● **SEE FIGURE 41–25**.

SERIES-PARALLEL CIRCUIT EXAMPLES

Each of the four examples includes solving for the following.

- Total resistance
- Current flow (amperes) through each branch, as well as total current flow
- Voltage drop across each resistance

Example 1:

● **SEE FIGURE 41–26**.

The unknown resistor is in series with the other two resistances, which are connected in parallel. The Ohm's law equation to determine resistance is:

$$R = E/I = 12 \text{ V}/3 \text{ A} = 4 \Omega$$

The total resistance of the circuit is therefore 4 ohms, and the value of the unknown can be determined by subtracting the value of the two resistors that are connected in parallel. The parallel branch resistance is 2 Ω.

$$R_T = \frac{4 \times 4}{4 + 4} = \frac{16}{8} = 2 \Omega$$

The value of the unknown resistance is therefore 2 Ω.

$$\text{Total } R = 4 \Omega - 2 \Omega = 2 \Omega$$

Example 2:

● **SEE FIGURE 41–27**.

The unknown unit in this circuit is the voltage of the battery. The Ohm's law equation is:

$$E = I \times R$$

Before solving the problem, the total resistance must be determined. Because each branch contains two 4-ohm resistors in series, the value in each branch can be added to help simplify the circuit. By adding the resistors in each branch together, the parallel circuit now consists of two 8-ohm resistors.

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{8 \times 8}{8 + 8} = \frac{64}{16} = 4 \Omega$$

Inserting the value for the total resistance into the Ohm's law equation results in a value of 12 volts for the battery voltage.

$$E = I \times R$$

$$E = 3 \text{ A} \times 4 \Omega$$

$$E = 12 \text{ volts}$$

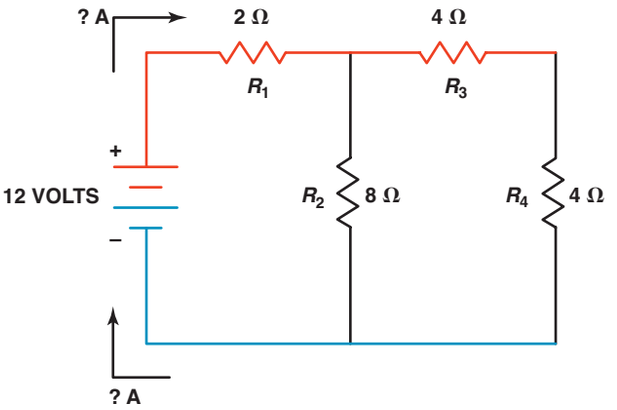


FIGURE 41–28 Example 3.

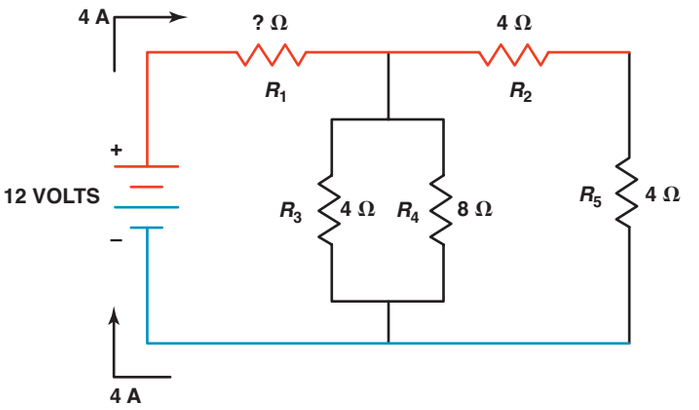


FIGURE 41–29 Example 4.

Example 3:

● **SEE FIGURE 41–28.**

In this example, the total current through the circuit is unknown. The Ohm's law equation to solve for it is:

$$I = E/R$$

The total resistance of the parallel circuit must be determined before the equation can be used to solve for current (amperes). To solve for total resistance, the circuit can first be simplified by adding R_3 and R_4 together because these two resistors are in series in the same branch of the parallel circuit. To simplify even more, the resulting parallel section of the circuit, now containing two 8-ohm resistors in parallel, can be replaced with one 4-ohm resistor.

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{8 \times 8}{8 + 8} = \frac{64}{16} = 4\ \Omega$$

With the parallel branches now reduced to just one 4-ohm resistor, this can be added to the 2-ohm (R_1) resistor because it is in series, creating a total circuit resistance of 6 ohms. Now the current flow can be determined from Ohm's law:

$$I = E/R = 12\ \text{V}/6\ \Omega = 2\ \text{A}$$

Example 4:

● **SEE FIGURE 41–29.**

In this example, the value of resistor R_1 is unknown. Using Ohm's law, the total resistance of the circuit is 3 ohms.

$$R = E/I = 12\ \text{V}/4\ \text{A} = 3\ \Omega$$

However, knowing the total resistance is not enough to determine the value of R_1. To simplify the circuit, R_2 and R_5 can combine to create a parallel branch resistance value of 8 ohms because they are in series. To simplify even further, the two 8-ohm branches can be reduced to one branch of 4 ohms.

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{8 \times 8}{8 + 8} = \frac{64}{16} = 4\ \Omega$$

Now the circuit has been simplified to one resistor in series (R_1) with two branches with 4 ohms in each branch. These two branches can be reduced to the equal of one 2-ohm resistor.

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{4 \times 4}{4 + 4} = \frac{16}{8} = 2\ \Omega$$

Now the circuit includes just one 2-ohm resistor plus the unknown R_1. Because the total resistance is 3 ohms, the value of R_1 must be 1 ohm.

$$3\ \Omega - 2\ \Omega = 1\ \Omega$$

REVIEW QUESTIONS

1. What is Kirchhoff's voltage law?
2. What would current (amperes) do if the voltage were doubled in a circuit?
3. What would current (amperes) do if the resistance in the circuit were doubled?
4. What is the formula for voltage drop?
5. Why is the total resistance of a parallel circuit less than the smallest resistance?
6. Why are parallel circuits (instead of series circuits) used in most automotive applications?
7. What does Kirchhoff's current law state?
8. What would be the effect of an open circuit in one leg of a parallel portion of a series-parallel circuit?
9. What would be the effect of an open circuit in a series portion of a series-parallel circuit?

CHAPTER QUIZ

1. The amperage in a series circuit is _____.
   - **a.** The same anywhere in the circuit
   - **b.** Varies in the circuit due to the different resistances
   - **c.** High at the beginning of the circuit and decreases as the current flows through the resistance
   - **d.** Always less returning to the battery than leaving the battery
2. The sum of the voltage drops in a series circuit equals the _____.
   - **a.** Amperage
   - **b.** Resistance
   - **c.** Source voltage
   - **d.** Wattage

3. If the resistance and the voltage are known, what is the formula for finding the current (amperes)?
   a. $E = I \times R$ **c.** $R = E \times I$
   b. $I = E \times R$ **d.** $I = E/R$

4. A series circuit has three resistors of 4 ohms each. The voltage drop across each resistor is 4 volts. Technician A says that the source voltage is 12 volts. Technician B says that the total resistance is 18 ohms. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B

5. If a 12-volt battery is connected to a series circuit with three resistors of 2 ohms, 4 ohms, and 6 ohms, how much current will flow through the circuit?
   a. 1 amp **c.** 3 amp
   b. 2 amp **d.** 4 amp

6. A series circuit has two 10-ohm bulbs. A third bulb is added in series. Technician A says that the three bulbs will be dimmer than when only two bulbs were in the circuit. Technician B says that the current in the circuit will increase. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B

7. Technician A says that the sum of the voltage drops in a series circuit should equal the source voltage. Technician B says that the current (amperes) varies depending on the value of the resistance in a series circuit. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B

8. Two bulbs are connected in parallel to a 12-volt battery. One bulb has a resistance of 6 ohms and the other bulb has a resistance of 2 ohms. Technician A says that only the 2-ohm bulb will light because all of the current will flow through the path with the least resistance and no current will flow through the 6-ohm bulb. Technician B says that the 6-ohm bulb will be dimmer than the 2-ohm bulb. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

9. Calculate the total resistance and current in a parallel circuit with three resistors of 4 Ω, 8 Ω, and 16 Ω, using any one of the five methods (calculator suggested). What is the total resistance and current?
   a. 27 ohms (0.4 ampere)
   b. 14 ohms (0.8 ampere)
   c. 4 ohms (3.0 amperes)
   d. 2.3 ohms (5.3 amperes)

10. A vehicle has four parking lights all connected in parallel and one of the bulbs burns out. Technician A says that this could cause the parking light circuit fuse to blow (open). Technician B says that it would decrease the current in the circuit. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

chapter 42

CIRCUIT TESTERS AND DIGITAL METERS

OBJECTIVES: **After studying Chapter 42, the reader should be able to:** • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "A" (General Electrical/Electronic System Diagnosis). • Discuss how to safely use a fused jumper wire, a test light, and a logic probe. • Explain how to set up and use a digital meter to read voltage, resistance, and current. • Explain meter terms and readings. • Interpret meter readings and compare to factory specifications. • Discuss how to properly and safely use meters.

KEY TERMS: AC/DC clamp-on DMM 450 • Continuity light 445 • DMM 446 • DVOM 446 • High-impedance test meter 446 • IEC 454 • Inductive ammeter 450 • Kilo (k) 451 • LED test light 445 • Logic probe 446 • Mega (M) 451 • Meter accuracy 455 • Meter resolution 454 • Milli (m) 451 • OL 448 • RMS 453 • Test light 445

FUSED JUMPER WIRE

DEFINITION A fused jumper wire is used to check a circuit by bypassing the switch or to provide a power or ground to a component. A fused jumper wire, also called a test lead, can be purchased or made by the service technician. ● **SEE FIGURE 42–1**.

It should include the following features.

- **Fused.** A typical fused jumper wire has a blade-type fuse that can be easily replaced. A 10 ampere fuse (red color) is often the value used.
- **Alligator clip ends.** Alligator clips on the ends allow the fused jumper wire to be clipped to a ground or power source while the other end is attached to the power side or ground side of the unit being tested.
- **Good-quality insulated wire.** Most purchased jumper wire is about 14 gauge stranded copper wire with a flexible rubberized insulation to allow it to move easily even in cold weather.

USES OF A FUSED JUMPER WIRE A fused jumper wire can be used to help diagnose a component or circuit by performing the following procedures.

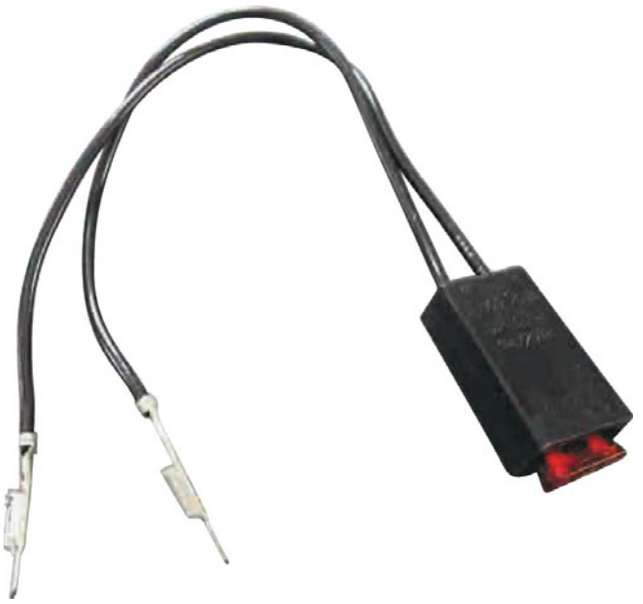


FIGURE 42–1 A technician-made fused jumper lead, which is equipped with a red 10 ampere fuse. This fused jumper wire uses terminals for testing circuits at a connector instead of alligator clips.

- **Supply power or ground.** If a component, such as a horn, does not work, a fused jumper wire can be used to supply a temporary power and/or ground. Start by unplugging the electrical connector from the device and connect a fused jumper lead to the power terminal. Another fused jumper wire may be needed to provide the ground. If the unit works, the problem is in the power side or ground side circuit.

CAUTION: Never use a fused jumper wire to bypass any resistance or load in the circuit. The increased current flow could damage the wiring and could blow the fuse on the jumper lead.

TEST LIGHTS

NONPOWERED TEST LIGHT

A 12 volt test light is one of the simplest testers that can be used to detect electricity. A **test light** is simply a light bulb with a probe and a ground wire attached. ● **SEE FIGURE 42–2**.

It is used to detect battery voltage potential at various test points. Battery voltage cannot be seen or felt, and can be detected only with test equipment.

The ground clip is connected to a clean ground on either the negative terminal of the battery or a clean metal part of the body and the probe touched to terminals or components. If the test light comes on, this indicates that voltage is available. ● **SEE FIGURE 42–3**.

A purchased test light could be labeled a "12 volt test light." Do not purchase a test light designed for household current (110 or 220 volts), as it will not light with 12 to 14 volts.

USES OF A 12 VOLT TEST LIGHT

A 12 volt test light can be used to check the following:

- **Electrical power.** If the test light lights, then there is power available. It will not, however, indicate the voltage level or if there is enough current available to operate an electrical load. This indicates only that there is enough voltage and current to light the test light (about 0.25 A).

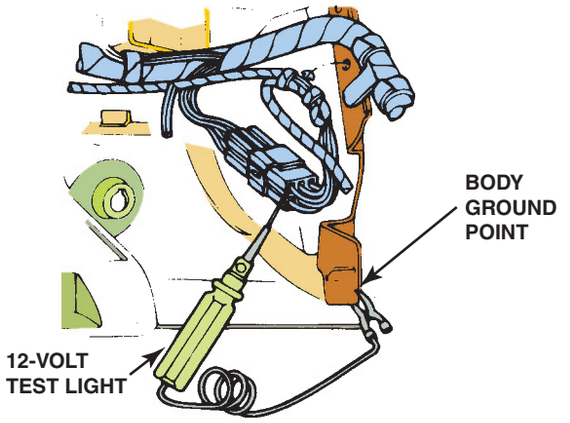


FIGURE 42–2 A 12 volt test light is attached to a good ground while probing for power.

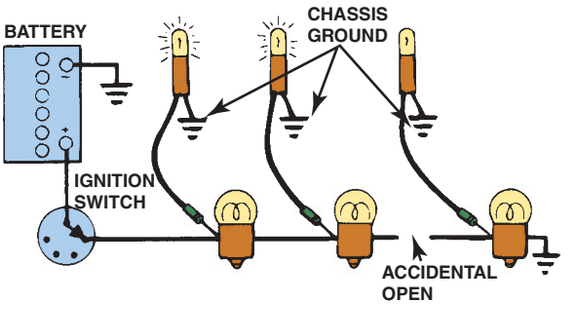


FIGURE 42–3 A test light can be used to locate an open in a circuit. Note that the test light is grounded at a different location than the circuit itself.

- **Grounds.** A test light can be used to check for grounds by attaching the clip of the test light to the positive terminal of the battery or any 12 volt electrical terminal. The tip of the test light can then be used to touch the ground wire. If there is a ground connection, the test light will light.

CONTINUITY TEST LIGHTS

A **continuity light** is similar to a test light but includes a battery for self-power. A continuity light illuminates whenever it is connected to both ends of a wire that has continuity or is not broken. ● **SEE FIGURE 42–4**.

CAUTION: The use of a self-powered (continuity) test light is not recommended on any electronic circuit, because a continuity light contains a battery and applies voltage; therefore, it may harm delicate electronic components.

HIGH-IMPEDANCE TEST LIGHT

A high-impedance test light has a high internal resistance and therefore draws very low current in order to light. High-impedance test lights are safe to use on computer circuits because they will not affect the circuit current in the same way as conventional 12 volt test lights when connected to a circuit. There are two types of high-impedance test lights.

- Some test lights use an electronic circuit to limit the current flow, to avoid causing damage to electronic devices.
- An **LED test light** uses a light-emitting diode (LED) instead of a standard automotive bulb for a visual indication of voltage. An LED test light requires only about 25 milliamperes (0.025 ampere) to light; therefore, it can be used on electronic circuits as well as on standard circuits.

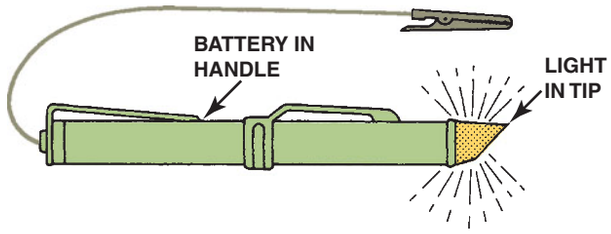


FIGURE 42–4 A continuity light should not be used on computer circuits because the applied voltage can damage delicate electronic components or circuits.

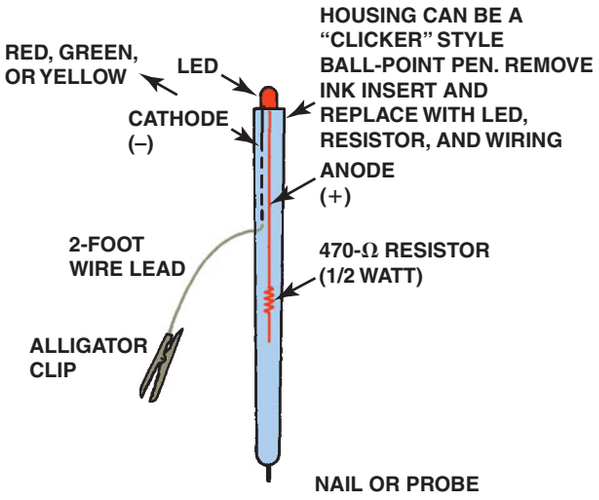


FIGURE 42–5 An LED test light can be easily made using low cost components and an old ink pen. With the 470 ohm resistor in series with the LED, this tester only draws 0.025 ampere (25 milliamperes) from the circuit being tested. This low current draw helps assure the technician that the circuit or component being tested will not be damaged by excessive current flow.

● **SEE FIGURE 42–5** for construction details for a homemade LED test light.

LOGIC PROBE

PURPOSE AND FUNCTION

A **logic probe** is an electronic device that lights up a red (usually) LED if the probe is touched to battery voltage. If the probe is touched to ground, a green (usually) LED lights. ● **SEE FIGURE 42–6**.

A logic probe can "sense" the difference between high- and low-voltage levels, which explains the name *logic.*

- A typical logic probe can also light another light (often amber color) when a change in voltage levels occurs.
- Some logic probes will flash the red light when a pulsing voltage signal is detected.
- Some will flash the green light when a pulsing ground signal is detected.

This feature is helpful when checking for a variable voltage output from a computer or ignition sensor.

USING A LOGIC PROBE

A logic probe must first be connected to a power and ground source such as the vehicle battery. This connection powers the probe and gives it a reference low (ground).

Most logic probes also make a distinctive sound for each high- and low-voltage level. This makes troubleshooting easier when probing connectors or component terminals. A sound (usually a beep) is heard when the probe tip is touched to a changing voltage source. The changing voltage also usually lights the pulse light on the logic probe. Therefore, the probe can be used to check components such as:

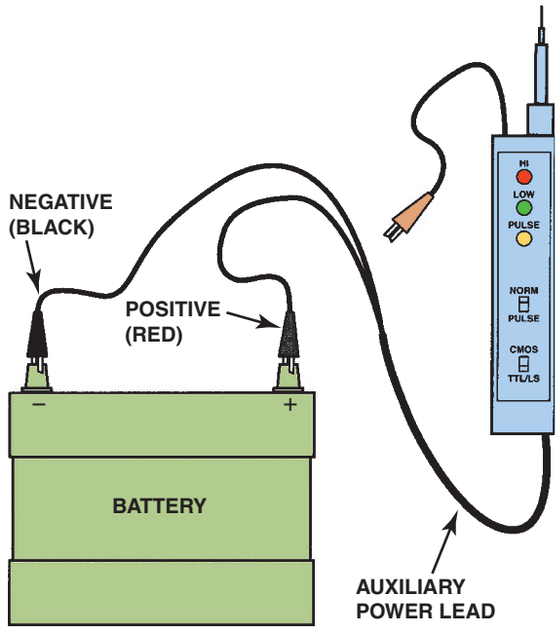


FIGURE 42–6 A logic probe connected to the vehicle battery. When the tip probe is connected to a circuit, it can check for power, ground, or a pulse.

- Pickup coils
- Hall-effect sensors
- Magnetic sensors

DIGITAL MULTIMETERS

TERMINOLOGY

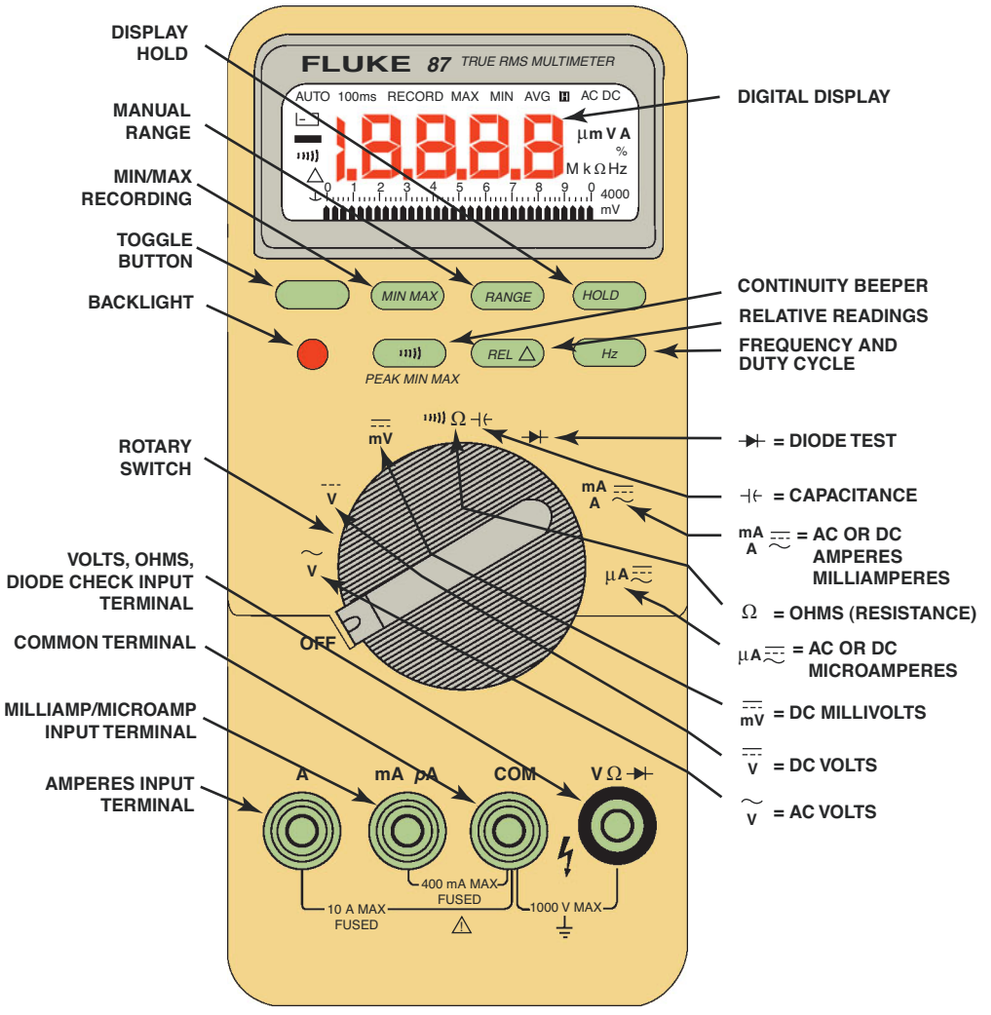
Digital multimeter (DMM) and **digital volt-ohm-meter (DVOM)** are terms commonly used for electronic **high-impedance test meters**. *High impedance* means that the electronic internal resistance of the meter is high enough to prevent excessive current draw from any circuit being tested. Most meters today have a minimum of 10 million ohms (10 megohms) of resistance. This high internal resistance between the meter leads is present only when measuring volts. The high resistance in the meter itself reduces the amount of current flowing through the meter when it is being used to measure voltage, leading to more accurate test results because the meter does not change the load on the circuit. High-impedance meters are required for measuring computer circuits.

CAUTION: Analog (needle-type) meters are almost always lower than 10 megohms and should not be used to measure any computer or electronic circuit. Connecting an analog meter to a computer circuit could damage the computer or other electronic modules.

A high-impedance meter can be used to measure any automotive circuit within the ranges of the meter. ● **SEE FIGURE 42–7**.

The common abbreviations for the units that many meters can measure are often confusing. ● **SEE CHART 42–1** for the most commonly used symbols and their meanings.

FIGURE 42–7 Typical digital multimeter. The black meter lead always is placed in the COM terminal. The red meter test lead should be in the volt-ohm terminal except when measuring current in amperes.



SYMBOL	MEANING
AC	Alternating current or voltage
DC	Direct current or voltage
V	Volts
mV	Millivolts (1/1,000 volts)
A	Ampere (amps), current
mA	Milliampere (1/1,000 amps)
%	Percent (for duty cycle readings only)
Ω	Ohms, resistance
kΩ	Kilohm (1,000 ohms), resistance
MΩ	Megohm (1,000,000 ohms), resistance
Hz	Hertz (cycles per second), frequency
kHz	Kilohertz (1,000 cycles/sec.), frequency
Ms	Milliseconds (1/1,000 sec.) for pulse width measurements

CHART 42–1

Common symbols and abbreviations used on digital meters.

MEASURING VOLTAGE

A voltmeter measures the *pressure* or potential of electricity in units of volts. A voltmeter is connected to a circuit in parallel. Voltage can be measured by selecting either AC or DC volts.



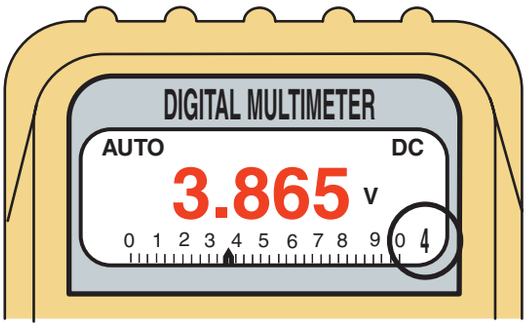
FIGURE 42–8 Typical digital multimeter (DMM) set to read DC volts.

- **DC volts (DCV).** This setting is the most common for automotive use. Use this setting to measure battery voltage and voltage to all lighting and accessory circuits.
- **AC volts (ACV).** This setting is used to check for unwanted AC voltage from alternators and some sensors.
- **Range.** The range is automatically set for most meters but can be manually ranged if needed.

● **SEE FIGURES 42–8 AND 42–9.**

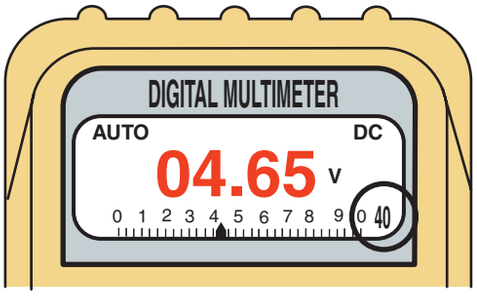
MEASURING RESISTANCE

An ohmmeter measures the resistance in ohms of a component or circuit section when no current is flowing through the circuit. An ohmmeter contains a battery (or other



BECAUSE THE SIGNAL READING IS BELOW 4 VOLTS, THE METER AUTORANGES TO THE 4-VOLT SCALE. IN THE 4-VOLT SCALE, THIS METER PROVIDES THREE DECIMAL PLACES.

(a)



WHEN THE VOLTAGE EXCEEDED 4 VOLTS, THE METER AUTORANGES INTO THE 40-VOLT SCALE. THE DECIMAL POINT MOVES ONE PLACE TO THE RIGHT LEAVING ONLY TWO DECIMAL PLACES.

(b)

FIGURE 42–9 A typical autoranging digital multimeter automatically selects the proper scale to read the voltage being tested. The scale selected is usually displayed on the meter face. (a) Note that the display indicates "4," meaning that this range can read up to 4 volts. (b) The range is now set to the 40 volt scale, meaning that the meter can read up to 40 volts on the scale. Any reading above this level will cause the meter to reset to a higher scale. If not set on autoranging, the meter display would indicate OL if a reading exceeds the limit of the scale selected.

power source) and is connected in series with the component or wire being measured. When the leads are connected to a component, current flows through the test leads and the difference in voltage (voltage drop) between the leads is measured as resistance. Note the following facts about using an ohmmeter.

- Zero ohms on the scale means that there is no resistance between the test leads, thus indicating continuity or a continuous path for the current to flow in a closed circuit.
- Infinity means no connection, as in an open circuit.
- Ohmmeters have no required polarity even though red and black test leads are used for resistance measurement.

CAUTION: The circuit must be electrically open with no current flowing when using an ohmmeter. If current is flowing when an ohmmeter is connected, the reading will be incorrect and the meter can be destroyed.

Different meters have different ways of indicating infinity resistance, or a reading higher than the scale allows. Examples of an over limit display include:

- **OL**, meaning **over limit** or overload
- Flashing or solid number 1
- Flashing or solid number 3 on the left side of the display
- Flashing or solid number 4 on the display.

Check the meter instructions for the exact display used to indicate an open circuit or over range reading. ● **SEE FIGURES 42–10 AND 42–11**.

To summarize, open and zero readings are as follows:

0.00 Ω = Zero resistance (component or circuit has continuity)

OL = An open circuit or reading is higher than the scale selected (no current flows)



FIGURE 42–10 Using a digital multimeter set to read ohms (Ω) to test this light bulb. The meter reads the resistance of the filament.

? FREQUENTLY ASKED QUESTION

How Much Voltage Does an Ohmmeter Apply?

Most digital meters that are set to measure ohms (resistance) apply 0.3 to 1 volt to the component being measured. The voltage comes from the meter itself to measure the resistance. Two things are important to remember about an ohmmeter.

1. The component or circuit must be disconnected from any electrical circuit while the resistance is being measured.
2. Because the meter itself applies a voltage (even though it is relatively low), a meter set to measure ohms can damage electronic circuits. Computer or electronic chips can be easily damaged if subjected to only a few milliamperes of current, similar to the amount an ohmmeter applies when a resistance measurement is being performed.

MEASURING AMPERES

An ammeter measures the flow of *current* through a complete circuit in units of amperes. The ammeter has to be installed in the circuit (in series) so that it can measure all the current flow in that circuit, just as a water flow meter would measure the amount of water flow (cubic feet per minute, for example). ● **SEE FIGURE 42–12**.

CAUTION: An ammeter must be installed in series with the circuit to measure the current flow in the circuit. If a meter set to read amperes is connected in parallel, such as across a battery, the meter or the leads may be destroyed, or the fuse will blow, by the current available across the battery. Some digital multimeters (DMMs) beep if the unit selection does not match the test lead connection on the meter. However, in a noisy shop, this beep sound may be inaudible.

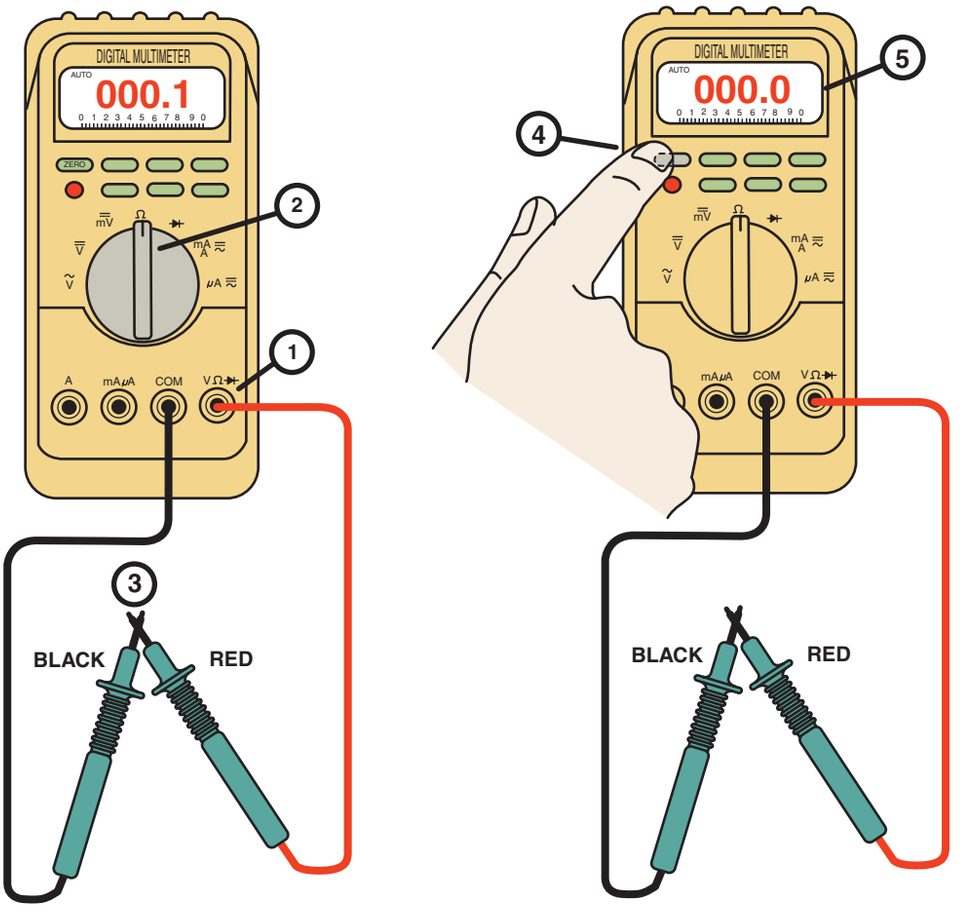


FIGURE 42–11 Many digital multimeters can have the display indicate zero to compensate for test lead resistance. (1) Connect leads in the V Ω and COM meter terminals. (2) Select the Ω scale. (3) Touch the two meter leads together. (4) Push the "zero" or "relative" button on the meter. (5) The meter display will now indicate zero ohms of resistance.

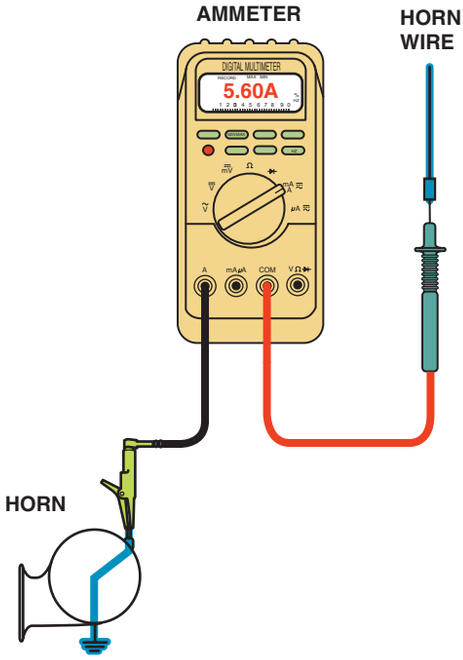


FIGURE 42–12 Measuring the current flow required by a horn requires that the ammeter be connected to the circuit in series and the horn button be depressed by an assistant.

Digital meters require that the meter leads be moved to the ammeter terminals. Most digital meters have an ampere scale that can accommodate a maximum of 10 amperes. See the Tech Tip, "Fuse Your Meter Leads!"

TECH TIP

Fuse Your Meter Leads!

Most digital meters include an ammeter capability. When reading amperes, the leads of the meter must be changed from volts or ohms (V or Ω) to amperes (A), milliamperes (mA), or microamperes (μA).

A common problem may then occur the next time voltage is measured. Although the technician may switch the selector to read volts, often the leads are not switched back to the volt or ohm position. Because the ammeter lead position results in zero ohms of resistance to current flow through the meter, the meter or the fuse inside the meter will be destroyed if the meter is connected to a battery. Many meter fuses are expensive and difficult to find.

To avoid this problem, simply solder an inline 10 ampere blade-fuse holder into one meter lead. ● **SEE FIGURE 42–13**.

Do not think that this technique is for beginners only. Experienced technicians often get in a hurry and forget to switch the lead. A blade fuse is faster, easier, and less expensive to replace than a meter fuse or the meter itself. Also, if the soldering is done properly, the addition of an inline fuse holder and fuse does not increase the resistance of the meter leads. All meter leads have some resistance. If the meter is measuring very low resistance, touch the two leads together and read the resistance (usually no more than 0.2 ohm). Simply subtract the resistance of the leads from the resistance of the component being measured.

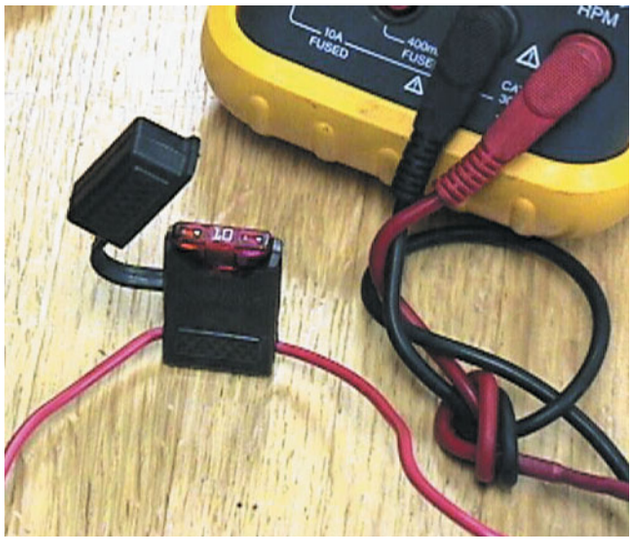


FIGURE 42–13 Note the blade-type fuse holder soldered in series with one of the meter leads. A 10 ampere fuse helps protect the internal meter fuse (if equipped) and the meter itself from damage that may result from excessive current flow if accidentally used incorrectly.

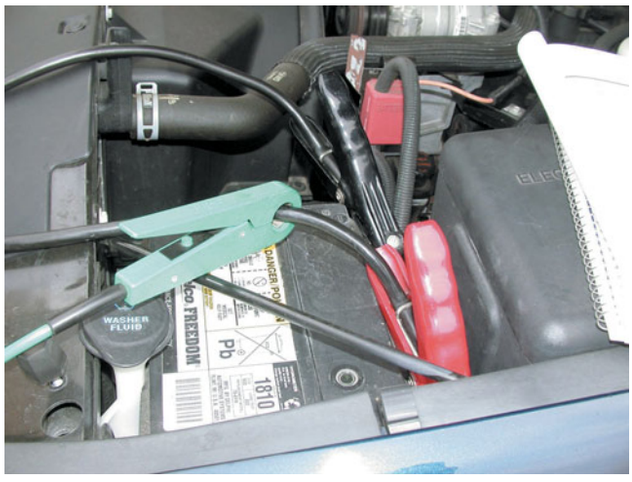


FIGURE 42–14 An inductive ammeter clamp is used with all starting and charging testers to measure the current flow through the battery cables.

FREQUENTLY ASKED QUESTION

What Does "CE" Mean on Many Meters?

The "CE" means that the meter meets the newest European Standards and the letters CE stands for a French term for "Conformite' Europeenne" meaning European Conformity in French.

INDUCTIVE AMMETERS

OPERATION **Inductive ammeters** do not make physical contact with the circuit. They measure the strength of the magnetic field surrounding the wire carrying the current, and use a Hall-effect sensor to measure current. The Hall-effect sensor detects the strength of the magnetic field that surrounds the wire carrying an electrical current. ● **SEE FIGURE 42–14**.



FIGURE 42–15 A typical mini clamp-on-type digital multimeter. This meter is capable of measuring alternating current (AC) and direct current (DC) without requiring that the circuit be disconnected to install the meter in series. The jaws are simply placed over the wire and current flow through the circuit is displayed.

This means that the meter probe surrounds the wire(s) carrying the current and measures the strength of the magnetic field that surrounds any conductor carrying a current.

AC/DC CLAMP-ON DIGITAL MULTIMETERS An **AC/DC clamp-on digital multimeter (DMM)** is a useful meter for automotive diagnostic work. ● **SEE FIGURE 42–15**.

The major advantage of the clamp-on-type meter is that there is no need to break the circuit to measure current (amperes). Simply clamp the jaws of the meter around the power lead(s) or ground lead(s) of the component being measured and read the display. Most clamp-on meters can also measure alternating current, which is helpful in the diagnosis of an alternator problem. Volts, ohms, frequency, and temperature can also be measured with the typical clamp-on DMM, but use conventional meter leads. The inductive clamp is only used to measure amperes.

DIODE CHECK, PULSE WIDTH, AND FREQUENCY

DIODE CHECK Diode check is a meter function that can be used to check diodes including light-emitting diodes (LEDs).

The meter is able to text diodes by way of the following:

- The meter applies roughly a 3 volt DC signal to the text leads.
- The voltage is high enough to cause a diode to work and the meter will display:
  1. 0.4 to 0.7 volt when testing silicon diodes such as found in alternators
  2. 1.5 to 2.3 volts when testing LEDs such as found in some lighting applications

PULSE WIDTH Pulse width is the amount of time in a percentage that a signal is on compared to being off.

- 100% pulse width indicates that a device is being commanded on all of the time.
- 50% pulse width indicates that a device is being commanded on half of the time.

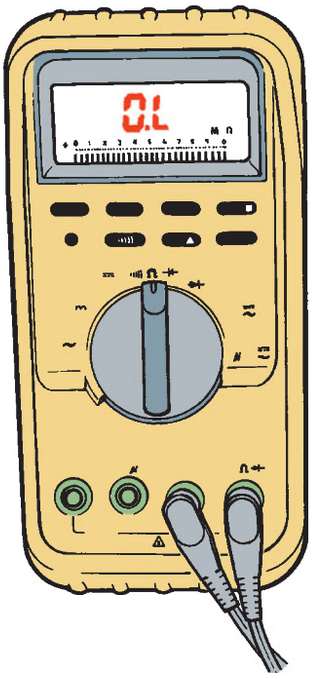
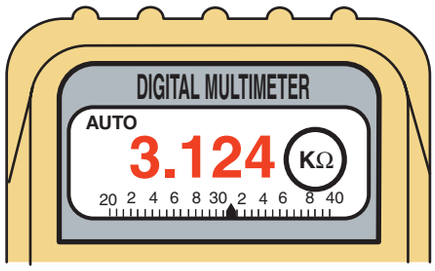


FIGURE 42–16 Typical digital multimeter showing OL (over limit) on the readout with the ohms (Ω) unit selected. This usually means that the unit being measured is open (infinity resistance) and has no continuity.



THE SYMBOL ON THE RIGHT SIDE OF THE DISPLAY INDICATES WHAT RANGE THE METER HAS BEEN SET TO READ.

Ω = OHMS

IF THE ONLY SYMBOL ON THE DISPLAY IS THE OHMS SYMBOL, THE READING ON THE DISPLAY IS EXACTLY THE RESISTANCE IN OHMS.

KΩ = KILOHMS = OHMS TIMES 1000

A "K" IN FRONT OF THE OHMS SYMBOL MEANS "KILOHMS"; THE READING ON THE DISPLAY IS IN KILOHMS. YOU HAVE TO MULTIPLY THE READING ON THE DISPLAY BY 1000 TO GET THE RESISTANCE IN OHMS.

MΩ = MEGOHMS = OHMS TIMES 1,000,000

A "M" IN FRONT OF THE OHMS SYMBOL MEANS "MEGOHMS"; THE READING ON THE DISPLAY IS IN MEGOHMS. YOU HAVE TO MULTIPLY THE READING ON THE DISPLAY BY 1,000,000 TO GET THE RESISTANCE IN OHMS.

FIGURE 42–17 Always look at the meter display when a measurement is being made, especially if using an autoranging meter.

TECH TIP

Over Limit Display Does Not Mean the Meter Is Reading "Nothing"

The meaning of the over limit display on a digital meter often confuses beginning technicians. When asked what the meter is reading when an over limit (OL) is displayed on the meter face, the response is often, "Nothing." Many meters indicate *over limit* or *over load,* which simply means that the reading is over the maximum that can be displayed for the selected range. For example, the meter will display OL if 12 volts are being measured but the meter has been set to read a maximum of 4 volts.

Autoranging meters adjust the range to match what is being measured. Here OL means a value higher than the meter can read (unlikely on the voltage scale for automobile usage), or infinity when measuring resistance (ohms). Therefore, OL means infinity when measuring resistance or an open circuit is being indicated. The meter will read 00.0 if the resistance is zero, so "nothing" in this case indicates continuity (zero resistance), whereas OL indicates infinity resistance. Therefore, when talking with another technician about a meter reading, make sure you know exactly what the reading on the face of the meter means. Also be sure that you are connecting the meter leads correctly. ● **SEE FIGURE 42–16.**

- 25% pulse width indicates that a device is being commanded on just 25% of the time.

Pulse width is used to measure the on time for fuel injectors and other computer-controlled solenoid and devices.

FREQUENCY Frequency is a measure of how many times per second a signal changes. Frequency is measured in a unit called hertz, formerly termed "cycles per second."

Frequency measurements are used when checking the following:

- Mass airflow (MAF) sensors for proper operation
- Ignition primary pulse signals when diagnosing a no-start condition
- Checking a wheel speed sensor

ELECTRICAL UNIT PREFIXES

DEFINITIONS Electrical units are measured in numbers such as 12 volts, 150 amperes, and 470 ohms. Large units over 1,000 may be expressed in kilo units. **Kilo (k)** means 1,000. ● **SEE FIGURE 42–17.**

4,700 ohms = 4.7 kilohms (kΩ)

If the value is over 1 million (1,000,000), then the prefix **mega (M)** is often used. For example:

1,100,000 volts = 1.1 megavolts (MV)

4,700,000 ohms = 4.7 megohms (MΩ)

Sometimes a circuit conducts so little current that a smaller unit of measure is required. Small units of measure expressed in 1/1,000 are prefixed by **milli (m)**. To summarize:

mega (M) = 1,000,000 (decimal point six places to the right = 1,000,000)

kilo (k) = 1,000 (decimal point three places to the right = 1,000)

milli (m) = 1/1,000 (decimal point three places to the left = 0.001)

HINT: Lowercase *m* equals a small unit (milli), whereas a capital *M* represents a large unit (mega).

● **SEE CHART 42–2.**

PREFIXES The prefixes can be confusing because most digital meters can express values in more than one unit, especially if the

TO/ FROM	MEGA	KILO	BASE	MILLI
Mega	0 places	3 places to the right	6 places to the right	9 places to the right
Kilo	3 places to the left	0 places	3 places to the right	6 places to the right
Base	6 places to the left	3 places to the left	0 places	3 places to the right
Milli	9 places to the left	6 places to the left	3 places to the left	0 places

CHART 42–2

A conversion chart showing the decimal point location for the various prefixes.

TECH TIP

Think of Money

Digital meter displays can often be confusing. The display for a battery measured as 12 1/2 volts would be 12.50 V, just as $12.50 is 12 dollars and 50 cents. A 1/2 volt reading on a digital meter will be displayed as 0.50 V, just as $0.50 is half of a dollar.

It is more confusing when low values are displayed. For example, if a voltage reading is 0.063 volt, an autoranging meter will display 63 millivolts (63 mV), or 63/1,000 of a volt, or $63 of $1,000. (It takes 1,000 mV to equal 1 volt.) Think of millivolts as one-tenth of a cent, with 1 volt being $1.00. Therefore, 630 millivolts are equal to $0.63 of $1.00 (630 tenths of a cent, or 63 cents).

To avoid confusion, try to manually range the meter to read base units (whole volts). If the meter is ranged to base unit volts, 63 millivolts would be displayed as 0.063 or maybe just 0.06, depending on the display capabilities of the meter.

meter is autoranging. For example, an ammeter reading may show 36.7 mA on autoranging. When the scale is changed to amperes ("A" in the window of the display), the number displayed will be 0.037 A. Note that the resolution of the value is reduced.

HINT: Always check the face of the meter display for the unit being measured. To best understand what is being displayed on the face of a digital meter, select a manual scale and move the selector until *whole units appear,* such as "A" for amperes instead of "mA" for milliamperes.

HOW TO READ DIGITAL METERS

STEPS TO FOLLOW Getting to know and use a digital meter takes time and practice. The first step is to read, understand, and follow all safety and operational instructions that come with the meter. Use of the meter usually involves the following steps.

STEP 1 **Select the proper unit of electricity for what is being measured.** This unit could be volts, ohms (resistance), or amperes (amount of current flow). If the meter is not autoranging, select the proper scale for the anticipated reading. For example, if a 12 volt battery is being measured, select a meter reading range that is higher than the voltage but not too high. A 20 or 30 volt range will accurately show the voltage of a 12 volt battery. If a 1,000 volt scale is selected, a 12 volt reading may not be accurate.

STEP 2 **Place the meter leads into the proper input terminals.**

- The black lead is inserted into the common (COM) terminal. This meter lead usually stays in this location for all meter functions.
- The red lead is inserted into the volt, ohm, or diode check terminal usually labeled "VΩ" when voltage, resistance, or diodes are being measured.
- When current flow in amperes is being measured, most digital meters require that the red test lead be inserted in the ammeter terminal, usually labeled "A" or "mA."

CAUTION: If the meter leads are inserted into ammeter terminals, even though the selector is set to volts, the meter may be damaged or an internal fuse may blow if the test leads touch both terminals of a battery.

STEP 3 **Measure the component being tested.** Carefully note the decimal point and the unit on the face of the meter.

- **Meter lead connections.** If the meter leads are connected to a battery backwards (red to the battery negative, for example), the display will still show the correct reading, but a negative sign (−) will be displayed in front of the number. The correct polarity is not important when measuring resistance (ohms) except where indicated, such as measuring a diode.
- **Autorange.** Many meters automatically default to the autorange position and the meter will display the value in the most readable scale. The meter can be manually ranged to select other levels or to lock in a scale for a value that is constantly changing.

  If a 12 volt battery is measured with an autoranging meter, the correct reading of 12.0 is given. "AUTO" and "V" should show on the face of the meter. For example, if a meter is manually set to the 2 kilohm scale, the highest that the meter will read is 2,000 ohms. If the reading is over 2,000 ohms, the meter will display OL. ● **SEE CHART 42–3**.

STEP 4 **Interpret the reading.** This is especially difficult on autoranging meters, where the meter itself selects the proper scale. The following are two examples of different readings.

Example 1: A voltage drop is being measured. The specifications indicate a maximum voltage drop of 0.2 volt. The meter reads "AUTO" and "43.6 mV." This reading means that the voltage drop is 0.0436 volt, or 43.6 mV, which is far lower than the 0.2 volt (200 millivolts). Because the number showing on the meter face is much larger than the specifications, many beginner technicians are led to believe that the voltage drop is excessive.

NOTE: Pay attention to the units displayed on the meter face and convert to whole units.

Example 2: A spark plug wire is being measured. The reading should be less than 10,000 ohms for each foot in length if the wire is okay. The wire being tested is 3 ft long (maximum allowable resistance is 30,000 ohms). The meter reads "AUTO" and "14.85 kΩ." This reading is equivalent to 14,850 ohms.

NOTE: When converting from kilohms to ohms, make the decimal point a comma.

Because this reading is well below the specified maximum allowable, the spark plug wire is okay.

	VOLTAGE BEING MEASURED					
	0.01 V (10 MV)	0.150 V (150 MV)	1.5 V	10.0 V	12.0 V	120 V
Scale Selected	**Voltmeter will display:**					
200 mV	10.0	150.0	OL	OL	OL	OL
2 V	0.100	0.150	1.500	OL	OL	OL
20 V	0.1	1.50	1.50	10.00	12.00	OL
200 V	00.0	01.5	01.5	10.0	12.0	120.0
2 kV	00.00	00.00	000.1	00.10	00.12	0.120
Autorange	10.0 mV	15.0 mV	1.50	10.0	12.0	120.0
	RESISTANCE BEING MEASURED					
	10 OHMS	**100 OHMS**	**470 OHMS**	**1 KILOHM**	**220 KILOHMS**	**1 MEGOHM**
Scale Selected	**Ohmmeter will display:**					
400 ohms	10.0	100.0	OL	OL	OL	OL
4 kilohms	010	100	0.470 k	1000	OL	OL
40 kilohms	00.0	0.10 k	0.47 k	1.00 k	OL	OL
400 kilohms	000.0	00.1 k	00.5 k	0.10 k	220.0 k	OL
4 megohms	00.00	0.01 M	0.05 M	00.1 M	0.22 M	1.0 M
Autorange	10.0	100.0	470.0	1.00 k	220 k	1.00 M
	CURRENT BEING MEASURED					
	50 MA	**150 MA**	**1.0 A**	**7.5 A**	**15.0 A**	**25.0 A**
Scale Selected	**Ammeter will display:**					
40 mA	OL	OL	OL	OL	OL	OL
400 mA	50.0	150	OL	OL	OL	OL
4 A	0.05	0.00	1.00	OL	OL	OL
40 A	0.00	0.000	01.0	7.5	15.0	25.0
Autorange	50.0 mA	150.0 mA	1.00	7.5	15.0	25.0

CHART 42–3

Sample meter readings using manually set and autoranging selection on the digital meter control.

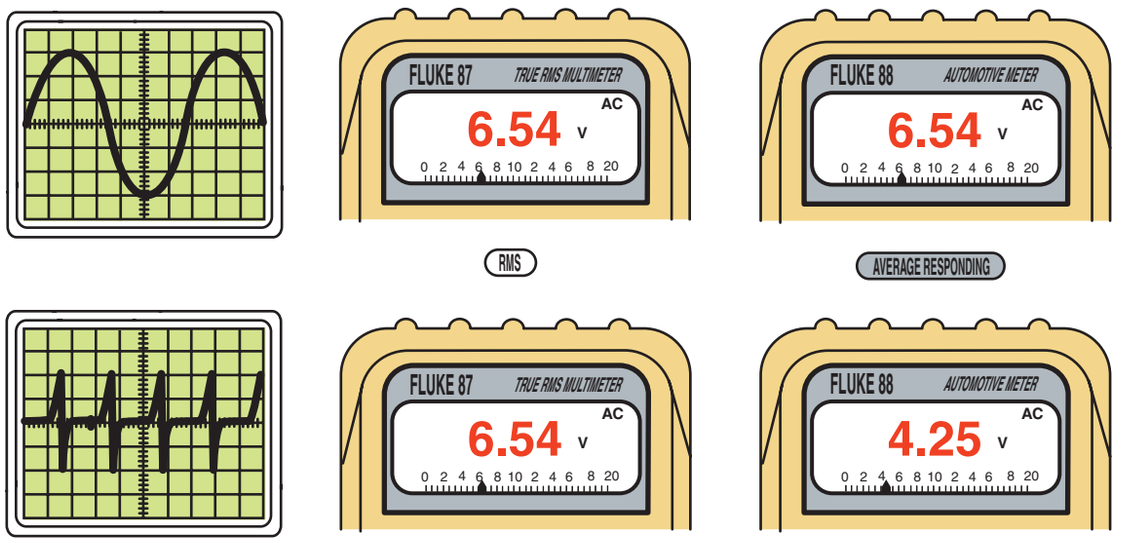


FIGURE 42–18 When reading AC voltage signals, a true RMS meter (such as a Fluke 87) provides a different reading than an average responding meter (such as a Fluke 88). The only place this difference is important is when a reading is to be compared with a specification.

RMS VERSUS AVERAGE

Alternating current voltage waveforms can be true sinusoidal or nonsinusoidal. A true sine wave pattern measurement will be the same for both **root-mean-square (RMS)** and average reading meters. RMS and averaging are two methods used to measure the true effective rating of a signal that is constantly changing. ● **SEE FIGURE 42–18**.

Only true RMS meters are accurate when measuring nonsinusoidal AC waveforms, which are seldom used in automotive applications.



FIGURE 42–19 This meter display shows 052.2 AC volts. Notice that the zero beside the 5 indicates that the meter can read over 100 volts AC with a resolution of 0.1 volt.

TECH TIP

Purchase a Digital Meter That Will Work for Automotive Use

Try to purchase a digital meter that is capable of reading the following:

- DC volts
- AC volts
- DC amperes (up to 10 A or more is helpful)
- Ohms (Ω) up to 40 MΩ (40 million ohms)
- Diode check

Additional features for advanced automotive diagnosis include:

- Frequency (hertz, abbreviated Hz)
- Temperature probe (°F and/or °C)
- Pulse width (millisecond, abbreviated ms)
- Duty cycle (%)

RESOLUTION, DIGITS, AND COUNTS

Meter resolution refers to how small or fine a measurement the meter can make. By knowing the resolution of a DMM you can determine whether the meter could measure down to only 1 volt or down to 1 millivolt (1/1,000 of a volt).

You would not buy a ruler marked in 1 in. segments (or centimeters) if you had to measure down to 1/4 in. (or 1 mm). A thermometer that only measured in whole degrees is not of much use when your normal temperature is 98.6°F. You need a thermometer with 0.1° *resolution.*

The terms *digits* and *counts* are used to describe a meter's resolution. DMMs are grouped by the number of counts or digits they display.

- A 3 1/2-digit meter can display three full digits ranging from 0 to 9, and one "half" digit that displays only a 1 or is left blank. A 3 1/2-digit meter will display up to 1,999 counts of resolution.
- A 4 1/2-digit meter can display up to 19,000 counts of resolution. It is more precise to describe a meter by counts of resolution than by 3 1/2 or 4 1/2 digits. Some 3 1/2-digit meters have enhanced resolution of up to 3,200 or 4,000 counts.

Meters with more counts offer better resolution for certain measurements. For example, a 1,999 count meter will not be able to measure down to a tenth of a volt when measuring 200 volts or more. ● **SEE FIGURE 42–19**.

However, a 3,200 count meter will display a tenth of a volt up to 320 volts. Digits displayed to the far right of the display may at times flicker or constantly change. This is called *digit rattle* and represents a changing voltage being measured on the ground (COM terminal of the meter lead). High-quality meters are designed to reject this unwanted voltage.

SAFETY TIP

Meter Usage on Hybrid Electric Vehicles

Many hybrid electric vehicles use system voltage as high as 650 volts DC. Be sure to follow all vehicle manufacturer's testing procedures; and if a voltage measurement is needed, be sure to use a meter and test leads that are designed to insulate against high voltages. The **International Electrotechnical Commission (IEC)** has several categories of voltage standards for meter and meter leads. These categories are ratings for overvoltage protection and are rated CAT I, CAT II, CAT III, and CAT IV. The higher the category, the greater the protection against voltage spikes caused by high-energy circuits. Under each category there are various energy and voltage ratings.

CAT I	Typically a CAT I meter is used for low-energy voltage measurements such as at wall outlets in the home. Meters with a CAT I rating are usually rated at 300 to 800 volts.
CAT II	This higher rated meter would be typically used for checking higher energy level voltages at the fuse panel in the home. Meters with a CAT II rating are usually rated at 300 to 600 volts.
CAT III	This minimum rated meter should be used for hybrid vehicles. The CAT III category is designed for high-energy levels and voltage measurements at the service pole at the transformer. Meters with this rating are usually rated at 600 to 1,000 volts.
CAT IV	CAT IV meters are for clamp-on meters only. If a clamp-on meter also has meter leads for voltage measurements, that part of the meter will be rated as CAT III.

NOTE: Always use the highest CAT rating meter, especially when working with hybrid vehicles. A CAT III, 600 volt meter is safer than a CAT II, 1,000 volt meter because of the energy level of the CAT ratings.

Therefore, for best personal protection, use only meters and meter leads that are CAT III or CAT IV rated when measuring voltage on a hybrid vehicle. ● **SEE FIGURES 42–20 AND 42–21**.



FIGURE 42–20 Be sure to only use a meter that is CAT III rated when taking electrical voltage measurements on a hybrid vehicle.



FIGURE 42–21 Always use meter leads that are CAT III rated on a meter that is also CAT III rated, to maintain the protection needed when working on hybrid vehicles.

ACCURACY

Meter accuracy is the largest allowable error that will occur under specific operating conditions. In other words, it is an indication of how close the DMM's displayed measurement is to the actual value of the signal being measured.

Accuracy for a DMM is usually expressed as a percent of reading. An accuracy of ±1% of reading means that for a displayed reading of 100.0 V, the actual value of the voltage could be anywhere between 99.0 V and 101.0 V. Thus, the lower the percent of accuracy is, the better.

- Unacceptable = 1.00%
- Okay = 0.50% (1/2%)
- Good = 0.25% (1/4%)
- Excellent = 0.10% (1/10%)

For example, if a battery had 12.6 volts, a meter could read between the following, based on its accuracy.

±0.1%	high = 12.61
	low = 12.59
±0.25%	high = 12.63
	low = 12.57
±0.50%	high = 12.66
	low = 12.54
±1.00%	high = 12.73
	low = 12.47

Before you purchase a meter, check the accuracy. Accuracy is usually indicated on the specifications sheet for the meter.

DIGITAL METER USAGE



1 For most electrical measurements, the black meter lead is inserted in the terminal labeled COM and the red meter lead is inserted into the terminal labeled V.



2 To use a digital meter, turn the power switch and select the unit of electricity to be measured. In this case, the rotary switch is turned to select DC volts. ($\bar{V}$)



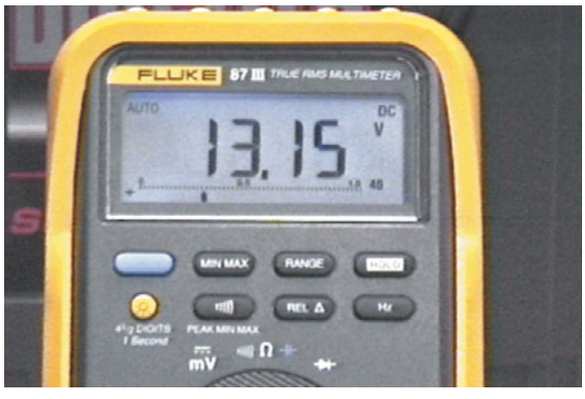
3 For most automotive electrical use, such as measuring battery voltage, select DC volts.



4 Connect the red meter lead to the positive (+) terminal of a battery and the black meter lead to the negative (−) terminal of a battery. The meter reads the voltage difference between the leads.



5 This jump start battery unit measures 13.151 volts with the meter set on autoranging on the DC voltage scale.



6 Another meter (Fluke 87 III) displays four digits when measuring the voltage of the battery jump start unit.



7 To measure resistance turn the rotary dial to the ohm (Ω) symbol. With the meter leads separated, the meter display reads OL (over limit).



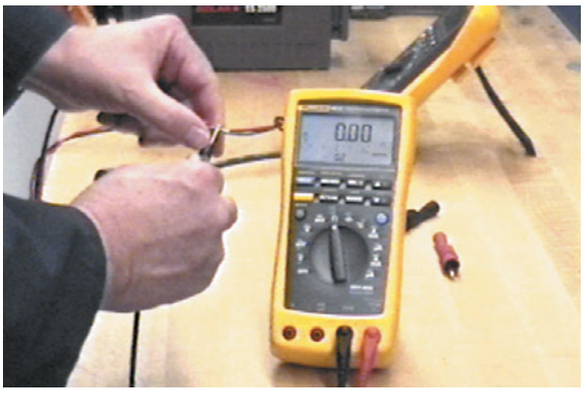
8 The meter can read your own body resistance if you grasp the meter lead terminals with your fingers. The reading on the display indicates 196.35 kΩ.



9 When measuring anything; be sure to read the symbol on the meter face. In this case, the meter is reading 291.10 kΩ.



10 A meter set on ohms can be used to check the resistance of a light bulb filament. In this case, the meter reads 3.15 ohms. If the bulb were bad (filament open), the meter would display OL.



11 A digital meter set to read ohms should measure 0.00 as shown when the meter leads are touched together.



12 The large letter V means volts and the wavy symbol over the V means that the meter measures alternating current (AC) voltage if this position is selected.

CONTINUED ▶



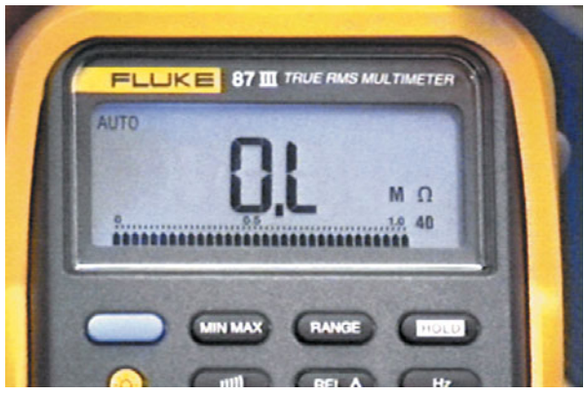
13 The next symbol is a V with a dotted and a straight line overhead. This symbol stands for direct current (DC) volts. This position is most used for automotive service.



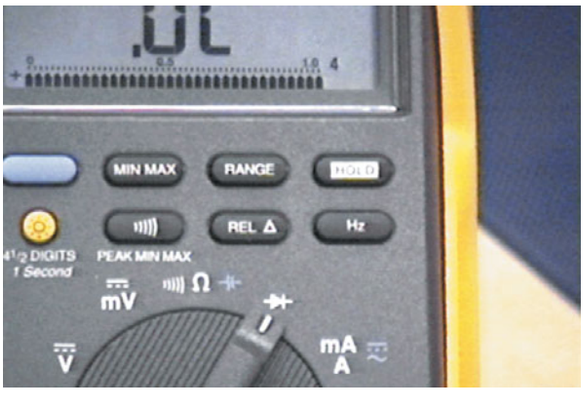
14 The symbol mV indicates millivolts or 1/1000 of a volt (0.001). The solid and dashed line above the mV means DC mV.



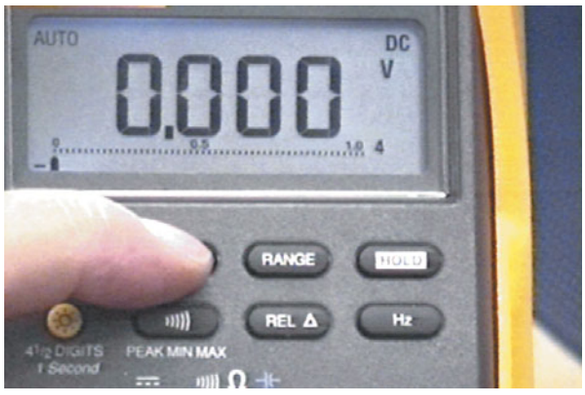
15 The rotary switch is turned to Ω (ohms) unit of resistance measure. The symbol to the left of the Ω symbol is the beeper or continuity indicator.



16 Notice that AUTO is in the upper left and the MΩ is in the lower right. This MΩ means megaohms or that the meter is set to read in millions of ohms.



17 The symbol shown is the symbol of a diode. In this position, the meter applies a voltage to a diode and the meter reads the voltage drop across the junction of a diode.



18 One of the most useful features of this meter is the MIN/MAX feature. By pushing the MIN/MAX button, the meter will be able to display the highest (MAX) and the lowest (MIN) reading.



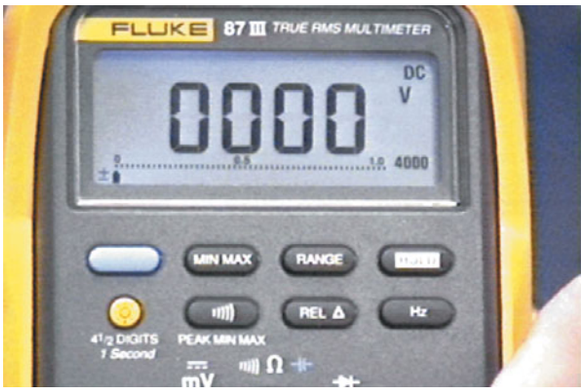
19 Pushing the MIN/MAX button puts the meter into record mode. Note the 100 mS and "REC" on the display. In this position, the meter is capturing any voltage charge that lasts 100 mS (0.1 sec) or longer.



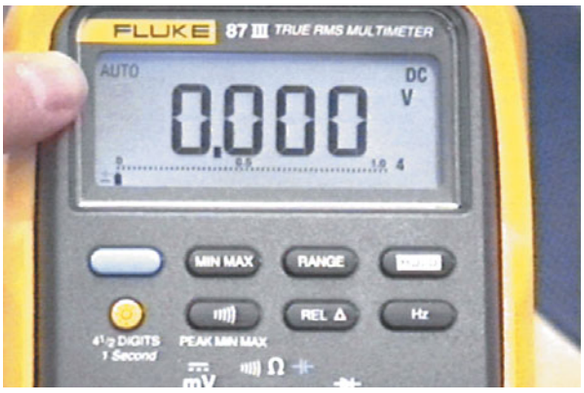
20 To increase the range of the meter touch the range button. Now the meter is set to read voltage up to 40 volts DC.



21 Pushing the range button one more time changes the meter scale to the 400-voltage range. Notice that the decimal point has moved to the right.



22 Pushing the range button again changes the meter to the 4000-volt range. This range is not suitable to use in automotive applications.



23 By pushing and holding the range button, the meter will reset to autorange. Autorange is the preferred setting for most automotive measurements except when using MIN/MAX record mode.

REVIEW QUESTIONS

1. Why should high-impedance meters be used when measuring voltage on computer-controlled circuits?
2. How is an ammeter connected to an electrical circuit?
3. Why must an ohmmeter be connected to a disconnected circuit or component?

CHAPTER QUIZ

1. Inductive ammeters work because of what principle?
   a. Magic
   b. Electrostatic electricity
   c. A magnetic field surrounds any wire carrying a current
   d. Voltage drop as it flows through a conductor
2. A meter used to measure amperes is called a(n) _____.
   a. Amp meter **c.** Ammeter
   b. Ampmeter **d.** Coulomb meter
3. A voltmeter should be connected to the circuit being tested _____.
   a. In series
   b. In parallel
   c. Only when no power is flowing
   d. Both a and c
4. An ohmmeter should be connected to the circuit or component being tested _____.
   a. With current flowing in the circuit or through the component
   b. When connected to the battery of the vehicle to power the meter
   c. Only when no power is flowing (electrically open circuit)
   d. Both b and c
5. A high-impedance meter _____.
   a. Measures a high amount of current flow
   b. Measures a high amount of resistance
   c. Can measure a high voltage
   d. Has a high internal resistance
6. A meter is set to read DC volts on the 4 volt scale. The meter leads are connected at a 12 volt battery. The display will read _____.
   a. 0.00 **c.** 12 V
   b. OL **d.** 0.012 V
7. What could happen if the meter leads were connected to the positive and negative terminals of the battery while the meter and leads were set to read amperes?
   a. Could blow an internal fuse or damage the meter
   b. Would read volts instead of amperes
   c. Would display OL
   d. Would display 0.00
8. The highest amount of resistance that can be read by the meter set to the 2 kΩ scale is _____.
   a. 2,000 ohms
   b. 200 ohms
   c. 200 kΩ (200,000 ohms)
   d. 20,000,000 ohms
9. If a digital meter face shows 0.93 when set to read kΩ, the reading means _____.
   a. 93 ohms **c.** 9,300 ohms
   b. 930 ohms **d.** 93,000 ohms
10. A reading of 432 shows on the face of the meter set to the millivolt scale. The reading means _____.
    a. 0.432 volt **c.** 43.2 volts
    b. 4.32 volts **d.** 4,320 volts

chapter 43

OSCILLOSCOPES AND GRAPHING MULTIMETERS

OBJECTIVES: **After studying Chapter 43, the reader should be able to:** • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "A" (General Electrical/Electronic System Diagnosis). • Use a digital storage oscilloscope to measure voltage signals. • Interpret meter and scope readings and determine if the values are within factory specifications. • Explain time base and volts per division settings.

KEY TERMS: AC coupling 462 • BNC connector 465 • Cathode ray tube (CRT) 461 • Channel 464 • DC coupling 462 • Digital storage oscilloscope (DSO) 461 • Division 462 • Duty cycle 464 • External trigger 464 • Frequency 463 • GMM 466 • Graticule 461 • Hertz 463 • Oscilloscope (scope) 461 • Pulse train 463 • Pulse width 464 • PWM 464 • Time base 462 • Trigger level 464 • Trigger slope 464

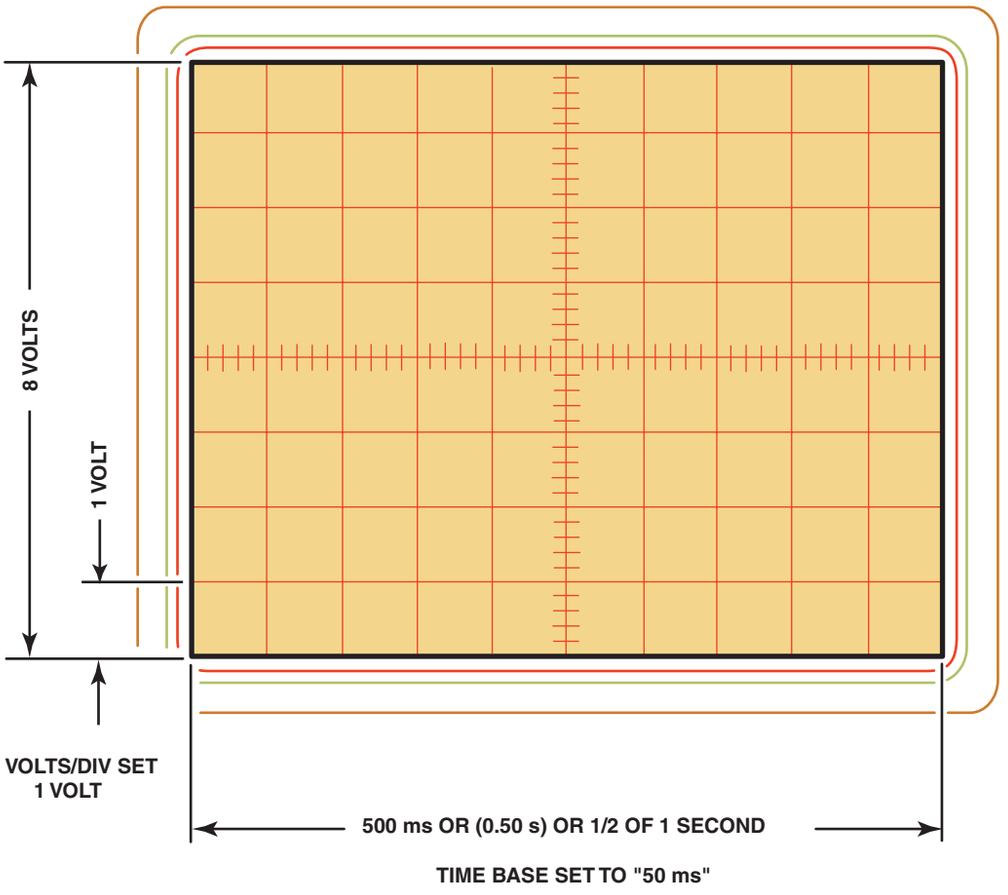


FIGURE 43–1 A scope display allows technicians to take measurements of voltage patterns. In this example, each vertical division is 1 volt and each horizontal division is set to represent 50 milliseconds.

TYPES OF OSCILLOSCOPES

TERMINOLOGY An **oscilloscope** (usually called a *scope*) is a visual voltmeter with a timer that shows when a voltage changes. Following are several types of oscilloscopes.

- An *analog scope* uses a **cathode ray tube (CRT)** similar to a television screen to display voltage patterns. The scope screen displays the electrical signal constantly.
- A *digital scope* commonly uses a liquid crystal display (LCD), but a CRT may also be used on some digital scopes. A digital scope takes samples of the signals that can be stopped or stored and is therefore called a **digital storage oscilloscope**, or DSO.
- A digital scope does not capture each change in voltage but instead captures voltage levels over time and stores them as dots. Each dot is a voltage level. Then the scope displays the waveforms using the thousands of dots (each representing a voltage level) and then electrically connects the dots to create a waveform.
- A DSO can be connected to a sensor output signal wire and can record over a long period of time the voltage signals. Then it can be replayed and a technician can see if any faults were detected. This feature makes a DSO the perfect tool to help diagnose intermittent problems.
- A digital storage scope, however, can sometimes miss faults called *glitches* that may occur between samples captured by the scope. This is why a DSO with a high "sampling rate" is preferred. Sampling rate means that a scope is capable of capturing voltage changes that occur over a very short period of time. Some digital storage scopes have a capture rate of 25 million (25,000,000) samples per second. This means that the scope can capture a glitch (fault) that lasts just 40 nano (0.00000040) seconds long.
- A scope has been called "a voltmeter with a clock."
  - The voltmeter part means that a scope can capture and display changing voltage levels.
  - The clock part means that the scope can display these changes in voltage levels within a specific time period; and with a DSO it can be replayed so that any faults can be seen and studied.

OSCILLOSCOPE DISPLAY GRID A typical scope face usually has eight or ten grids vertically (up and down) and ten grids horizontally (left to right). The transparent scale (grid), used for reference measurements, is called a **graticule**. This arrangement is commonly 8 × 10 or 10 × 10 divisions. ● **SEE FIGURE 43–1**.

NOTE: These numbers originally referred to the metric dimensions of the graticule in centimeters. Therefore, an 8 × 10 display would be 8 cm (80 mm or 3.14 in.) high and 10 cm (100 mm or 3.90 in.) wide.

- Voltage is displayed on a scope starting with zero volts at the bottom and higher voltage being displayed vertically.
- The scope illustrates time left to right. The pattern starts on the left and sweeps across the screen from left to right.

MILLISECONDS PER DIVISION (MS/DIV)	TOTAL TIME DISPLAYED
1 ms	10 ms (0.010 sec.)
10 ms	100 ms (0.100 sec.)
50 ms	500 ms (0.500 sec.)
100 ms	1 sec. (1.000 sec.)
500 ms	5 sec. (5.0 sec.)
1,000 ms	10 sec. (10.0 sec.)

CHART 43–1

The time base is milliseconds (ms) and total time of an event that can be displayed.

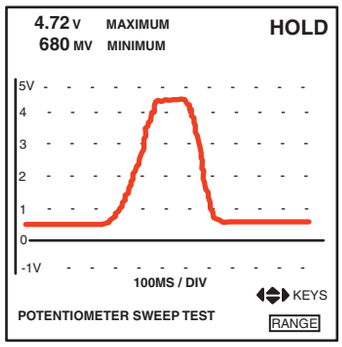


FIGURE 43–2 The display on a digital storage oscilloscope (DSO) displays the entire waveform of a throttle position (TP) sensor from idle to wide-open throttle and then returns to idle. The display also indicates the maximum reading (4.72 V) and the minimum (680 mV or 0.68 V). The display does not show anything until the throttle is opened, because the scope has been set up to only start displaying a waveform after a certain voltage level has been reached. This voltage is called the trigger or trigger point.

SCOPE SETUP AND ADJUSTMENTS

SETTING THE TIME BASE

Most scopes use 10 graticules from left to right on the display. Setting the **time base** means setting how much time will be displayed in each block called a **division**. For example, if the scope is set to read 2 seconds per division (referred to as *s/div*), then the total displayed would be 20 seconds (2 × 10 divisions = 20 sec.). The time base should be set to an amount of time that allows two to four events to be displayed. Milliseconds (0.001 sec.) are commonly used in scopes when adjusting the time base. Sample time is milliseconds per division (indicated as *ms/div*) and total time. ● **SEE CHART 43–1**.

NOTE: Increasing the time base reduces the number of samples per second.

The horizontal scale is divided into 10 divisions (sometimes called *grats*). If each division represents 1 second of time, then the total time period displayed on the screen will be 10 seconds. The time per division is selected so that several events of the waveform are displayed. Time per division settings can vary greatly in automotive use, including:

- MAP/MAF sensors: 2 ms/div (20 ms total)
- Network (CAN) communications network: 2 ms/div (20 ms total)
- Throttle position (TP) sensor: 100 ms per division (1 sec. total)
- Fuel injector: 2 ms/div (20 ms total)
- Oxygen sensor: 1 sec. per division (10 sec. total)
- Primary ignition: 10 ms/div (100 ms total)
- Secondary ignition: 10 ms/div (100 ms total)
- Voltage measurements: 5 ms/div (50 ms total)

The total time displayed on the screen allows comparisons to see if the waveform is consistent or is changing. Multiple waveforms shown on the display at the same time also allow for measurements to be seen more easily. ● **SEE FIGURE 43–2** for an example of a throttle position sensor waveform created by measuring the voltage output as the throttle was depressed and then released.

VOLTS PER DIVISION

The volts per division, abbreviated *V/div,* should be set so that the entire anticipated waveform can be viewed. Examples include:

Throttle position (TP) sensor: 1 V/div (8 V total)

Battery, starting and charging: 2 V/div (16 V total)

Oxygen sensor: 200 mV/div (1.6 V total)

Notice from the examples that the total voltage to be displayed exceeds the voltage range of the component being tested. This ensures that all the waveform will be displayed. It also allows for some unexpected voltage readings. For example, an oxygen sensor should read between 0 V and 1 V (1,000 mV). By setting the V/div to 200 mV, up to 1.6 V (1,600 mV) will be displayed.

DC AND AC COUPLING

DC COUPLING

DC coupling is the most used position on a scope because it allows the scope to display both alternating current (AC) voltage signals and direct current (DC) voltage signals present in the circuit. The AC part of the signal will ride on top of the DC component. For example, if the engine is running and the charging voltage is 14.4 volts DC, this will be displayed as a horizontal line on the screen. Any AC ripple voltage leaking past the alternator diodes will be displayed as an AC signal on top of the horizontal DC voltage line. Therefore, both components of the signal can be observed at the same time.

AC COUPLING

When the **AC coupling** position is selected, a capacitor is placed into the meter lead circuit, which effectively blocks all DC voltage signals but allows the AC portion of the signal to pass and be displayed. AC coupling can be used to show output signal waveforms from sensors such as:

- Distributor pickup coils
- Magnetic wheel speed sensors
- Magnetic crankshaft position sensors
- Magnetic camshaft position sensors
- Magnetic vehicle speed sensors
- The AC ripple from an alternator. ● **SEE FIGURE 43–3**.

NOTE: Check the instructions from the scope manufacturer for the recommended settings to use. Sometimes it is necessary to switch from DC coupling to AC coupling or from AC coupling to DC coupling to properly see some waveforms.

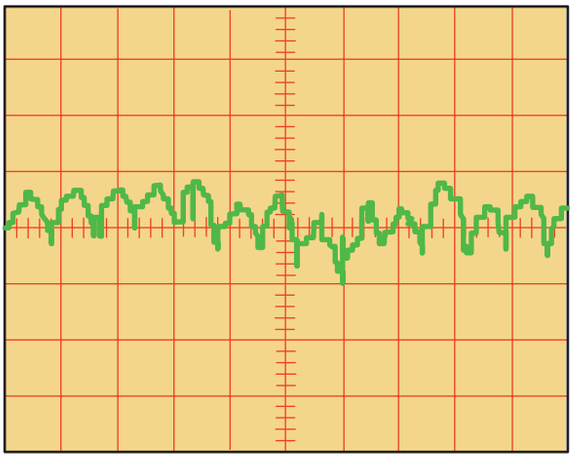


FIGURE 43–3 Ripple voltage is created from the AC voltage from an alternator. Some AC ripple voltage is normal but if the AC portion exceeds 0.5 volt, then a bad diode is the most likely cause. Excessive AC ripple can cause many electrical and electronic devices to work incorrectly.

PULSE TRAINS

DEFINITION Scopes can show all voltage signals. Among the most commonly found in automotive applications is a DC voltage that varies up and down and does not go below zero like an AC voltage. A DC voltage that turns on and off in a series of pulses is called a **pulse train**. Pulse trains differ from an AC signal in that they do not go below zero. An alternating voltage goes above and below zero voltage. Pulse train signals can vary in several ways. ● **SEE FIGURE 43–4**.

FREQUENCY **Frequency** is the number of cycles per second measured in **hertz**. The engine revolutions per minute (RPM) signal is an example of a signal that can occur at various frequencies. At low engine speed, the ignition pulses occur fewer times per second (lower frequency) than when the engine is operated at higher engine speeds (RPM).

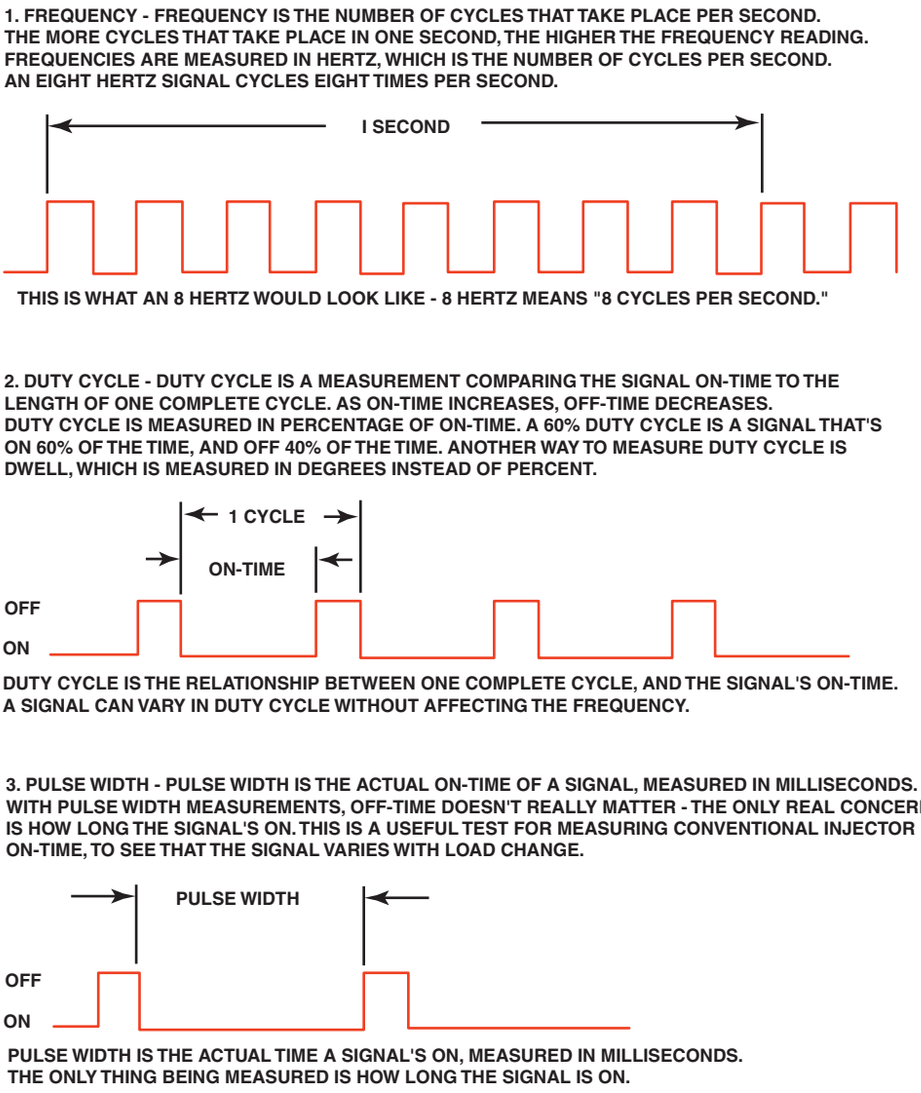
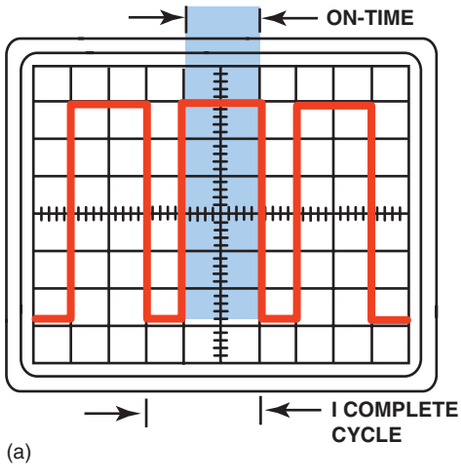
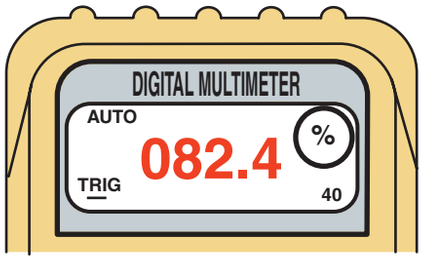


FIGURE 43–4 A pulse train is any electrical signal that turns on and off, or goes high and low in a series of pulses. Ignition module and fuel-injector pulses are examples of a pulse train signal.



(a)



THE % SIGN IN THE UPPER RIGHT CORNER OF THE DISPLAY INDICATES THAT THE METER IS READING A DUTY CYCLE SIGNAL.

(b)

FIGURE 43–5 (a) A scope representation of a complete cycle showing both on-time and off-time. (b) A meter display indicating the on-time duty cycle in a percentage (%). Note the trigger and negative (−) symbol. This indicates that the meter started to record the percentage of on-time when the voltage dropped (start of on-time).

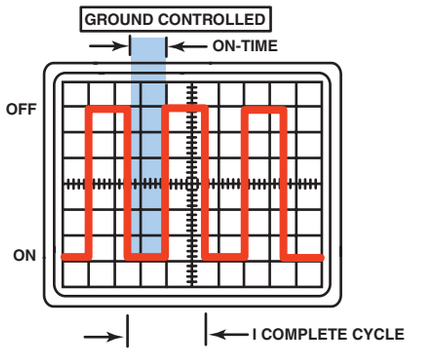
DUTY CYCLE **Duty cycle** refers to the percentage of on-time of the signal during one complete cycle. As on-time increases, the amount of time the signal is off decreases and is usually measured in percentage. Duty cycle is also called **pulse-width modulation (PWM)** and can be measured in degrees. ● **SEE FIGURE 43–5**.

PULSE WIDTH The **pulse width** is a measure of the actual on-time measured in milliseconds. Fuel injectors are usually controlled by varying the pulse width. ● **SEE FIGURE 43–6**.

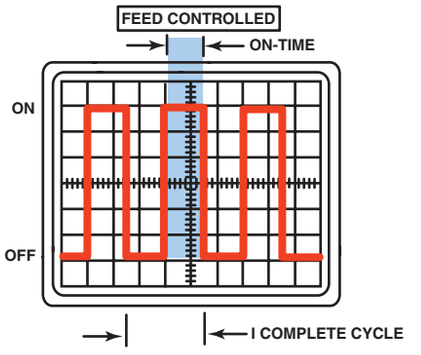
NUMBER OF CHANNELS

DEFINITION Scopes are available that allow the viewing of more than one sensor or event at the same time on the display. The number of events, which require leads for each, is called a **channel**. A channel is an input to a scope. Commonly available scopes include:

- **Single channel.** A single channel scope is capable of displaying only one sensor signal waveform at a time.
- **Two channel.** A two-channel scope can display the waveform from two separate sensors or components at the same time. This feature is very helpful when testing the camshaft and crankshaft position sensors on an engine to see if they are properly timed. ● **SEE FIGURE 43–7**.



ON A GROUND-CONTROLLED CIRCUIT, THE ON-TIME PULSE IS THE LOWER HORIZONTAL PULSE.



ON A FEED-CONTROLLED CIRCUIT, THE ON-TIME PULSE IS THE UPPER HORIZONTAL PULSE.

FIGURE 43–6 Most automotive computer systems control the device by opening and closing the ground to the component.

- **Four channel.** A four-channel scope allows the technician to view up to four different sensors or actuators on one display.

NOTE: Often the capture speed of the signals is slowed when using more than one channel.

TRIGGERS

EXTERNAL TRIGGER An **external trigger** is when the waveform starts when a signal is received from another external source rather than from the signal pickup lead. A common example of an external trigger comes from the probe clamp around the cylinder #1 spark plug wire to trigger the start of an ignition pattern.

TRIGGER LEVEL **Trigger level** is the voltage that must be detected by the scope before the pattern will be displayed. A scope will only start displaying a voltage signal when it is triggered or is told to start. The trigger level must be set to start the display. If the pattern starts at 1 volt, then the trace will begin displaying on the left side of the screen *after* the trace has reached 1 volt.

TRIGGER SLOPE The **trigger slope** is the voltage direction that a waveform must have in order to start the display. Most often, the trigger to start a waveform display is taken from the signal itself. Besides trigger voltage level, most scopes can be adjusted to trigger only when the voltage rises past the trigger-level voltage. This is called a *positive slope.* When the voltage falling past the higher level activates the trigger, this is called a *negative slope.*

The scope display indicates both a positive and a negative slope symbol. For example, if a waveform such as a magnetic sensor used for crankshaft position or wheel speed starts moving upward, a

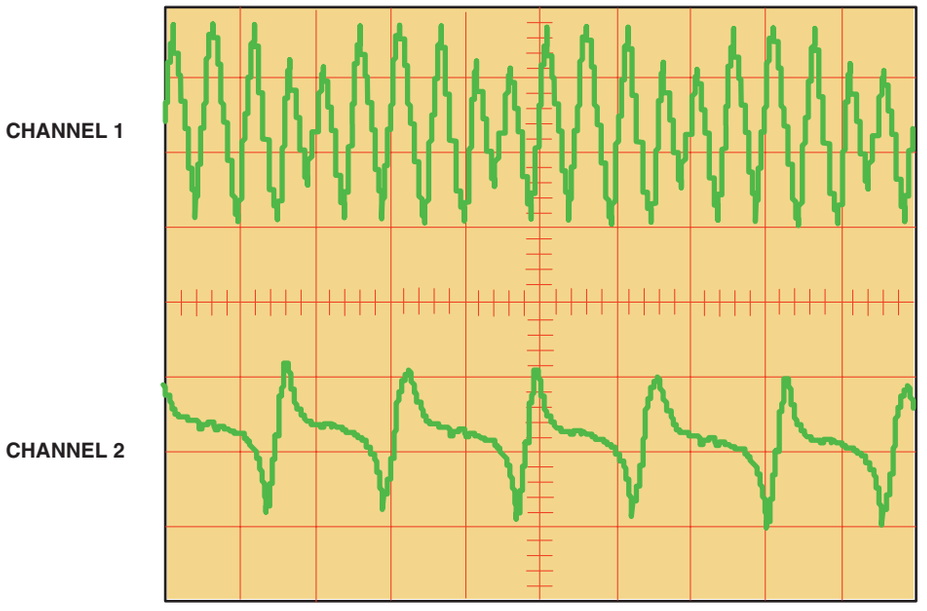


FIGURE 43–7 A two-channel scope being used to compare two signals on the same vehicle.



FIGURE 43–8 (a) A symbol for a positive trigger—a trigger occurs at a rising (positive) edge of the signal (waveform). (b) A symbol for a negative trigger—a trigger occurs at a falling (negative) edge of the signal (waveform).

positive slope should be selected. If a negative slope is selected, the waveform will not start showing until the voltage reaches the trigger level in a downward direction. A negative slope should be used when a fuel-injector circuit is being analyzed. In this circuit, the computer provides the ground and the voltage level drops when the computer commands the injector on. Sometimes the technician needs to change from negative to positive or positive to negative trigger if a waveform is not being shown correctly. ● **SEE FIGURE 43–8**.

USING A SCOPE

USING SCOPE LEADS

Most scopes, both analog and digital, normally use the same test leads. These leads usually attach to the scope through a **BNC connector**, a miniature standard coaxial cable connector. BNC is an international standard that is used in the electronics industry. If using a BNC connector, be sure to connect one lead to a good clean, metal engine ground. The probe of the scope lead attaches to the circuit or component being tested. Many scopes use one ground lead and then each channel has it own signal pickup lead.

MEASURING BATTERY VOLTAGE WITH A SCOPE

One of the easiest things to measure and observe on a scope is battery voltage. A lower voltage can be observed on the scope display as the engine is started and a higher voltage should be displayed after the engine starts. ● **SEE FIGURE 43–9**.

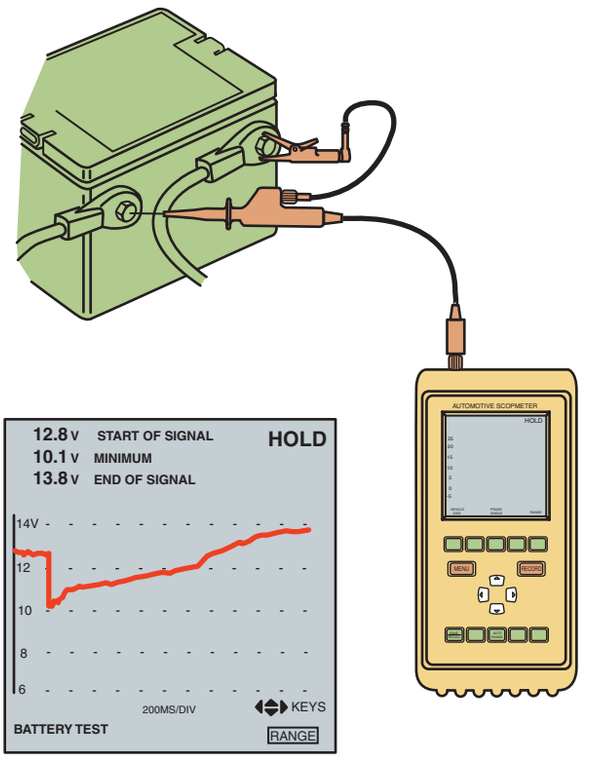


FIGURE 43–9 Constant battery voltage is represented by a flat horizontal line. In this example, the engine was started and the battery voltage dropped to about 10 V as shown on the left side of the scope display. When the engine started, the alternator started to charge the battery and the voltage is shown as climbing.

An analog scope displays rapidly and cannot be set to show or freeze a display. Therefore, even though an analog scope shows all voltage signals, it is easy to miss a momentary glitch on an analog scope.

CAUTION: Check the instructions for the scope being used before attempting to scope household AC circuits. Some scopes, such as the Snap-On MODIS, are not designed to measure high-voltage AC circuits.

GRAPHING MULTIMETER

A graphing multimeter, abbreviated **GMM**, is a cross between a digital meter and a digital storage oscilloscope. A graphing multimeter displays the voltage levels at two places:

- On a display screen
- In a digital readout

It is usually not capable of capturing very short duration faults or glitches that would likely be captured with a digital storage oscilloscope. ● **SEE FIGURE 43–10**.



FIGURE 43–10 A typical graphing multimeter that can be used as a digital meter, plus it can display the voltage levels on the display screen.

GRAPHING SCAN TOOLS

Many scan tools are capable of displaying the voltage levels captured by the scan tool through the data link connector (DLC) on a screen. This feature is helpful where seeing changes in voltage levels is difficult to detect by looking at numbers that are constantly changing. Read and follow the instructions for the scan tool being used.

REVIEW QUESTIONS

1. What are the differences between an analog and a digital oscilloscope?
2. What is the difference between DC coupling and AC coupling?
3. Why are DC signals that change called pulse trains?
4. What is the difference between an oscilloscope and a graphing multimeter?

CHAPTER QUIZ

1. Technician A says an analog scope can store the waveform for viewing later. Technician B says that the trigger level has to be set on most scopes to be able to view a changing waveform. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
2. An oscilloscope display is called a _____.
   a. Grid **c.** Division
   b. Graticule **d.** Box
3. A signal showing the voltage of a battery displayed on a digital storage oscilloscope (DSO) is being discussed. Technician A says that the display will show one horizontal line above the zero line. Technician B says that the display will show a line sloping upward from zero to the battery voltage level. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
4. Setting the time base to 50 ms per division will allow the technician to view a waveform how long in duration?
   a. 50 ms **c.** 400 ms
   b. 200 ms **d.** 500 ms
5. A throttle position sensor waveform is going to be observed. At what setting should the volts per division be set to see the entire waveform from 0 to 5 volts?
   a. 0.5 V/division **c.** 2.0 V/division
   b. 1.0 V/division **d.** 5.0 V/division
6. Two technicians are discussing the DC coupling setting on a DSO. Technician A says that the position allows both the DC and AC signals of the waveform to be displayed. Technician B says that this setting allows just the DC part of the waveform to be displayed. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. Voltage signals (waveforms) that do not go below zero are called _____.
   a. AC signals
   b. Pulse trains
   c. Pulse width
   d. DC coupled signals
8. Cycles per second are expressed in _____.
   a. Hertz **c.** Pulse width
   b. Duty cycle **d.** Slope
9. Oscilloscopes use what type of lead connector?
   a. Banana plugs **c.** Single conductor plugs
   b. Double banana plugs **d.** BNC
10. A digital meter that can show waveforms is called a _____.
    a. DVOM **c.** GMM
    b. DMM **d.** DSO

chapter 44

AUTOMOTIVE WIRING AND WIRE REPAIR

OBJECTIVES: **After studying Chapter 44, the reader should be able to:** • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "A" (General Electrical/Electronic Systems Diagnosis). • Explain the wire gauge number system. • Describe how fusible links and fuses protect circuits and wiring. • Discuss electrical terminals and connectors • Describe how to solder • Discuss circuit breakers and PTC electronic circuit protection devices. • Explain the types of electrical conduit. • List the steps for performing a proper wire repair.

KEY TERMS: Adhesive-lined heat shrink tubing 476 • American wire gauge (AWG) 467 • Auto link 471 • Battery cables 469 • Braided ground straps 468 • Circuit breakers 472 • Cold solder joint 476 • Connector 474 • CPA 474 • Crimp-and-seal connectors 476 • Fuse link 471 • Fuses 469 • Fusible link 473 • Heat shrink tubing 476 • Jumper cables 469 • Lock tang 474 • Metric wire gauge 467 • Pacific fuse element 471 • Primary wire 468 • PTC circuit protectors 472 • Rosin-core solder 475 • Skin effect 468 • Terminal 474 • Twisted pair 469

AUTOMOTIVE WIRING

DEFINITION AND TERMINOLOGY

Most automotive wire is made from strands of copper covered by plastic insulation. Copper is an excellent conductor of electricity that is reasonably priced and very flexible. However, solid copper wire can break when moved repeatedly; therefore, most copper wiring is constructed of multiple small strands that allow for repeated bending and moving without breaking. Solid copper wire is generally used for components such as starter armature and alternator stator windings that do not bend or move during normal operation. Copper is the best electrical conductor besides silver, which is a great deal more expensive. The conductivity of various metals is rated. ● **SEE CHART 44–1**.

1.	Silver
2.	Copper
3.	Gold
4.	Aluminum
5.	Tungsten
6.	Zinc
7.	Brass (copper and zinc)
8.	Platinum
9.	Iron
10.	Nickel
11.	Tin
12.	Steel
13.	Lead

CHART 44–1

The list of relative conductivity of metals, showing silver to be the best.

AMERICAN WIRE GAUGE

Wiring is sized and purchased according to gauge size as assigned by the **American wire gauge (AWG)** system. AWG numbers can be confusing because as the gauge number *increases,* the size of the conductor wire *decreases.* Therefore, a 14 gauge wire is smaller than a 10 gauge wire. The *greater* the amount of current (in amperes) that is flowing through a wire, the *larger the diameter (smaller gauge number)* that will be required. ● **SEE CHART 44–2**, which compares the AWG number to the actual wire diameter in inches. The diameter refers to the diameter of the metal conductor and does not include the insulation.

Following are general applications for the most commonly used wire gauge sizes. Always check the installation instructions or the manufacturer's specifications for wire gauge size before replacing any automotive wiring.

- 20 to 22 gauge: radio speaker wires
- 18 gauge: small bulbs and short leads
- 16 gauge: taillights, gas gauge, turn signals, windshield wipers
- 14 gauge: horn, radio power lead, headlights, cigarette lighter, brake lights
- 12 gauge: headlight switch-to-fuse box, rear window defogger, power windows and locks
- 10 gauge: alternator-to-battery
- 4, 2, or 0 (1/0) gauge: battery cables

METRIC WIRE GAUGE

Most manufacturers indicate on the wiring diagrams the **metric wire gauge** sizes measured in square millimeters (mm^2) of cross-sectional area. The following chart gives conversions or comparisons between metric gauge and AWG sizes. Notice that the metric wire size increases with size (area), whereas the AWG size gets smaller with larger size wire. ● **SEE CHART 44–3**.

The AWG number should be decreased (wire size increased) with increased lengths of wire. ● **SEE CHART 44–4**.

WIRE GAUGE DIAMETER TABLE	
AMERICAN WIRE GAUGE (AWG)	WIRE DIAMETER IN INCHES
20	0.03196118
18	0.040303
16	0.0508214
14	0.064084
12	0.08080810
10	0.10189
8	0.128496
6	0.16202
5	0.18194
4	0.20431
3	0.22942
2	0.25763
1	0.2893
0	0.32486
00	0.3648

CHART 44–2

American wire gauge (AWG) number and the actual conductor diameter in inches.

METRIC SIZE (MM^2)	AWG SIZE
0.5	20
0.8	18
1.0	16
2.0	14
3.0	12
5.0	10
8.0	8
13.0	6
19.0	4
32.0	2
52.0	0

CHART 44–3

Metric wire size in squared millimeters (mm^2) conversion chart to American wire gauge (AWG).

? FREQUENTLY ASKED QUESTION

Do They Make 13 Gauge Wire?

Yes. AWG sizing of wire includes all gauge numbers, including 13, even though the most commonly used sizes are even numbered, such as 12, 14, or 16.

Because the sizes are so close, wire in every size is not commonly stocked, but can be ordered for a higher price. Therefore, if a larger wire size is needed, it is common practice to select the next lower, even-numbered gauge.

12 V	RECOMMENDED WIRE GAUGE (AWG) (FOR LENGTH IN FEET)*						
AMPS	3′	5′	7′	10′	15′	20′	25′
5	18	18	18	18	18	18	18
7	18	18	18	18	18	18	16
10	18	18	18	18	16	16	16
12	18	18	18	18	16	16	14
15	18	18	18	18	14	14	12
18	18	18	16	16	14	14	12
20	18	18	16	16	14	12	10
22	18	18	16	16	12	12	10
24	18	18	16	16	12	12	10
30	18	16	16	14	10	10	10
40	18	16	14	12	10	10	8
50	16	14	12	12	10	10	8
100	12	12	10	10	6	6	4
150	10	10	8	8	4	4	2
200	10	8	8	6	4	4	2

CHART 44–4

Recommended AWG wire size increases as the length increases because all wire has internal resistance. The longer the wire is, the greater the resistance. The larger the diameter is, the lower the resistance.

*When mechanical strength is a factor, use the next larger wire gauge.

For example, a trailer may require 14 gauge wire to light all the trailer lights, but if the wire required is over 25 ft long, 12 gauge wire should be used. Most automotive wire, except for spark plug wire, is often called **primary wire** (named for the voltage range used in the primary ignition circuit) because it is designed to operate at or near battery voltage.

GROUND WIRES

PURPOSE AND FUNCTION All vehicles use ground wires between the engine and body and/or between the body and the negative terminal of the battery. The two types of ground wires are:

- Insulated copper wire
- Braided ground straps

Braided grounds straps are uninsulated. It is not necessary to insulate a ground strap because it does not matter if it touches metal, as it already attaches to ground. Braided ground straps are more flexible than stranded wire. Because the engine will move slightly on its mounts, the braided ground strap must be able to flex without breaking. ● **SEE FIGURE 44–1**.

SKIN EFFECT The braided strap also dampens out some radio-frequency interference that otherwise might be transmitted through standard stranded wiring due to the skin effect.

The **skin effect** is the term used to describe how high-frequency AC electricity flows through a conductor. Direct current flows through

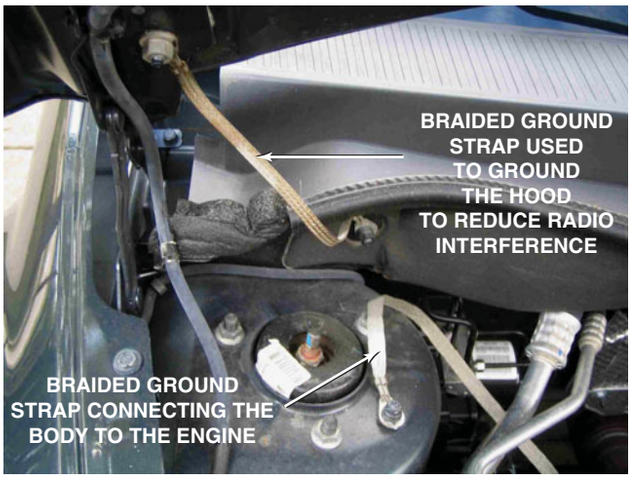


FIGURE 44–1 All lights and accessories ground to the body of the vehicle. Body ground wires such as this one are needed to conduct all of the current from these components back to the negative terminal of the battery. The body ground wire connects the body to the engine. Most battery negative cables attach to the engine.



FIGURE 44–2 Battery cables are designed to carry heavy starter current and are therefore usually 4 gauge or larger wire. Note that this battery has a thermal blanket covering to help protect the battery from high underhood temperatures. The wiring is also covered with plastic conduit called split-loom tubing.

? FREQUENTLY ASKED QUESTION

What Is a Twisted Pair?

A **twisted pair** is used to transmit low-voltage signals using two wires that are twisted together. Electromagnetic interference can create a voltage in a wire and twisting the two signal wires cancels out the induced voltage. A twisted pair means that the two wires have at least nine turns per foot (turns per meter). A rule of thumb is a twisted pair should have one twist per inch of length.

a conductor, but alternating current tends to travel through the outside (skin) of the conductor. Because of the skin effect, most audio (speaker) cable is constructed of many small-diameter copper wires instead of fewer larger strands, because the smaller wire has a greater surface area and therefore results in less resistance to the flow of AC voltage.

NOTE: Body ground wires are necessary to provide a circuit path for the lights and accessories that ground to the body and flow to the negative battery terminal.

BATTERY CABLES

Battery cables are the largest wires used in the automotive electrical system. The cables are usually 4 gauge, 2 gauge, or 1 gauge wires (19 mm^2 or larger). ● **SEE FIGURE 44–2**.

Wires larger than 1 gauge are called 0 gauge (pronounced "ought"). Larger cables are labeled 2/0 or 00 (2 ought) and 3/0 or 000 (3 ought). Electrical systems that are 6 volts require battery cables two sizes larger than those used for 12 volt electrical systems, because the lower voltage used in antique vehicles resulted in twice the amount of current (amperes) to supply the same electrical power.

JUMPER CABLES

Jumper cables are 4 to 2/0 gauge electrical cables with large clamps attached and are used to connect a vehicle that has a discharged battery to a vehicle that has a good battery. Good-quality jumper cables are necessary to prevent excessive voltage drops caused by cable resistance. Aluminum wire jumper cables should not be used, because even though aluminum is a good electrical conductor (although not as good as copper), it is less flexible and can crack and break when bent or moved repeatedly. The size should be 6 gauge or larger.

1/0 AWG welding cable can be used to construct an excellent set of jumper cables using welding clamps on both ends. Welding cable is usually constructed of many very fine strands of wire, which allow for easier bending of the cable as the strands of fine wire slide against each other inside the cable.

NOTE: Always check the wire gauge of any battery cables or jumper cables and do not rely on the outside diameter of the wire. Many lower cost jumper cables use smaller gauge wire, but may use thick insulation to make the cable look as if it is the correct size wire.

FUSES AND CIRCUIT PROTECTION DEVICES

CONSTRUCTION **Fuses** should be used in every circuit to protect the wiring from overheating and damage caused by excessive current flow as a result of a short circuit or other malfunction. The symbol for a fuse is a wavy line between two points: —∿—

A fuse is constructed of a fine tin conductor inside a glass, plastic, or ceramic housing. The tin is designed to melt and open the circuit if excessive current flows through the fuse. Each fuse is rated according to its maximum current-carrying capacity.

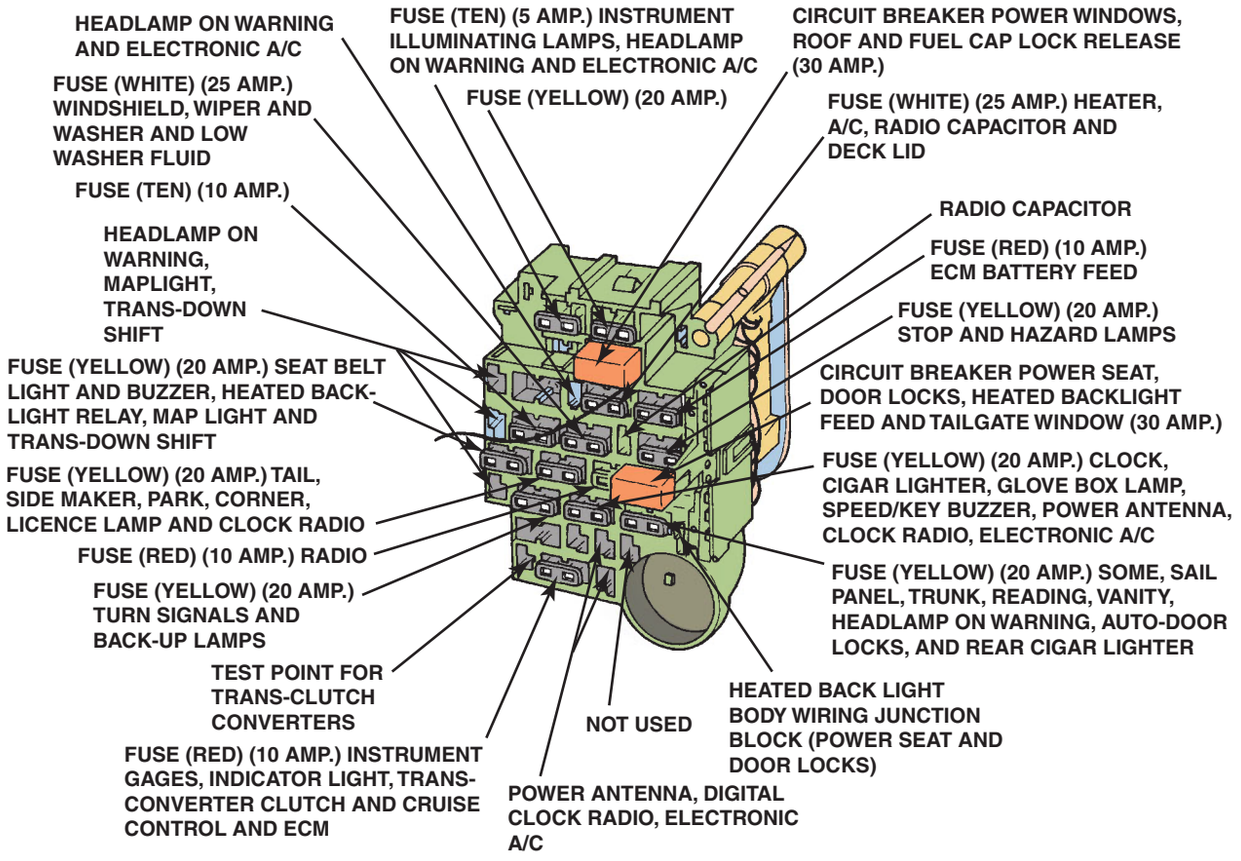


FIGURE 44–3 A typical automotive fuse panel.

NORMAL CURRENT IN THE CIRCUIT (AMPERES)	FUSE RATING
7.5 A	10 A
16 A	20 A
24 A	30 A

CHART 44–5

The fuse rating should be 20% higher than the maximum current in the circuit to provide the best protection for the wiring and the component being protected.

Many fuses are used to protect more than one circuit of the automobile. ● **SEE FIGURE 44–3**.

A typical example is the fuse for the cigarette lighter that also protects many other circuits, such as those for the courtesy lights, clock, and other circuits. A fault in one of these circuits can cause this fuse to melt, which will prevent the operation of all other circuits that are protected by the fuse.

NOTE: The SAE term for a cigarette lighter is *cigar lighter* because the diameter of the heating element is large enough for a cigar. The term *cigarette lighter* will be used throughout this book because it is the most common usage.

AMPERAGE RATING	COLOR
1	Dark green
2	Gray
2.5	Purple
3	Violet
4	Pink
5	Tan
6	Gold
7.5	Brown
9	Orange
10	Red
14	Black
15	Blue
20	Yellow
25	White
30	Green

CHART 44–6

The amperage rating and the color of the blade fuse are standardized.

FUSE RATINGS Fuses are used to protect the wiring and components in the circuit from damage if an excessive amount of current flows. The fuse rating is normally about 20% higher than the normal current in the circuit. ● **SEE CHART 44–5** for a typical fuse rating based on the normal current in the circuit. In other words, the normal current flow should be about 80% of the fuse rating.

BLADE FUSES Colored blade-type fuses are also referred to as ATO fuses and have been used since 1977. The color of the plastic of blade fuses indicates the maximum current flow, measured in amperes.

● **SEE CHART 44–6** for the color and the amperage rating of blade fuses.

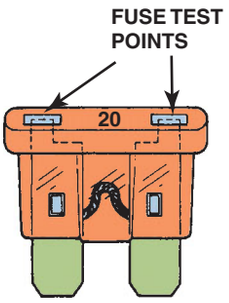


FIGURE 44–4 Blade-type fuses can be tested through openings in the plastic at the top of the fuse.

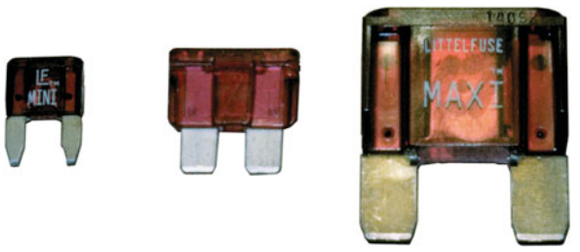


FIGURE 44–5 Three sizes of blade-type fuses: mini on the left, standard or ATO type in the center, and maxi on the right.

AMPERAGE RATING	COLOR
5	Tan
7.5	Brown
10	Red
15	Blue
20	Yellow
25	Natural
30	Green

CHART 44–7

Mini fuse amperage rating and colors.

AMPERAGE RATING	COLOR
20	Yellow
30	Green
40	Amber
50	Red
60	Blue
70	Brown
80	Natural

CHART 44–8

Maxi fuse amperage rating and colors.

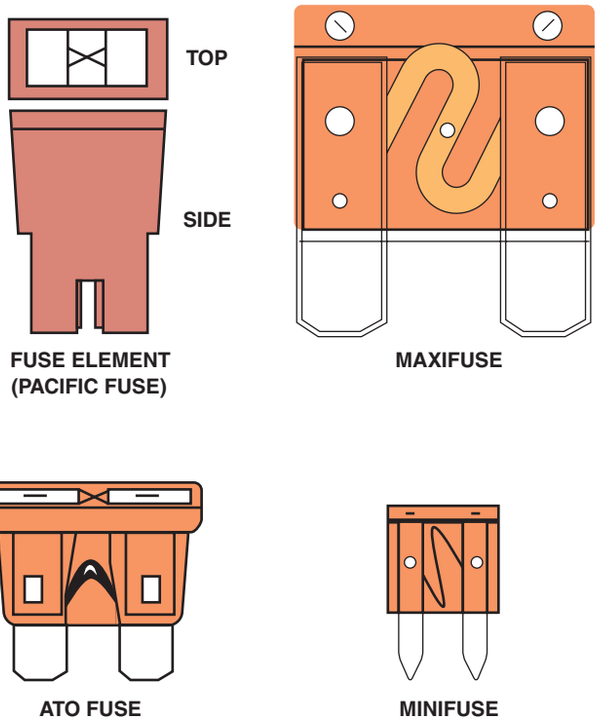


FIGURE 44–6 A comparison of the various types of protective devices used in most vehicles.

Each fuse has an opening in the top of its plastic portion to allow access to its metal contacts for testing purposes. ● **SEE FIGURE 44–4**.

MINI FUSES To save space, many vehicles use mini (small) blade fuses. Not only do they save space but they also allow the vehicle design engineer to fuse individual circuits instead of grouping many different components on one fuse. This improves customer satisfaction because if one component fails, it only affects that one circuit without stopping electrical power to several other circuits as well. This makes troubleshooting a lot easier too, because each circuit is separate. ● **SEE CHART 44–7** for the amperage rating and corresponding fuse color for mini fuses.

MAXI FUSES Maxi fuses are a large version of blade fuses and are used to replace fusible links in many vehicles. Maxi fuses are rated up to 80 amperes or more. ● **SEE CHART 44–8** for the amperage rating and corresponding color for maxi fuses.

● **SEE FIGURE 44–5** for a comparison of the various sizes of blade-type fuses.

PACIFIC FUSE ELEMENT First used in the late 1980s, **Pacific fuse elements** (also called a **fuse link** or **auto link**) are used to protect wiring from a direct short-to-ground. The housing contains a short link of wire sized for the rated current load. The transparent top allows inspection of the link inside. ● **SEE FIGURE 44–6**.

TESTING FUSES It is important to test the condition of a fuse if the circuit being protected by the fuse does not operate. Most blown fuses can be detected quickly because the center conductor is melted. Fuses can also fail and open the circuit because of a poor connection in the fuse itself or in the fuse holder. Therefore, just because a fuse "looks okay" does not mean that it *is* okay. All fuses should be tested with a test light. The test light should be connected to first one side of the fuse and then the other. A test light should light on both sides. If the test light only lights on one side, the fuse is blown or open. If the test light does not light on either side of the fuse, then that circuit is not being supplied power. ● **SEE FIGURE 44–7**. An ohmmeter can be used to test fuses.



FIGURE 44–7 To test a fuse, use a test light to check for power at the power side of the fuse. The ignition switch and lights may have to be on before some fuses receive power. If the fuse is good, the test light should light on both sides (power side and load side) of the fuse.

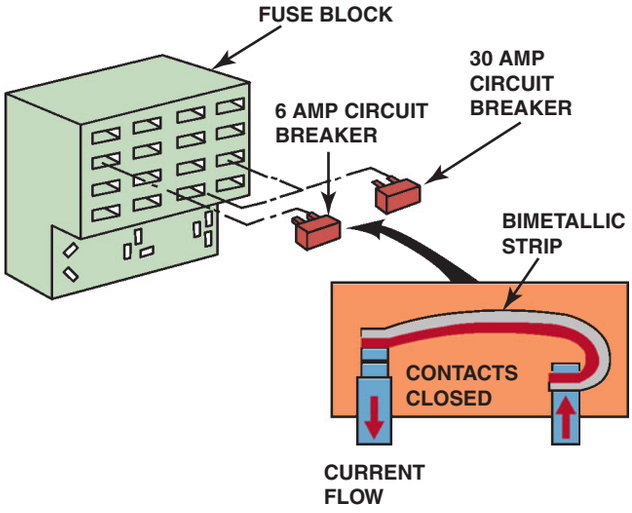


FIGURE 44–8 Typical blade circuit breaker fits into the same space as a blade fuse. If excessive current flows through the bimetallic strip, the strip bends and opens the contacts and stops current flow. When the circuit breaker cools, the contacts close again, completing the electrical circuit.

CIRCUIT BREAKERS

Circuit breakers are used to prevent harmful overload (excessive current flow) in a circuit by opening the circuit and stopping the current flow to prevent overheating and possible fire caused by hot wires or electrical components. **Circuit breakers** are mechanical units made of two different metals (bimetallic) that deform when heated and open a set of contact points that work in the same manner as an "off" switch. ● **SEE FIGURE 44–8**.

Cycling-type circuit breakers, therefore, are reset when the current stops flowing, which causes the bimetallic strip to cool and the circuit to close again. A circuit breaker is used in circuits that could affect the safety of passengers if a conventional nonresetting fuse were used. The headlight circuit is an excellent example of the use of a circuit breaker rather than a fuse. A short or grounded circuit anywhere in the headlight circuit could cause excessive current flow and, therefore, the opening of the circuit. Obviously, a sudden loss of headlights at night could have disastrous results. A circuit breaker opens and closes the circuit rapidly, thereby protecting the circuit from overheating and also providing sufficient current flow to maintain at least partial headlight operation.



FIGURE 44–9 Electrical symbols used to represent circuit breakers.

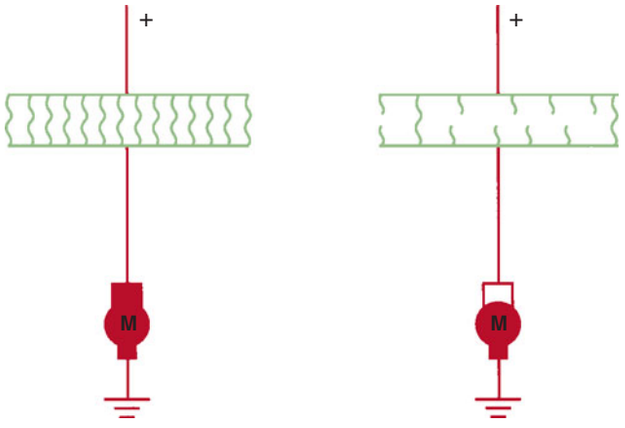


FIGURE 44–10 (a) The normal operation of a PTC circuit protector such as in a power window motor circuit showing the many conducting paths. With normal current flow, the temperature of the PTC circuit protector remains normal. (b) When current exceeds the amperage rating of the PTC circuit protector, the polymer material that makes up the electronic circuit protector increases in resistance. As shown, a high-resistance electrical path still exists even though the motor will stop operating as a result of the very low current flow through the very high resistance. The circuit protector will not reset or cool down until voltage is removed from the circuit.

Circuit breakers are also used in other circuits where conventional fuses could not provide for the surges of high current commonly found in those circuits. ● **SEE FIGURE 44–9** for the electrical symbols used to represent a circuit breaker.

Examples are the circuits for the following accessories.

1. Power seats
2. Power door locks
3. Power windows

PTC CIRCUIT PROTECTORS

Positive temperature coefficient (PTC) circuit protectors are solid state (without moving parts). Like all other circuit protection devices, PTCs are installed in series in the circuit being protected. If excessive current flows, the temperature and resistance of the PTC increase.

This increased resistance reduces current flow (amperes) in the circuit and may cause the electrical component in the circuit not to function correctly. For example, when a PTC circuit protector is used in a power window circuit, the increased resistance causes the operation of the power window to be much slower than normal.

Unlike circuit breakers or fuses, PTC circuit protection devices do *not* open the circuit, but rather provide a very high resistance between the protector and the component. ● **SEE FIGURE 44–10**.

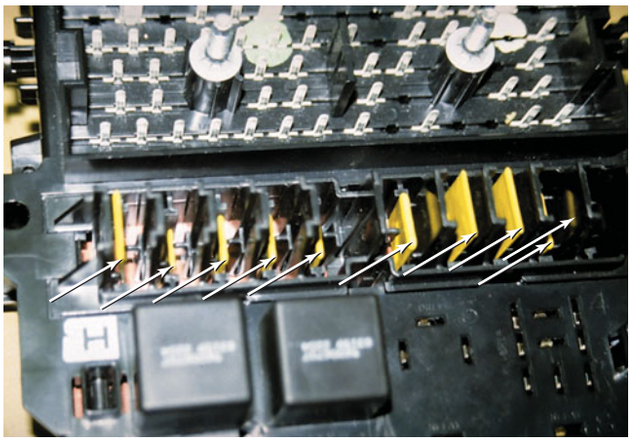


FIGURE 44–11 PTC circuit protectors are used extensively in the power distribution center of this Chrysler vehicle.

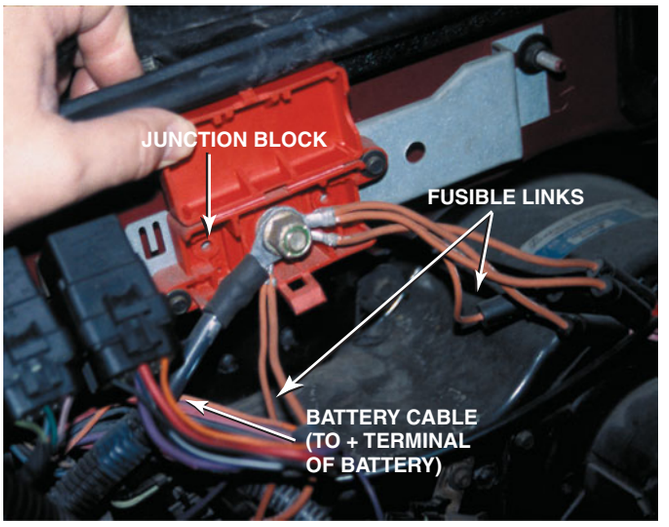


FIGURE 44–12 Fusible links are usually located close to the battery and are usually attached to a junction block. Notice that they are only 6 to 9 in. long and feed more than one fuse from each fusible link.

In other words, voltage will be available to the component. This fact has led to a lot of misunderstanding about how these circuit protection devices actually work. It is even more confusing when the circuit is opened and the PTC circuit protector cools down. When the circuit is turned back on, the component may operate normally for a short time; however, the PTC circuit protector will again get hot because of too much current flow. Its resistance again increases to limit current flow.

The electronic control unit (computer) used in most vehicles today incorporates thermal overload protection devices. ● **SEE FIGURE 44–11**.

Therefore, when a component fails to operate, do not blame the computer. The current control device is controlling current flow to protect the computer. Components that do not operate correctly should be checked for proper resistance and current draw.

FUSIBLE LINKS

A **fusible link** is a type of fuse that consists of a short length (6 to 9 in. long) of standard copper-strand wire covered with a special nonflammable insulation. This wire is usually four wire numbers smaller than the wire of the circuits it protects. For example, a 12 gauge circuit is protected by a 16 gauge fusible link. The special thick insulation over the wire may make it look larger than other wires of the same gauge number. ● **SEE FIGURE 44–12**.

If excessive current flow (caused by a short-to-ground or a defective component) occurs, the fusible link will melt in half and open the circuit to prevent a fire hazard. Some fusible links are identified with "fusible link" tags at the junction between the fusible link and the standard chassis wiring, which represent only the junction. Fusible links are the backup system for circuit protection. All current except the current used by the starter motor flows through fusible links and then through individual circuit fuses. It is possible that a fusible link will melt and not blow a fuse. Fusible links are installed as close to the battery as possible so that they can protect the wiring and circuits coming directly from the battery.

MEGA FUSES

Many newer vehicles are equipped with mega fuses instead of fusible links to protect high-amperage circuits. Circuits often controlled by mega fuses include:

- Charging circuit
- HID headlights
- Heated front or rear glass
- Multiple circuits usually protected by mega fuses
- Mega fuse rating for vehicles, including 80, 100, 125, 150, 175, 200, 225, and 250 amperes

● **SEE FIGURE 44–13**.



FIGURE 44–13 A 125 ampere rated mega fuse used to control the current from the alternator.

TECH TIP

Find the Root Cause

If a mega fuse or fusible link fails, find the root cause before replacing it. A mega fuse can fail due to vibration or physical damage as a result of a collision or corrosion. Check to see if the fuse itself is loose and can be moved by hand. If loose, then simply replace the mega fuse. If a fusible link or mega fuse has failed due to excessive current, check for evidence of a collision or any other reason that could cause an excessive amount of current to flow. This inspection should include each electrical component being supplied current from the fusible link. After being sure that the root cause has been found and corrected, then replace the fusible link or mega fuse.

CHECKING FUSIBLE LINKS AND MEGA FUSES

Fusible links and mega fuses are usually located near where electrical power is sent to other fuses or circuits, such as:

- Starter solenoid battery terminals
- Power distribution centers

- Output terminals of alternators
- Positive terminals of the battery

Fusible links can melt and not show any external evidence of damage. To check a fusible link, gently pull on each end to see if it stretches. If the insulation stretches, then the wire inside has melted and the fusible link must be replaced after determining what caused the link to fail.

Another way to check a fusible link is to use a test light or a voltmeter and check for available voltage at both ends of the fusible link. If voltage is available at only one end, then the link is electrically open and should be replaced.

REPLACING A FUSIBLE LINK If a fusible link is found to be melted, perform the following steps.

STEP 1 Determine why the fusible link failed and repair the fault.

STEP 2 Check service information for the exact length, gauge, and type of fusible link required.

STEP 3 Replace the fusible link with the specified fusible link wire and according to the instructions found in the service information.

CAUTION: Always use the *exact* length of fusible link wire required because if it is too short, it will not have enough resistance to generate the heat needed to melt the wire and protect the circuits or components. If the wire is too long, it could melt during normal operation of the circuits it is protecting. Fusible link wires are usually longer than 6 in. and shorter than 9 in.

TERMINALS AND CONNECTORS

A **terminal** is a metal fastener attached to the end of a wire, which makes the electrical connection. The term **connector** usually refers to the plastic portion that snaps or connects together, thereby making the mechanical connection. Wire terminal ends usually snap into and are held by a connector. Male and female connectors can then be snapped together, thereby completing an electrical connection. Connectors exposed to the environment are also equipped with a weather-tight seal. ● **SEE FIGURE 44–14**.

Terminals are retained in connectors by the use of a **lock tang**. Removing a terminal from a connector includes the following steps.

STEP 1 Release the **connector position assurance (CPA)**, if equipped, that keeps the latch of the connector from releasing accidentally.

STEP 2 Separate the male and female connector by opening the lock. ● **SEE FIGURE 44–15**.

STEP 3 Release the secondary lock, if equipped. ● **SEE FIGURE 44–16**.

STEP 4 Using a pick, look for the slot in the plastic connector where the lock tang is located, depress the lock tang, and gently remove the terminal from the connector. ● **SEE FIGURE 44–17**.

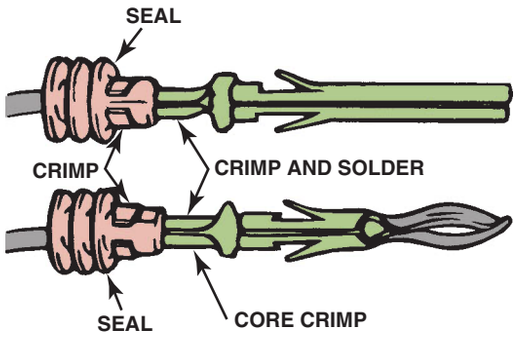


FIGURE 44–14 Some terminals have seals attached to help seal the electrical connections.

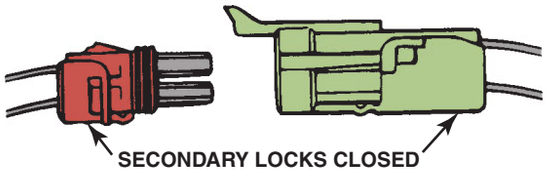


FIGURE 44–15 Separate a connector by opening the lock and pulling the two apart.

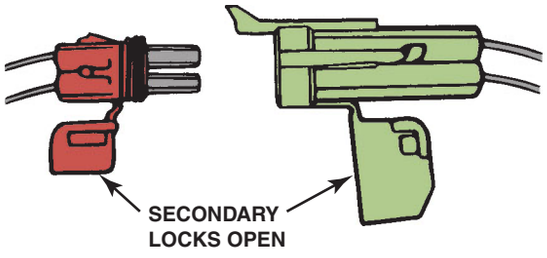


FIGURE 44–16 The secondary locks help retain the terminals in the connector.

TECH TIP

Look for the "Green Crud"

Corroded connections are a major cause of intermittent electrical problems and open circuits. The usual sequence of conditions is as follows:

1. **Heat causes expansion.** This heat can be from external sources such as connectors being too close to the exhaust system. Another possible source of heat is a poor connection at the terminal, causing a voltage drop and heat due to the electrical resistance.
2. **Condensation occurs when a connector cools.** The moisture in the condensation causes rust and corrosion.
3. **Water gets into the connector.** The solution is, if corroded connectors are noticed, the terminal should be cleaned and the condition of the electrical connection to the wire terminal end(s) confirmed. Many vehicle manufacturers recommend using a dielectric silicone or lithium-based grease inside connectors to prevent moisture from getting into and attacking the connector.

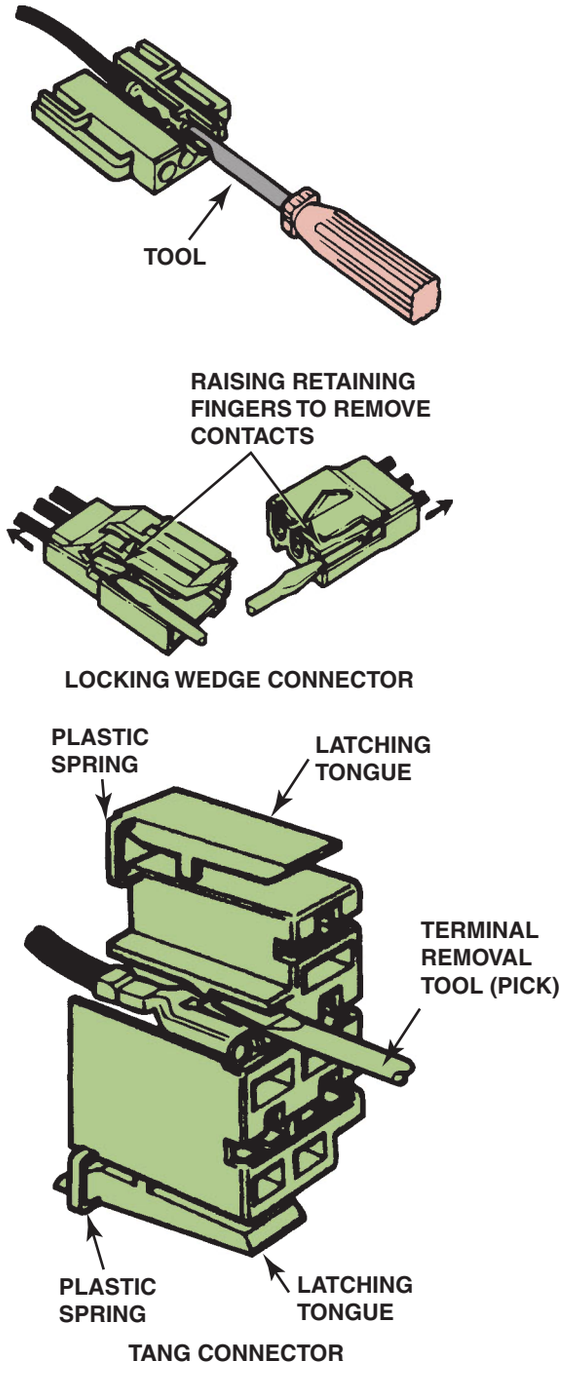


FIGURE 44–17 Use a small removal tool, sometimes called a pick, to release terminals from the connector.



FIGURE 44–18 Always use rosin-core solder for electrical or electronic soldering. Also, use small-diameter solder for small soldering irons. Use large-diameter solder only for large-diameter (large-gauge) wire and higher-wattage soldering irons (guns).



FIGURE 44–19 A butane-powered soldering tool. The cap has a built-in striker to light a converter in the tip of the tool. This handy soldering tool produces the equivalent of 60 watts of heat. It operates for about 1/2 hour on one charge from a commonly available butane refill dispenser.

WIRE REPAIR

SOLDER Many manufacturers recommend that all wiring repairs be soldered. Solder is an alloy of tin and lead used to make a good electrical contact between two wires or connections in an electrical circuit. However, a flux must be used to help clean the area and to help make the solder flow. Therefore, solder is made with a resin (rosin) contained in the center, called **rosin-core solder**.

CAUTION: Never use acid-core solder to repair electrical wiring as the acid will cause corrosion.

● **SEE FIGURE 44–18.**

An acid-core solder is also available but should only be used for soldering sheet metal. Solder is available with various percentages of tin and lead in the alloy. Ratios are used to identify these various types of solder, with the first number denoting the percentage of tin in the alloy and the second number giving the percentage of lead. The most commonly used solder is 50/50, which means that 50% of the solder is tin and the other 50% is lead. The percentages of each alloy primarily determine the melting point of the solder.

- 60/40 solder (60% tin/40% lead) melts at 361°F (183°C).
- 50/50 solder (50% tin/50% lead) melts at 421°F (216°C).
- 40/60 solder (40% tin/60% lead) melts at 460°F (238°C).

NOTE: The melting points stated here can vary depending on the purity of the metals used.

Because of the lower melting point, 60/40 solder is the most highly recommended solder to use, followed by 50/50.

SOLDERING GUNS When soldering wires, be sure to heat the wires (not the solder) using:

- An electric soldering gun or soldering pencil (60 to 150 watt rating)
- Butane-powered tool that uses a flame to heat the tip (about 60 watt rating)

● **SEE FIGURE 44–19.**

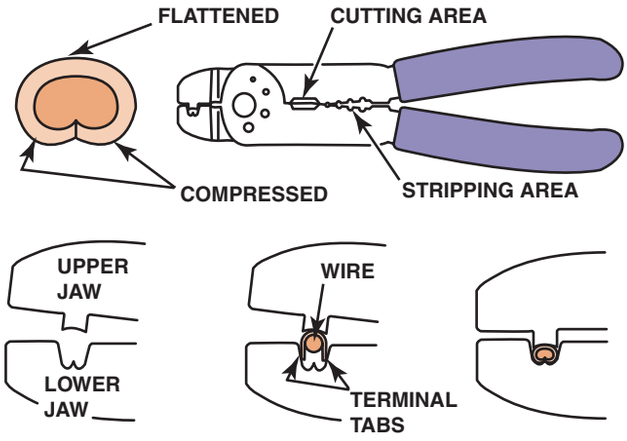


FIGURE 44–20 Notice that to create a good crimp the open part of the terminal is placed in the jaws of the crimping tool toward the anvil or the W-shape part.



FIGURE 44–22 A butane torch especially designed for use on heat shrink applies heat without an open flame, which could cause damage.

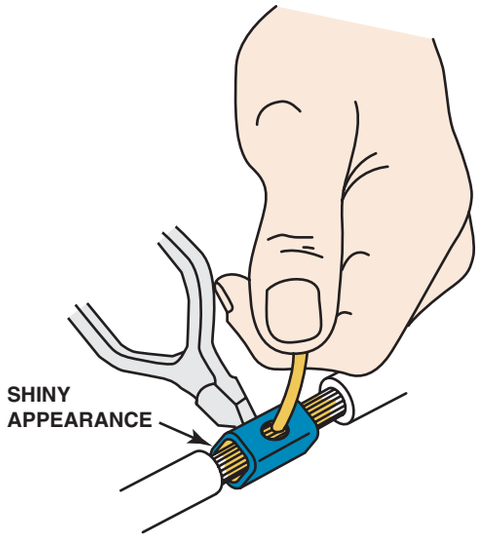


FIGURE 44–21 All hand-crimped splices or terminals should be soldered to be assured of a good electrical connection.

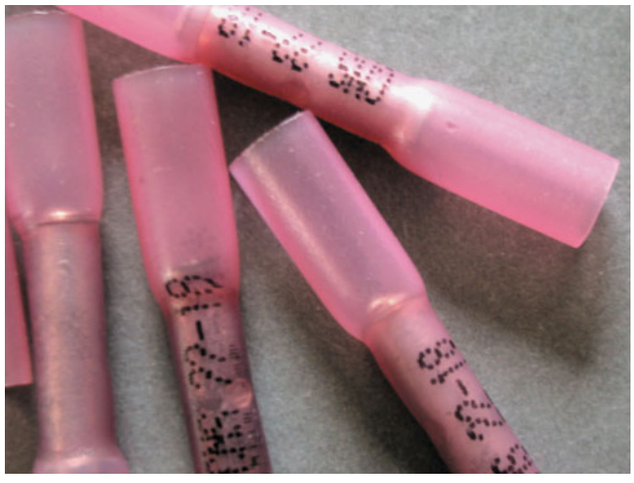


FIGURE 44–23 A typical crimp-and-seal connector. This type of connector is first lightly crimped to retain the ends of the wires and then it is heated. The tubing shrinks around the wire splice, and thermoplastic glue melts on the inside to provide an effective weather-resistant seal.

SOLDERING PROCEDURE

Soldering a wiring splice includes the following steps.

STEP 1 While touching the soldering gun to the splice, apply solder to the junction of the gun and the wire.

STEP 2 The solder will start to flow. Do not move the soldering gun.

STEP 3 Just keep feeding more solder into the splice as it flows into and around the strands of the wire.

STEP 4 After the solder has flowed throughout the splice, remove the soldering gun and the solder from the splice and allow the solder to cool slowly.

The solder should have a shiny appearance. Dull-looking solder may be caused by not reaching a high enough temperature, which results in a **cold solder joint**. Reheating the splice and allowing it to cool often restores the shiny appearance.

CRIMPING TERMINALS

Terminals can be crimped to create a good electrical connection if the proper type of crimping tool is used. Most vehicle manufacturers recommend that a W-shaped crimp be used to force the strands of the wire into a tight space. ● **SEE FIGURE 44–20**.

Most vehicle manufacturers also specify that all hand-crimped terminals or splices be soldered. ● **SEE FIGURE 44–21**.

HEAT SHRINK TUBING

Heat shrink tubing is usually made from polyvinyl chloride (PVC) or polyolefin and shrinks to about half of its original diameter when heated; this is usually called a 2:1 shrink ratio. Heat shrink by itself does not provide protection against corrosion, because the ends of the tubing are not sealed against moisture. DaimlerChrysler Corporation recommends that all wire repairs that may be exposed to the elements be repaired and sealed using **adhesive-lined heat shrink tubing**. The tubing is usually made from flame-retardant flexible polyolefin with an internal layer of special thermoplastic adhesive. When heated, this tubing shrinks to one-third of its original diameter (3:1 shrink ratio) and the adhesive melts and seals the ends of the tubing. ● **SEE FIGURE 44–22**.

CRIMP-AND-SEAL CONNECTORS

General Motors Corporation recommends the use of crimp-and-seal connectors as the method for wire repair. **Crimp-and-seal connectors** contain a sealant and shrink tubing in one piece and are not simply butt connectors. ● **SEE FIGURE 44–23**.

The usual procedure specified for making a wire repair using a crimp-and-seal connector is as follows:

STEP 1 Strip the insulation from the ends of the wire (about 5/16 in., or 8 mm).

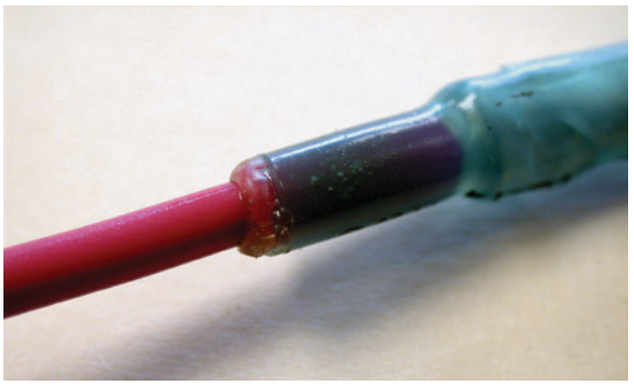


FIGURE 44–24 Heating the crimp-and-seal connector melts the glue and forms an effective seal against moisture.

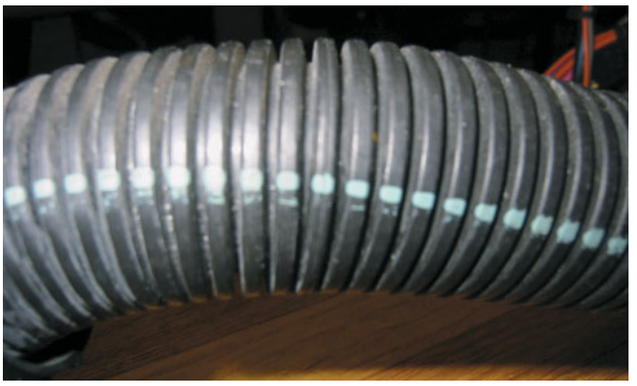


FIGURE 44–25 Conduit that has a paint strip is constructed of plastic that can withstand high underhood temperatures.

? FREQUENTLY ASKED QUESTION

What Method of Wire Repair Should I Use?

Good question. Vehicle manufacturers recommend all wire repairs performed under the hood, or where the repair could be exposed to the elements, be weatherproof. The most commonly recommended methods include:

- **Crimp and seal connector.** These connectors are special and are not like low cost insulated-type crimp connectors. This type of connector is recommended by General Motors and others and is sealed using heat after the mechanical crimp has secured the wire ends together.
- **Solder and adhesive-lined heat shrink tubing.** This method is recommended by Chrysler and it uses the special heat shrink that has glue inside that melts when heated to form a sealed connection. Regular heat shrink tubing can be used inside a vehicle, but should not be used where it can be exposed to the elements.
- **Solder and electrical tape.** This is acceptable to use inside the vehicle where the splice will not be exposed to the outside elements. It is best to use a crimp and seal even on the inside of the vehicle for best results.

STEP 2 Select the proper size of crimp-and-seal connector for the gauge of wire being repaired. Insert the wires into the splice sleeve and crimp.

NOTE: Only use the specified crimping tool to help prevent the pliers from creating a hole in the cover.

STEP 3 Apply heat to the connector until the sleeve shrinks down around the wire and a small amount of sealant is observed around the ends of the sleeve, as shown in **FIGURE 44–24**.

ALUMINUM WIRE REPAIR Some vehicle manufacturers used plastic-coated solid aluminum wire for some body wiring. Because aluminum wire is brittle and can break as a result of vibration, it is only used where there is no possible movement of the wire, such as along the floor or sill area. This section of wire is stationary, and the wire changes back to copper at a junction terminal after the trunk or rear section of the vehicle, where movement of the wiring may be possible.

? FREQUENTLY ASKED QUESTION

What Is in Lead-Free Solder?

Lead is an environmental and a health concern and all vehicle manufacturers are switching to lead-free solder. Lead free solder does not contain lead but usually a very high percentage of tin. Several formulations of lead-free solder include:

- 95% Tin; 5% Antimony (melting temperature 450°F (245°C)
- 97% Tin; 3% Copper (melting temperature 441°F (227°C)
- 96% Tin; 4% Silver (melting temperature 443°F (228°C)

If any aluminum wire must be repaired or replaced, the following procedure should be used to be assured of a proper repair. The aluminum wire is usually found protected in a plastic conduit. This conduit is then normally slit, after which the wires can easily be removed for repair.

STEP 1 Carefully strip only about 1/4 in. (6 mm) of insulation from the aluminum wire, being careful not to nick or damage the aluminum wire case.

STEP 2 Use a crimp connector to join two wires together. Do not solder an aluminum wire repair. Solder will not readily adhere to aluminum because the heat causes an oxide coating on the surface of the aluminum.

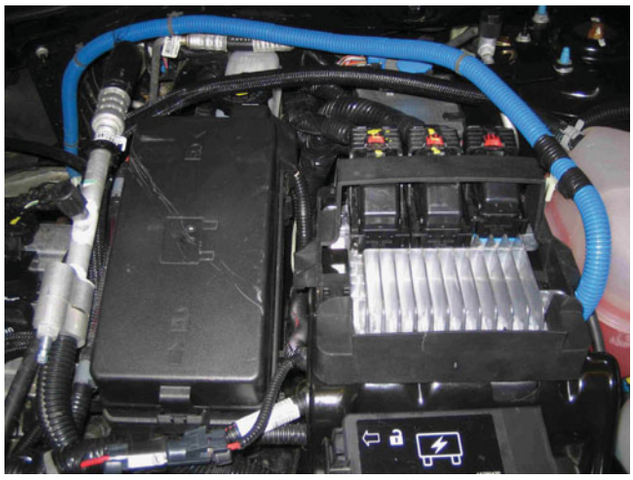
STEP 3 The spliced, crimped connection must be coated with petroleum jelly to prevent corrosion.

STEP 4 The coated connection should be covered with shrinkable plastic tubing or wrapped with electrical tape to seal out moisture.

ELECTRICAL CONDUIT

Electrical conduit covers and protects wiring. The color used on electrical convoluted conduit tells the technician a lot if some information is known, such as the following:

- **Black conduit with a green or blue stripe.** This conduit is designed for high temperatures and is used under the hood and near hot engine parts. Do not replace high-temperature conduit with low-temperature conduit that does not have a stripe when performing wire repairs. **SEE FIGURE 44–25.**



(a)



(b)

FIGURE 44–26 (a) Blue conduit is used to cover circuits that carry up to 42 volts. (b) Yellow conduit can also be used to cover 42 volt wiring.

- **Blue or yellow conduit.** This color conduit is used to cover wires that have voltages ranging from 12 to 42 volts. Circuits that use this high voltage usually are for the electric power steering. While 42 volts does not represent a shock hazard, an arc will be maintained if a line circuit is disconnected. Use caution around these circuits. ● **SEE FIGURE 44–26**.
- **Orange conduit.** This color conduit is used to cover wiring that carries high-voltage current from 144 to 650 volts. These circuits are found in hybrid electric vehicles (HEVs). An electric shock from these wires can be fatal, so extreme caution has to be taken when working on or near the components that have orange conduit. Follow the vehicle manufacturer's instruction for de-powering the high-voltage circuits before work begins on any of the high-voltage components. ● **SEE FIGURE 44–27**.



FIGURE 44–27 Always follow the vehicle manufacturer's instructions which include the use of linesman's (high-voltage) gloves if working on circuits that are covered in orange conduit.

REVIEW QUESTIONS

1. What is the difference between the American wire gauge (AWG) system and the metric system?
2. What is the difference between a wire and a cable?
3. What is the difference between a terminal and a connector?
4. How do fuses, PTC circuit protectors, circuit breakers, and fusible links protect a circuit?
5. How should a wire repair be done if the repair is under the hood where it is exposed to the outside?

CHAPTER QUIZ

1. The higher the AWG number, _____.
   a. The smaller the wire diameter
   b. The larger the wire diameter
   c. The thicker the insulation
   d. The more strands in the conductor core
2. Metric wire size is measured in units of _____.
   a. Meters
   b. Cubic centimeters
   c. Square millimeters
   d. Cubic millimeters
3. Which statement is true about fuse ratings?
   a. The fuse rating should be less than the maximum current for the circuit.
   b. The fuse rating should be higher than the normal current for the circuit.
   c. Of the fuse rating, 80% should equal the current in the circuit.
   d. Both b and c

4. Which statements are true about wire, terminals, and connectors?
   a. Wire is called a lead, and the metal end is a connector.
   b. A connector is usually a plastic piece where terminals lock in.
   c. A lead and a terminal are the same thing.
   d. Both a and c

5. The type of solder that should be used for electrical work is _____.
   a. Rosin core
   b. Acid core
   c. 60/40 with no flux
   d. 50/50 with acid paste flux

6. A technician is performing a wire repair on a circuit under the hood of the vehicle. Technician A says to use solder and adhesive-lined heat shrink tubing or a crimp and seal connector. Technician B says to solder and use electrical tape. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

7. Two technicians are discussing fuse testing. Technician A says that a test light should light on both test points of the fuse if it is okay. Technician B says the fuse is defective if a test light only lights on one side of the fuse. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

8. What is true about the plastic conduit covering the wiring?
   a. The color stripe is used to identify the temperature rating of the conduit
   b. The color identifies the voltage level of the circuits being protected.
   c. Protects the wiring.
   d. All of the above

9. Many ground straps are uninsulated and braided because _____.
   a. They are more flexible to allow movement of the engine without breaking the wire.
   b. They are less expensive than conventional wire.
   c. They help dampen radio-frequency interference (RFI).
   d. Both a and c

10. What causes a fuse to blow?
    a. A decrease in circuit resistance
    b. An increase in the current flow through the circuit
    c. A sudden decrease in current flow through the circuit
    d. Both a and b

chapter 45 WIRING SCHEMATICS AND CIRCUIT TESTING

OBJECTIVES: **After studying Chapter 45, the reader should be able to:** • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "A" (General Electrical/Electronics System Diagnosis). • Interpret wiring schematics. • Explain how relays work. • Discuss the various methods that can be used to locate a short circuit. • List the electrical troubleshooting diagnosis steps.

KEY TERMS: Coil 485 • DPDT 484 • DPST 484 • Gauss gauge 490 • Momentary switch 484 • N.C. 484 • N.O. 484 • Poles 484 • Relay 485 • Short circuit 489 • SPDT 484 • SPST 484 • Terminal 480 • Throws 484 • Tone generator tester 490 • Wiring schematic 479

WIRING SCHEMATICS AND SYMBOLS

TERMINOLOGY The service manuals of automotive manufacturers include wiring schematics of every electrical circuit in a vehicle. A **wiring schematic**, sometimes called a *diagram*, shows electrical components and wiring using symbols and lines to represent components and wires. A typical wiring schematic may include all of the circuits combined on several large foldout sheets, or they may be broken down to show individual circuits. All circuit schematics or diagrams include:

- Power-side wiring of the circuit
- All splices
- Connectors
- Wire size
- Wire color
- Trace color (if any)
- Circuit number
- Electrical components
- Ground return paths
- Fuses and switches

CIRCUIT INFORMATION Many wiring schematics include numbers and letters near components and wires that may confuse readers of the schematic. Most letters used near or on a wire identify the color or colors of the wire.

- The first color or color abbreviation is the color of the wire insulation.
- The second color (if mentioned) is the color of the stripe or tracer on the base color. **SEE FIGURE 45–1**.

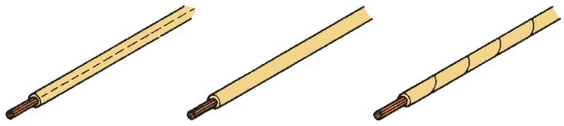


FIGURE 45–1 The center wire is a solid color wire, meaning that the wire has no other identifying tracer or stripe color. The two end wires could be labeled "BRN/WHT," indicating a brown wire with a white tracer or stripe.

ABBREVIATION	COLOR
BRN	Brown
BLK	Black
GRN	Green
WHT	White
PPL	Purple
PNK	Pink
TAN	Tan
BLU	Blue
YEL	Yellow
ORN	Orange
DK BLU	Dark blue
LT BLU	Light blue
DK GRN	Dark green
LT GRN	Light green
RED	Red
GRY	Gray
VIO	Violet

CHART 45–1

Typical abbreviations used on schematics to show wire color. Some vehicle manufacturers use two letters to represent a wire color. Check service information for the color abbreviations used.

Wires with different color tracers are indicated by both colors with a slash (/) between them. For example, BRN/WHT means a brown wire with a white stripe or tracer. ● **SEE CHART 45–1**.

WIRE SIZE Wire size is shown on all schematics. ● **FIGURE 45–2** illustrates a rear side-marker bulb circuit diagram where ".8" indicates the metric wire gauge size in square millimeters (mm^2) and "PPL" indicates a solid purple wire.

The wire diagram also shows that the color of the wire changes at the number C210. This stands for "connector #210" and is used for reference purposes. The symbol for the connection can vary depending on the manufacturer. The color change from purple (PPL) to purple with a white tracer (PPL/WHT) is not important except for knowing where the wire changes color in the circuit. The wire gauge has remained the same on both sides of the connection (0.8 mm^2 or 18 gauge). The ground circuit is the ".8 BLK" wire. ● **FIGURE 45–3** shows many of the electrical and electronic symbols that are used in wiring and circuit diagrams.

SCHEMATIC SYMBOLS

In a schematic drawing, photos or line drawings of actual components are replaced with a symbol that represents the actual component. The following discussion centers on these symbols and their meanings.

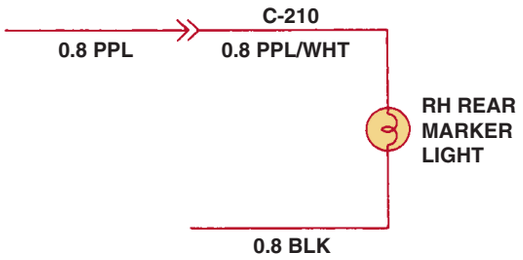


FIGURE 45–2 Typical section of a wiring diagram. Notice that the wire color changes at connection C210. The ".8" represents the metric wire size in square millimeters.

TECH TIP

Read the Arrows

Wiring diagrams indicate connections by symbols that look like arrows. ● **SEE FIGURE 45–4** on page 481.

Do *not* read these "arrows" as pointers showing the direction of current flow. Also observe that the power side (positive side) of the circuit is usually the female end of the connector. If a connector becomes disconnected, it will be difficult for the circuit to become shorted to ground or to another circuit because the wire is recessed inside the connector.

BATTERY The plates of a battery are represented by long and short lines. ● **SEE FIGURE 45–5**.

The longer line represents the positive plate of a battery and the shorter line represents the negative plate of the battery. Therefore, each pair of short and long lines represents one cell of a battery. Because each cell of a typical automotive lead-acid battery has 2.1 volts, a battery symbol showing a 12 volt battery should have six pairs of lines. However, most battery symbols simply use two or three pairs of long and short lines and then list the voltage of the battery next to the symbol. As a result, the battery symbols are shorter and yet clear, because the voltage is stated. The positive terminal of the battery is often indicated with a plus sign (+), representing the positive post of the battery, and is placed next to the long line of the end cell. The negative terminal of the battery is represented by a negative sign (−) and is placed next to the shorter cell line. The negative battery terminal is connected to ground. ● **SEE FIGURE 45–6**.

WIRING Electrical wiring is shown as straight lines and with a few numbers and/or letters to indicate the following:

- **Wire size.** This can be either AWG, such as 18 gauge, or in square millimeters, such as 0.8 mm^2.
- **Circuit numbers.** Each wire in part of a circuit is labeled with the circuit number to help the service technician trace the wiring and to provide an explanation of how the circuit should work.
- **Wire color.** Most schematics also indicate an abbreviation for the color of the wire and place it next to the wire. Many wires have two colors: a solid color and a stripe color. In this case, the solid color is listed, followed by a dark slash (/) and the color of the stripe. For example, Red/Wht would indicate a red wire with a white tracer. ● **SEE FIGURE 45–7**.
- **Terminals.** The metal part attached at the end of a wire is called a **terminal**. A symbol for a terminal is shown in ● **FIGURE 45–8**.

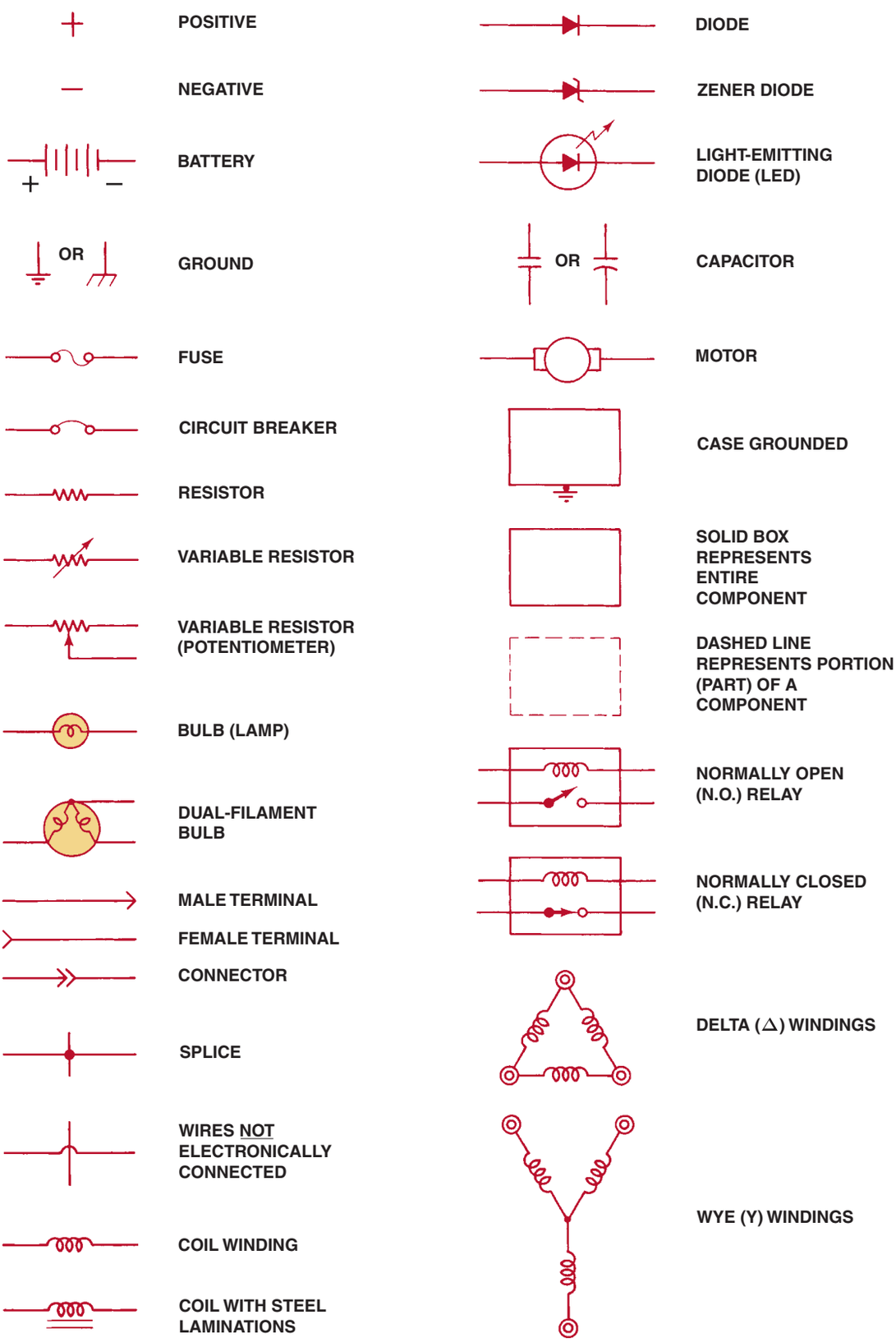


FIGURE 45–3 Typical electrical and electronic symbols used in automotive wiring and circuit diagrams.



FIGURE 45–4 In this typical connector, note that the positive terminal is usually a female connector.



FIGURE 45–5 The symbol for a battery. The positive plate of a battery is represented by the longer line and the negative plate by the shorter line. The voltage of the battery is usually stated next to the symbol.

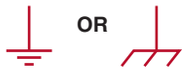


FIGURE 45–6 The ground symbol on the left represents earth ground. The ground symbol on the right represents a chassis ground.

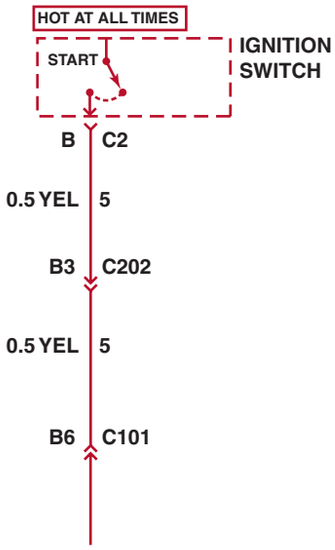


FIGURE 45–7 Starting at the top, the wire from the ignition switch is attached to terminal B of connector C2, the wire is 0.5 mm² (20 gauge AWG), and is yellow. The circuit number is 5. The wire enters connector C202 at terminal B3.



FIGURE 45–8 The electrical terminals are usually labeled with a letter or number.



FIGURE 45–9 Two wires that cross at the dot indicate that the two are electrically connected.



FIGURE 45–10 Wires that cross, but do not electrically contact each other, are shown with one wire bridging over the other.

- **Splices.** When two wires are electrically connected, the junction is shown with a black dot. The identification of the splice is an "S" followed by three numbers, such as S103. ● **SEE FIGURE 45–9**. When two wires cross in a schematic that are not electrically connected, one of the wires is shown as going over the other wire and does not connect. ● **SEE FIGURE 45–10**.
- **Connectors.** An electrical connector is a plastic part that contains one or more terminals. Although the terminals provide the electrical connection in a circuit, it is the plastic connector that keeps the terminals together mechanically.

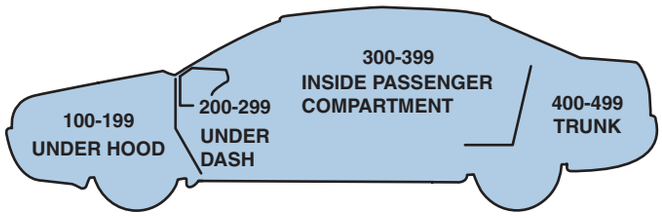


FIGURE 45–11 Connectors (C), grounds (G), and splices (S) are followed by a number, generally indicating the location in the vehicle. For example, G209 is a ground connection located under the dash.

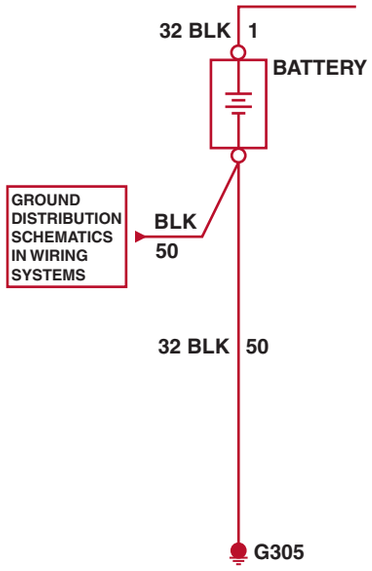


FIGURE 45–12 The ground for the battery is labeled G305 indicating the ground connector is located in the passenger compartment of the vehicle. The ground wire is black (BLK), the circuit number is 50, and the wire is 32 mm² (2 gauge AWG).

- **Location.** Connections are usually labeled "C" and then three numbers. The three numbers indicate the general location of the connector. Normally, the connector number represents the general area of the vehicle, including:

100 to 199	Under the hood
200 to 299	Under the dash
300 to 399	Passenger compartment
400 to 499	Rear package or trunk area
500 to 599	Left-front door
600 to 699	Right-front door
700 to 799	Left-rear door
800 to 899	Right-rear door

Even-numbered connectors are on the right (passenger side) of the vehicle and odd-numbered connectors are on the left (driver's side) of the vehicle. For example, C102 is a connector located under the hood (between 100 and 199) on the right side of the vehicle (even number 102). ● **SEE FIGURE 45–11**.

- **Grounds and splices.** These are also labeled using the same general format as connectors. Therefore, a ground located under the dash on the driver's side could be labeled G305 (*G* means "ground" and the "305" means that it is located in the passenger compartment). ● **SEE FIGURE 45–12**.

ELECTRICAL COMPONENTS

Most electrical components have their own unique symbol that shows the basic function or parts.

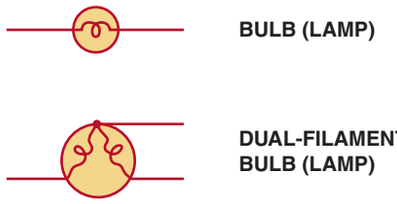


FIGURE 45–13 The symbol for light bulbs shows the filament inside a circle, which represents the glass ampoule of the bulb.



FIGURE 45–14 An electric motor symbol shows a circle with the letter *M* in the center and two black sections that represent the brushes of the motor. This symbol is used even though the motor is a brushless design.

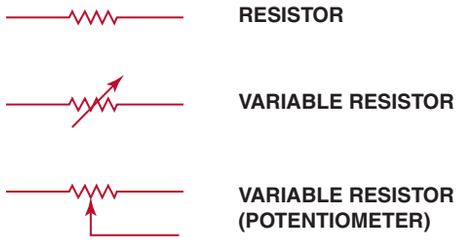


FIGURE 45–15 Resistor symbols vary depending on the type of resistor.



FIGURE 45–16 A rheostat uses only two wires—one is connected to a voltage source and the other is attached to the movable arm.

- **Bulbs.** Light bulbs often use a filament, which heats and then gives off light when electrical current flows. The symbol used for a light bulb is a circle with a filament inside. A dual-filament bulb, such as is used for taillights and brake light/turn signals, is shown with two filaments. ● **SEE FIGURE 45–13**.

ELECTRIC MOTORS An electric motor symbol shows a circle with the letter *M* in the center and two electrical connections, one to the top and one at the bottom. ● **SEE FIGURE 45–14** for an example of a cooling fan motor.

RESISTORS Although resistors are usually part of another component, the symbol appears on many schematics and wiring diagrams. A resistor symbol is a jagged line representing resistance to current flow. If the resistor is variable, such as a thermistor, an arrow is shown running through the symbol of a fixed resistor. A potentiometer is a three-wire variable resistor, shown with an arrow pointing toward the resistance part of a fixed resistor. ● **SEE FIGURE 45–15**.

A two-wire rheostat is usually shown as part of another unit, such as a fuel level sending unit. ● **SEE FIGURE 45–16**.

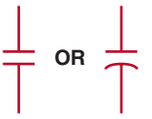


FIGURE 45–17 Symbols used to represent capacitors. If one of the lines is curved, this indicates that the capacitor being used has a polarity, while the one without a curved line can be installed in the circuit without concern about polarity.

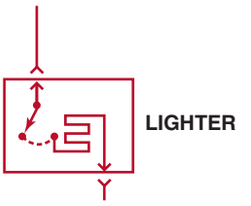


FIGURE 45–18 The gridlike symbol represents an electrically heated element. This symbol is used to represent a cigarette lighter or a heated rear window (rear window defogger)



FIGURE 45–19 A dashed outline represents a portion (part) of a component.



FIGURE 45–20 A solid box represents an entire component.

CAPACITORS Capacitors are usually part of an electronic component, but not a replaceable component unless the vehicle is an older model. Many older vehicles used capacitors to reduce radio interference and were installed inside alternators inside alternators or attached to or attached to wiring connectors. ● **SEE FIGURE 45–17**.

ELECTRIC HEATED UNIT Electric grid-type rear window defoggers and cigarette lighters are shown with a square box-type symbol. ● **SEE FIGURE 45–18**.

BOXED COMPONENTS If a component is shown in a box using a solid line, the box is the entire component. If a box uses dashed lines, it represents part of a component. A commonly used dashed-line box is a fuse panel. Often, just one or two fuses are shown in a dashed-line box. This means that a fuse panel has more fuses than shown. ● **SEE FIGURES 45–19 AND 45–20**.

SEPARATE REPLACEABLE PART Often components are shown on a schematic that cannot be replaced, but are part of a complete assembly. When looking at a schematic of General Motors vehicles, the following is shown.

- If a part name is underlined, it is a replaceable part.
- If a part is not underlined, it is not available as a replaceable part, but is included with other components shown and sold as an assembly.
- If the case itself is grounded, the ground symbol is attached to the component as shown in ● **FIGURE 45–21**.

SWITCHES Electrical switches are drawn on a wiring diagram in their normal position. This can be one of two possible positions.



FIGURE 45–21 This symbol represents a component that is case grounded.

- **Normally open.** The switch is not connected to its internal contacts and no current will flow. This type of switch is labeled **N.O**.
- **Normally closed.** The switch is electrically connected to its internal contacts and current will flow through the switch. This type of switch is labeled **N.C**.

Other switches can use more than two contacts.

The **poles** refer to the number of circuits completed by the switch and the **throws** refer to the number of output circuits. A **single-pole, single-throw (SPST)** switch has only two positions, on or off. A **single-pole, double-throw (SPDT)** switch has three terminals, one wire in and two wires out. A headlight dimmer switch is an example of a typical SPDT switch. In one position, the current flows to the low-filament headlight; in the other, the current flows to the high-filament headlight.

NOTE: A SPDT switch is not an on or off type of switch but instead directs power from the source to either the high-beam lamps or the low-beam lamps.

There are also **double-pole, single-throw (DPST)** switches and **double-pole, double-throw (DPDT)** switches. ● **SEE FIGURE 45–22**.

NOTE: All switches are shown on schematics in their normal position. This means that the headlight switch will be shown normally off, as are most other switches and controls.

MOMENTARY SWITCH

A **momentary switch** is a switch primarily used to send a voltage signal to a module or controller to request that a device be turned on or off. The switch makes momentary contact and then returns to the open position. A horn switch is a commonly used momentary switch. The symbol that represents a momentary switch uses two dots for the contact with a switch above them. A momentary switch can be either normally open or normally closed. ● **SEE FIGURE 45–23**.

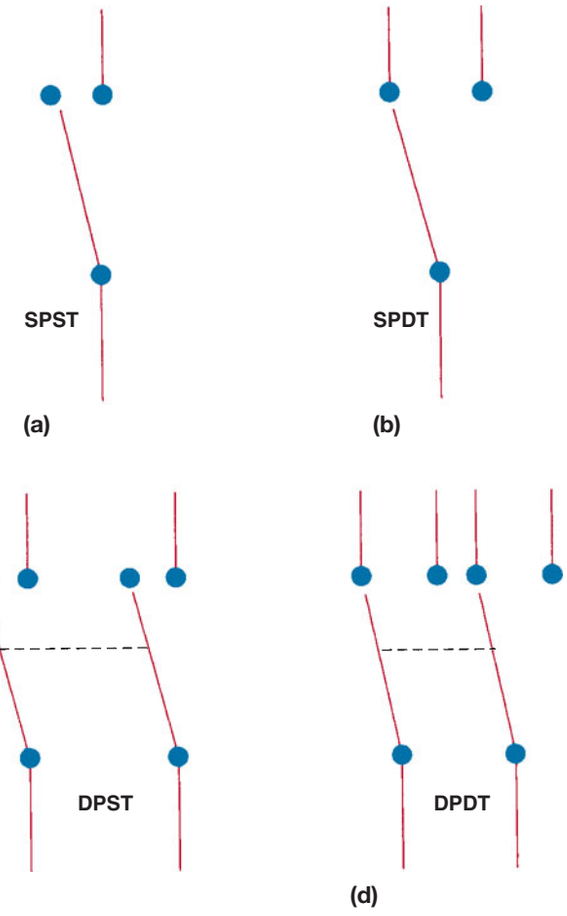


FIGURE 45–22 (a) A symbol for a single-pole, single-throw (SPST) switch. This type of switch is normally open (N.O.) because nothing is connected to the terminal that the switch is contacting in its normal position. (b) A single-pole, double-throw (SPDT) switch has three terminals. (c) A double-pole, single-throw (DPST) switch has two positions (off and on) and can control two separate circuits. (d) A double-pole, double-throw (DPDT) switch has six terminals—three for each pole. Note: Both (c) and (d) also show a dotted line between the two arms indicating that they are mechanically connected, called a "ganged switch".

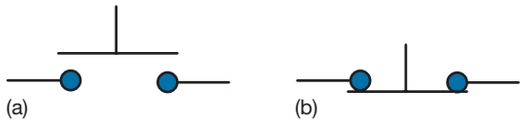


FIGURE 45–23 (a) A symbol for a normally open (N.O.) momentary switch. (b) A symbol for a normally closed (N.C.) momentary switch.

TECH TIP

Color-Coding Is Key to Understanding

Whenever diagnosing an electrical problem, it is common practice to print out the schematic of the circuit and then take it to the vehicle. A meter is then used to check for voltage at various parts of the circuit to help determine where there is a fault. The diagnosis can be made easier if the parts of the circuit are first color coded using markers or color pencils. A color-coding system that has been widely used is one developed by Jorge Menchu **(www.aeswave.com)**.

The colors represent voltage conditions in various parts of a circuit. Once the circuit has been color coded, then the circuit can be tested using the factory wire colors as a guide. ● **SEE FIGURE 45–24**.

A momentary switch, for example, can be used to lock or unlock a door or to turn the air conditioning on or off. If the device is currently operating, the signal from the momentary switch will turn it off, and if it is off, the switch will signal the module to turn it on. The major advantage of momentary switches is that they can be lightweight and small, because the switch does not carry any heavy electrical current, just a small voltage signal. Most momentary switches use a membrane constructed of foil and plastic.

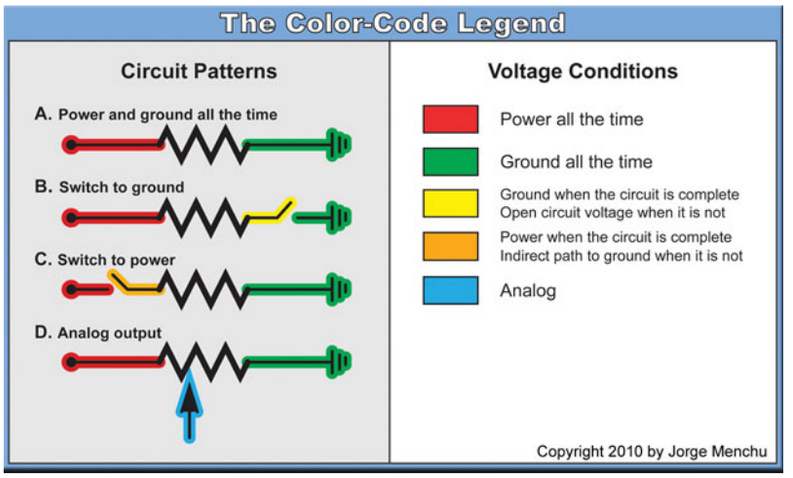
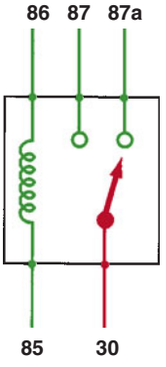


FIGURE 45–24 Using a marker and color-coding the various parts of the circuit makes the circuit easier to understand and helps diagnosing electrical problems easier. (*Courtesy of Jorge Menchu.*)



86 - POWER SIDE OF THE COIL
85 - GROUND SIDE OF THE COIL

(MOSTLY RELAY COILS HAVE BETWEEN 50–150 OHMS OF RESISTANCE)

30 - COMMON POWER FOR RELAY CONTACTS
87 - NORMALLY OPEN OUTPUT (N.O.)
87a - NORMALLY CLOSED OUTPUT (N.C.)

FIGURE 45–25 A relay uses a movable arm to complete a circuit whenever there is a power at terminal 86 and a ground at terminal 85. A typical relay only requires about 1/10 ampere through the relay coil. The movable arm then closes the contacts (#30 to #87) and can relay 30 amperes or more.

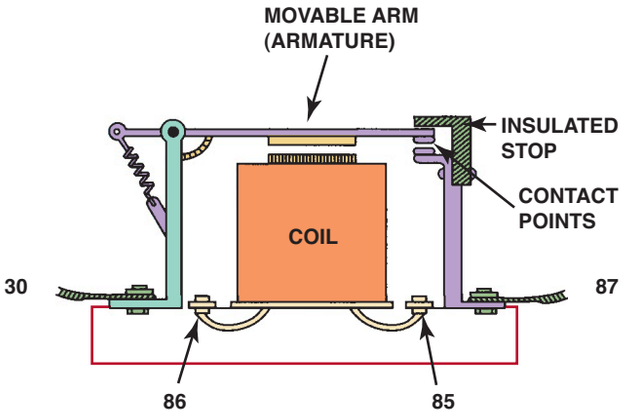


FIGURE 45–26 A cross-sectional view of a typical four-terminal relay. Current flowing through the coil (terminals 86 and 85) causes the movable arm (called the armature) to be drawn toward the coil magnet. The contact points complete the electrical circuit connected to terminals 30 and 87.

RELAY TERMINAL IDENTIFICATION

DEFINITION A **relay** is a magnetic switch that uses a movable armature to control a high-amperage circuit by using a low-amperage electrical switch.

ISO RELAY TERMINAL IDENTIFICATION Most automotive relays adhere to common terminal identification. The primary source for this common identification comes from the standards established by the International Standards Organization (ISO). Knowing this terminal information will help in the correct diagnosis and troubleshooting of any circuit containing a relay. ● **SEE FIGURES 45–25 AND 45–26**.

Relays are found in many circuits because they are capable of being controlled by computers, yet are able to handle enough current to power motors and accessories. Relays include the following components and terminals.

RELAY OPERATION

1. **Coil** (terminals 85 and 86)
   - A coil provides the magnetic pull to a movable armature (arm).
   - The resistance of most relay coils ranges from 50 to 150 ohms, but is usually between 60 and 100 ohms.
   - The ISO identification of the coil terminals are 86 and 85. The terminal number 86 represents the power to the relay coil and the terminal labeled 85 represents the ground side of the relay coil.
   - The relay coil can be controlled by supplying either power or ground to the relay coil winding.
   - The coil winding represents the control circuit which uses low current to control the higher current through the other terminals of the relay. ● **SEE FIGURE 45–27**.
2. Other terminals used to control the load current
   - The higher amperage current flow through a relay flows through terminals 30 and 87, and often 87a.
   - Terminal 30 is usually where power is applied to a relay. Check service information for the exact operation of the relay being tested.
   - When the relay is at rest without power and ground to the coil, the armature inside the relay electrically connects terminals 30 and 87a if the relay has five terminals. When

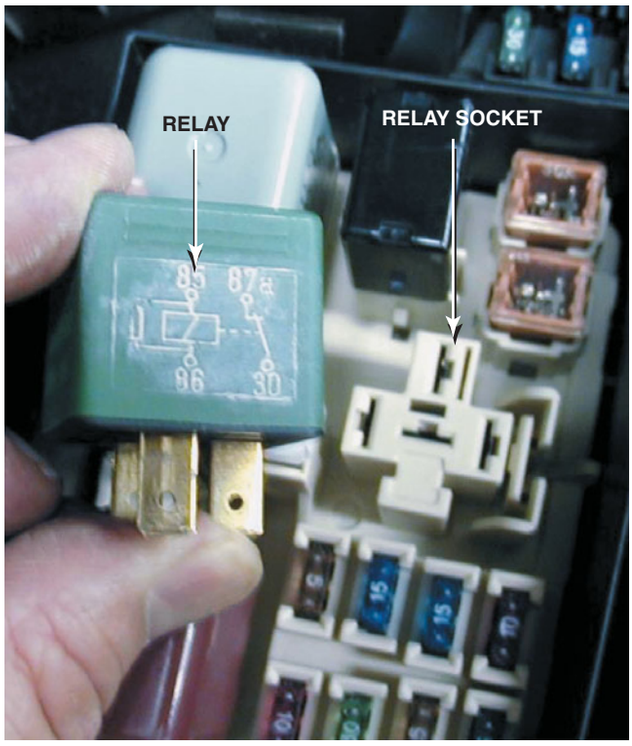


FIGURE 45–27 A typical relay showing the schematic of the wiring in the relay.

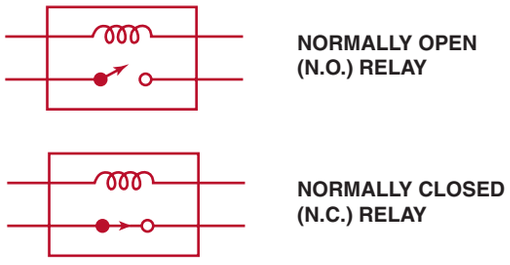


FIGURE 45–28 All schematics are shown in their normal, nonenergized position.

there is power at terminal 85 and a ground at terminal 86 of the relay, a magnetic field is created in the coil winding, which draws the armature of the relay toward the coil. The armature, when energized electrically, connects terminals 30 and 87.

The maximum current through the relay is determined by the resistance of the circuit, and relays are designed to safely handle the designed current flow. ● **SEE FIGURES 45–28 AND 45–29**.

RELAY VOLTAGE SPIKE CONTROL Relays contain a coil and when power is removed, the magnetic field surrounding the coil collapses, creating a voltage to be induced in the coil winding. This induced voltage can be as high as 100 volts or more and can cause problems with other electronic devices in the vehicle. For example, the short high-voltage surge can be heard as a "pop" in the radio. To reduce the induced voltage, some relays contain a diode connected across the coil. ● **SEE FIGURE 45–30**.

When the current flows through the coil, the diode is not part of the circuit because it is installed to block current. However, when the voltage is removed from the coil, the resulting voltage induced in the coil windings has a reversed polarity to the applied voltage. Therefore, the voltage in the coil is applied to the coil in a forward direction through the diode, which conducts the current back into the winding. As a result, the induced voltage spike is eliminated.

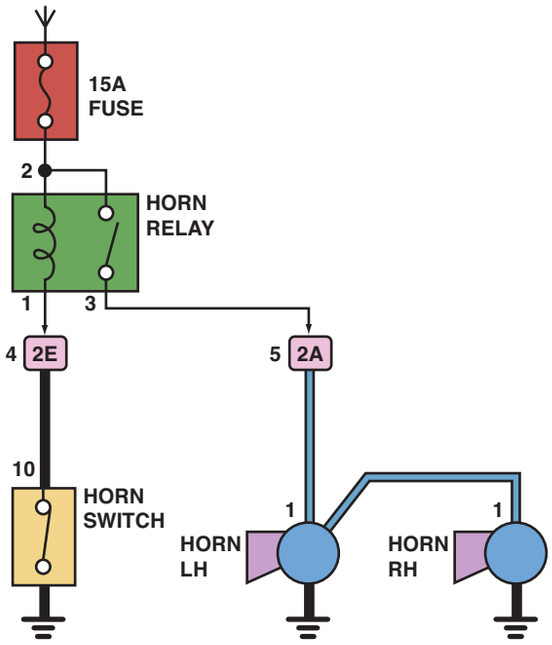


FIGURE 45–29 A typical horn circuit. Note that the relay contacts supply the heavy current to operate the horn when the horn switch simply completes a low-current circuit to ground, causing the relay contacts to close.

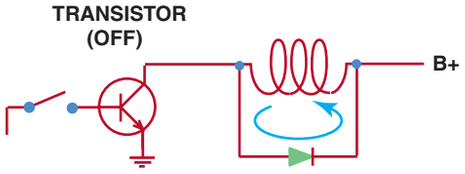


FIGURE 45–30 When the relay or solenoid coil current is turned off, the stored energy in the coil flows through the clamping diode and effectively reduces voltage spike.

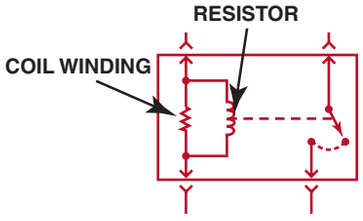


FIGURE 45–31 A resistor used in parallel with the coil windings is a common spike reduction method used in many relays.

Most relays use a resistor connected in parallel with the coil winding. The use of a resistor, typically about 400 to 600 ohms, reduces the voltage spike by providing a path for the voltage created in the coil to flow back through the coil windings when the coil circuit is opened. ● **SEE FIGURE 45–31**.

LOCATING AN OPEN CIRCUIT

TERMINOLOGY An open circuit is a break in the electrical circuit that prevents current from flowing and operating an electrical device. Examples of open circuits include:

- Blown (open) light bulbs
- Cut or broken wires
- Disconnected or partially disconnected electrical connectors

TECH TIP

Divide the Circuit in Half

When diagnosing any circuit that has a relay, start testing at the relay and divide the circuit in half.

- **High current portion:** Remove the relay and check that there are 12 volts at the terminal 30 socket. If there is, then the power side is okay. Use an ohmmeter and check between terminal 87 socket and ground. If the load circuit has continuity, there should be some resistance. If OL, the circuit is electrically open.
- **Control circuit (low current):** With the relay removed from the socket, check that there is 12 volts to terminal 86 with the ignition on and the control switch on. If not, check service information to see if power should be applied to terminal 86, then continue troubleshooting the switch power and related circuit.
- **Check the relay itself:** Use an ohmmeter and measure for continuity and resistance.
  - Between terminals 85 and 86 (coil), there should be 60 to 100 ohms. If not, replace the relay.
  - Between terminals 30 and 87 (high-amperage switch controls), there should be continuity (low ohms) when there is power applied to terminal 85 and a ground applied to terminal 86 that operates the relay. If OL is displayed on the meter set to read ohms, the circuit is open which requires that the reply be replaced.
  - Between terminals 30 and 87a (if equipped), with the relay turned off, there should be low resistance (less than 5 ohms).

FREQUENTLY ASKED QUESTION

What Is the Difference Between a Relay and a Solenoid?

Often, these terms are used differently among vehicle manufacturers, which can lead to some confusion.

Relay: A relay is an electromagnetic switch that uses a movable arm. Because a relay uses a movable arm, it is generally limited to current flow not exceeding 30 amperes.

Solenoid: A solenoid is an electromagnetic switch that uses a movable core. Because of this type of design, a solenoid is capable of handling 200 amperes or more and is used in the starter motor circuit and other high-amperage applications, such as in the glow plug circuit of diesel engines.

- Electrically open switches
- Loose or broken ground connections or wires
- Blown fuse

PROCEDURE TO LOCATE AN OPEN CIRCUIT The typical procedure for locating an open circuit involves the following steps.

STEP 1 **Perform a thorough visual inspection.** Check the following:
- Look for evidence of a previous repair. Often, an electrical connector or ground connection can be accidentally left disconnected.
- Look for evidence of recent body damage or body repairs. Movement due to a collision can cause metal to move, which can cut wires or damage connectors or components.

STEP 2 **Print out the schematic.** Trace the circuit and check for voltage at certain places. This will help pinpoint the location of the open circuit.

STEP 3 **Check everything that does and does not work.** Often, an open circuit will affect more than one component. Check the part of the circuit that is common to the other components that do not work.

STEP 4 **Check for voltage.** Voltage is present up to the location of the open circuit fault. For example, if there is battery voltage at the positive terminal and the negative (ground) terminal of a two-wire light bulb socket with the bulb plugged in, then the ground circuit is open.

REAL WORLD FIX

The Electric Mirror Fault Story

Often, a customer will notice just one fault even though other lights or systems may not be working correctly. For example, a customer noticed that the electric mirrors stopped working. The service technician checked all electrical components in the vehicle and discovered that the interior lights were also not working.

The interior lights were not mentioned by the customer as being a problem most likely because the driver only used the vehicle in daylight hours.

The service technician found the interior light and power accessory fuse blown. Replacing the fuse restored the proper operation of the electric outside mirror and the interior lights. However, what caused the fuse to blow? A visual inspection of the dome light, next to the electric sunroof, showed an area where a wire was bare. Evidence showed the bare wire had touched the metal roof, which could cause the fuse to blow. The technician covered the bare wire with a section of vacuum hose and then taped the hose with electrical tape to complete the repair.

COMMON POWER OR GROUND

When diagnosing an electrical problem that affects more than one component or system, check the electrical schematic for a common power source or a common ground. ● **SEE FIGURE 45–32** for an example of lights being powered by one fuse (power source).

- Underhood light
- Inside lighted mirrors
- Dome light
- Left-side courtesy light
- Right-side courtesy light

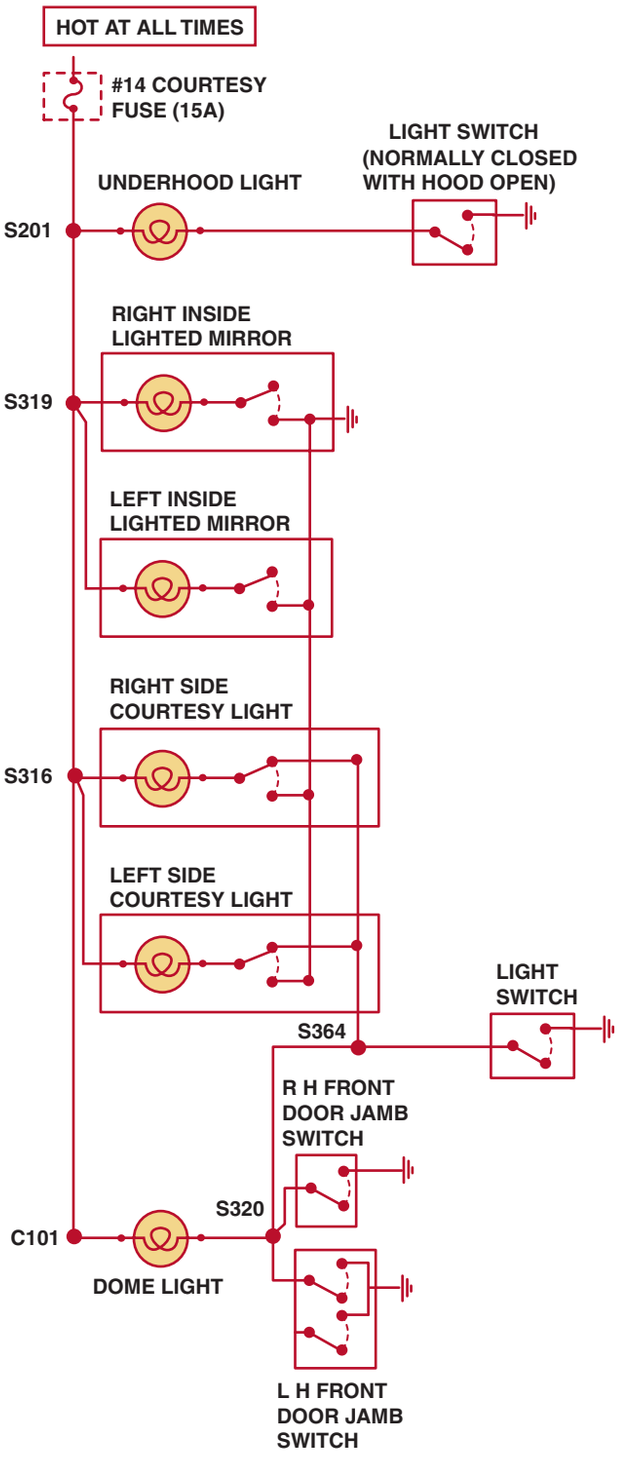


FIGURE 45–32 A typical wiring diagram showing multiple switches and bulbs powered by one fuse.

Therefore, if a customer complains about one or more of the items listed, check the fuse and the common part of the circuit that feeds all of the affected lights. Check for a common ground if several components that seem unrelated are not functioning correctly.

CIRCUIT TROUBLESHOOTING PROCEDURE

Follow these steps when troubleshooting wiring problems.

STEP 1 Verify the malfunction. If, for example, the backup lights do not operate, make certain that the ignition is on (key on, engine off), with the gear selector in reverse, and check for operation of the backup lights.

STEP 2 Check everything else that does or does not operate correctly. For example, if the taillights are also not working, the problem could be a loose or broken ground connection in the trunk area that is shared by both the backup lights and the taillights.

STEP 3 Check the fuse for the backup lights. ● **SEE FIGURE 45–34.**

STEP 4 Check for voltage at the backup light socket. This can be done using a test light or a voltmeter.

If voltage is available at the socket, the problem is either a defective bulb or a poor ground at the socket or a ground wire connection to the body or frame. If no voltage is available at the socket, consult a wiring diagram for the type of vehicle being tested. The wiring diagram should show all of the wiring and components

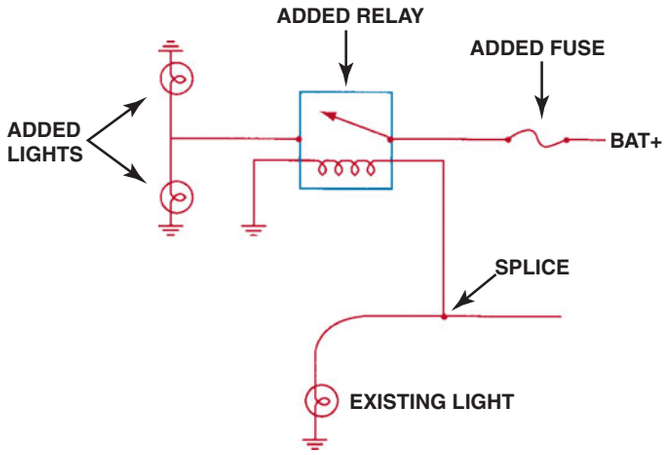


FIGURE 45–33 To add additional lighting, simply tap into an existing light wire and connect a relay. Whenever the existing light is turned on, the coil of the relay is energized. The arm of the relay then connects power from another circuit (fuse) to the auxiliary lights without overloading the existing light circuit.

TECH TIP

Do It Right—Install a Relay

Often the owners of vehicles, especially owners of pickup trucks and sport utility vehicles (SUVs), want to add additional electrical accessories or lighting. It is tempting in these cases to simply splice into an existing circuit. However, when another circuit or component is added, the current that flows through the newly added component is also added to the current for the original component. This additional current can easily overload the fuse and wiring. Do not simply install a larger amperage fuse; the wire gauge size was not engineered for the additional current and could overheat.

The solution is to install a relay, which uses a small coil to create a magnetic field that causes a movable arm to switch on a higher current circuit. The typical relay coil has from 50 to 150 ohms (usually 60 to 100 ohms) of resistance and requires just 0.24 to 0.08 ampere when connected to a 12 volt source. This small additional current will not be enough to overload the existing circuit. ● **SEE FIGURE 45–33** for an example of how additional lighting can be added.



FIGURE 45–34 Always check the simple things first. Check the fuse for the circuit you are testing. Maybe a fault in another circuit controlled by the same fuse could have caused the fuse to blow. Use a test light to check that both sides of the fuse have voltage.

? FREQUENTLY ASKED QUESTION

Where to Start?

The common question is, where does a technician start the troubleshooting when using a wiring diagram (schematic)?

HINT 1 If the circuit contains a relay, start your diagnosis at the relay. The entire circuit can be tested at the terminals of the relay.

HINT 2 The easiest first step is to locate the unit on the schematic that is not working at all or not working correctly.

a. Trace where the unit gets its ground connection.
b. Trace where the unit gets its power connection.

Often a ground is used by more than one component. Therefore, ensure that everything else is working correctly. If not, then the fault may lie at the common ground (or power) connection.

HINT 3 Divide the circuit in half by locating a connector or a part of the circuit that can be accessed easily. Then check for power and ground at this midpoint. This step could save you much time.

HINT 4 Use a fused jumper wire to substitute a ground or a power source to replace a suspected switch or section of wire.

included in the circuit. For example, the backup light current must flow through the fuse and ignition switch to the gear selector switch before traveling to the rear backup light socket. As stated in the second step, the fuse used for the backup lights may also be used for other vehicle circuits.

The wiring diagram can be used to determine all other components that share the same fuse. If the fuse is blown (open circuit), the cause can be a short in any of the circuits sharing the same fuse. Because the backup light circuit current must be switched on and off by the gear selector switch, an open in the switch can also prevent the backup lights from functioning.

LOCATING A SHORT CIRCUIT

TERMINOLOGY A short circuit usually blows a fuse, and a replacement fuse often also blows in the attempt to locate the source of the short circuit. A **short circuit** is an electrical connection to another wire or to ground before the current flows through some or all of the resistance in the circuit. A short-to-ground will always blow a fuse and usually involves a wire on the power side of the circuit coming in contact with metal. Therefore, a thorough visual inspection should be performed around areas involving heat or movement, especially if there is evidence of a previous collision or previous repair that may not have been properly completed.

A short-to-voltage may or may not cause the fuse to blow and usually affects another circuit. Look for areas of heat or movement where two power wires could come in contact with each other. Several methods can be used to locate the short.

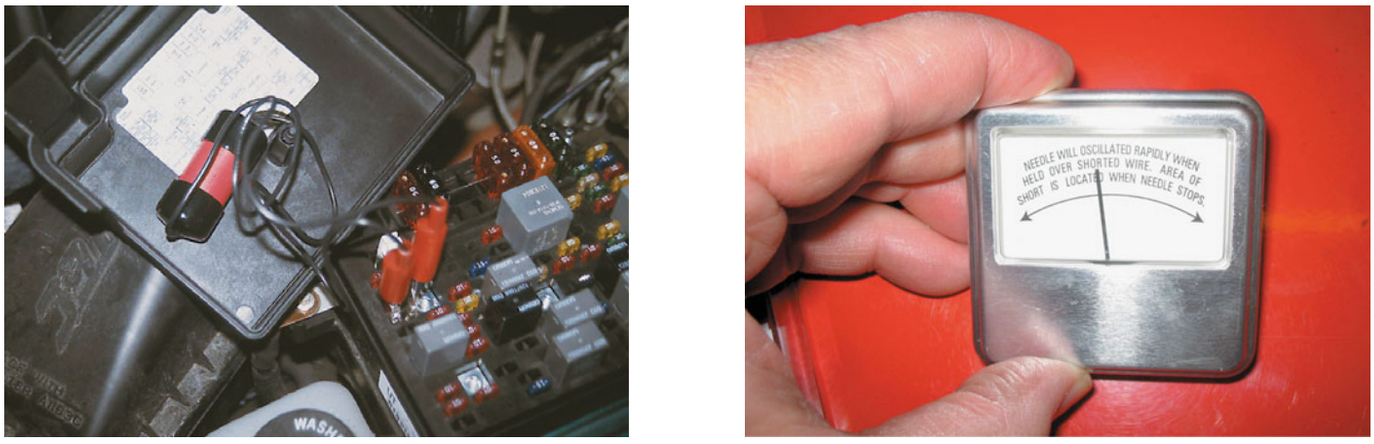
FUSE REPLACEMENT METHOD Disconnect one component at a time and then replace the fuse. If the new fuse blows, continue the process until you determine the location of the short. This method uses many fuses and is *not* a preferred method for finding a short circuit.

CIRCUIT BREAKER METHOD Another method is to connect an automotive circuit breaker to the contacts of the fuse holder with alligator clips. Circuit breakers are available that plug directly into the fuse panel, replacing a blade-type fuse. The circuit breaker will alternately open and close the circuit, protecting the wiring from possible overheating damage while still providing current flow through the circuit.

NOTE: A heavy-duty (HD) flasher can also be used in place of a circuit breaker to open and close the circuit. Wires and terminals must be made to connect the flasher unit where the fuse normally plugs in.

All components included in the defective circuit should be disconnected one at a time until the circuit breaker stops clicking. The unit that was disconnected and stopped the circuit breaker clicking is the unit causing the short circuit. If the circuit breaker continues to click with all circuit components unplugged, the problem is in the wiring *from* the fuse panel *to* any one of the units in the circuit. Visual inspection of all the wiring or further disconnecting will be necessary to locate the problem.

TEST LIGHT METHOD To use the test light method, simply remove the blown fuse and connect a test light to the terminals of the fuse holder (polarity does not matter). If there is a short circuit, current will flow from the power side of the fuse holder through the test light and on to ground through the short circuit, and the test light will then light. Unplug the connectors or components protected by the fuse until the test light goes out. The circuit that was disconnected, which caused the test light to go out, is the circuit that is shorted.



(a) (b)

FIGURE 45–35 (a) After removing the blown fuse, a pulsing circuit breaker is connected to the terminals of the fuse. (b) The circuit breaker causes current to flow, then stop, then flow again, through the circuit up to the point of the short-to-ground. By observing the Gauss gauge, the location of the short is indicated near where the needle stops moving due to the magnetic field created by the flow of current through the wire.

BUZZER METHOD

The buzzer method is similar to the test light method, but uses a buzzer to replace a fuse and act as an electrical load. The buzzer will sound if the circuit is shorted and will stop when the part of the circuit that is grounded is unplugged.

OHMMETER METHOD

The fourth method uses an ohmmeter connected to the fuse holder and ground. This is the recommended method of finding a short circuit, as an ohmmeter will indicate low ohms when connected to a short circuit. However, an ohmmeter should never be connected to an operating circuit. The correct procedure for locating a short using an ohmmeter is as follows:

1. Connect one lead of an ohmmeter (set to a low scale) to a good clean metal ground and the other lead to the circuit *(load) side* of the fuse holder.

   CAUTION: Connecting the lead to the power side of the fuse holder will cause current flow through and damage to the ohmmeter.

2. The ohmmeter will read zero or almost zero ohms if the circuit or a component in the circuit is shorted.
3. Disconnect one component in the circuit at a time and watch the ohmmeter. If the ohmmeter reading goes to high ohms or infinity, the component just unplugged was the source of the short circuit.
4. If all of the components have been disconnected and the ohmmeter still reads low ohms, then disconnect electrical connectors until the ohmmeter reads high ohms. The location of the short to ground is then between the ohmmeter and the disconnected connector.

   NOTE: Some meters, such as the Fluke 87, can be set to beep (alert) when the circuit closes or when the circuit opens—a very useful feature.

GAUSS GAUGE METHOD

If a short circuit blows a fuse, a special pulsing circuit breaker (similar to a flasher unit) can be installed in the circuit in place of the fuse. Current will flow through the circuit until the circuit breaker opens the circuit. As soon as the circuit breaker opens the circuit, it closes again. This on-and-off current flow creates a pulsing magnetic field around the wire carrying the current.

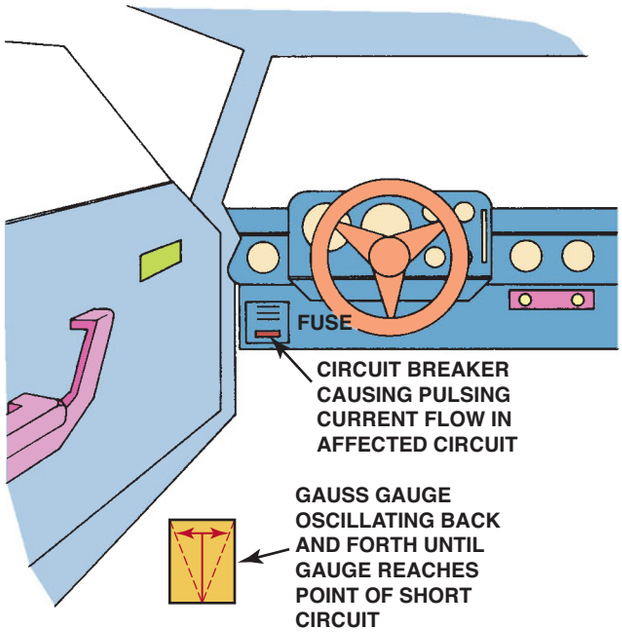


FIGURE 45–36 A Gauss gauge can be used to determine the location of a short circuit even behind a metal panel.

A **Gauss gauge** is a handheld meter that responds to weak magnetic fields. It is used to observe this pulsing magnetic field, which is indicated on the gauge as needle movement. This pulsing magnetic field will register on the Gauss gauge even through the metal body of the vehicle. A needle-type compass can also be used to observe the pulsing magnetic field. ● **SEE FIGURES 45–35 AND 45–36.**

ELECTRONIC TONE GENERATOR TESTER

An electronic tone generator tester can be used to locate a short-to-ground or an open circuit. Similar to test equipment used to test telephone and cable television lines, a **tone generator tester** generates a tone that can be heard through a receiver (probe). ● **SEE FIGURE 45–37.**

The tone will be generated as long as there is a continuous electrical path along the circuit. The signal will stop if there is a short-to-ground or an open in the circuit. ● **SEE FIGURE 45–38.**

The windings in the solenoids and relays will increase the strength of the signal in these locations.

TECH TIP

Heat or Movement

Electrical shorts are commonly caused either by movement, which causes the insulation around the wiring to be worn away, or by heat melting the insulation. When checking for a short circuit, first check the wiring that is susceptible to heat, movement, and damage.

1. **Heat.** Wiring near heat sources, such as the exhaust system, cigarette lighter, or alternator
2. **Wire movement.** Wiring that moves, such as in areas near the doors, trunk, or hood
3. **Damage.** Wiring subject to mechanical injury, such as in the trunk, where heavy objects can move around and smash or damage wiring; can also occur as a result of an accident or a previous repair



FIGURE 45–37 A tone generator-type tester used to locate open circuits and circuits that are shorted-to-ground. Included with this tester is a transmitter (tone generator), receiver probe, and headphones for use in noisy shops.

ELECTRICAL TROUBLESHOOTING GUIDE

When troubleshooting any electrical component, remember the following hints to find the problem faster and more easily.

1. For a device to work, it must have two things: power and ground.
2. If there is no power to a device, an open power side (blown fuse, etc.) is indicated.
3. If there is power on both sides of a device, an open ground is indicated.
4. If a fuse blows immediately, a grounded power-side wire is indicated.
5. Most electrical faults result from heat or movement.

TECH TIP

Wiggle Test

Intermittent electrical problems are common yet difficult to locate. To help locate these hard-to-find problems, try operating the circuit and then start wiggling the wires and connections that control the circuit. If in doubt where the wiring goes, try moving all the wiring starting at the battery. Pay particular attention to wiring running near the battery or the windshield washer container. Corrosion can cause wiring to fail, and battery acid fumes and alcohol-based windshield washer fluid can start or contribute to the problem. If you notice any change in the operation of the device being tested while wiggling the wiring, look closer in the area you were wiggling until you locate and correct the actual problem.

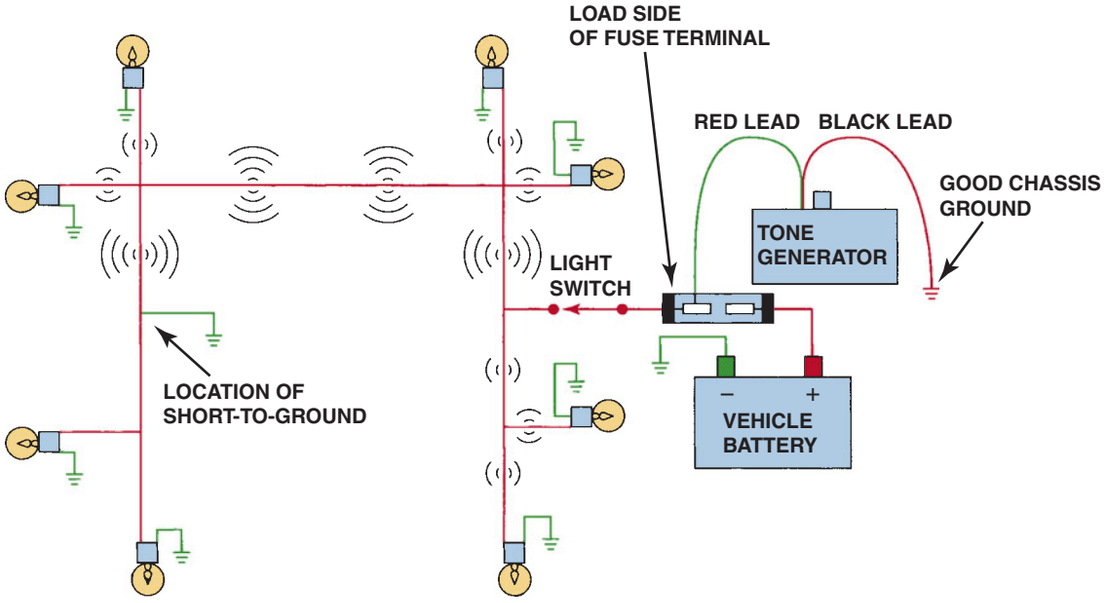


FIGURE 45–38 To check for a short-to-ground using a tone generator, connect the black transmitter lead to a good chassis ground and the red lead to the load side of the fuse terminal. Turn the transmitter on and check for tone signal with the receiver. Using a wiring diagram, follow the strongest signal to the location of the short-to-ground. There will be no signal beyond the fault, either a short-to-ground as shown or an open circuit.

6. Most noncomputer-controlled devices operate by opening and closing the power side of the circuit (power-side switch).
7. Most computer-controlled devices operate by opening and closing the ground side of the circuit (ground-side switch).

STEP-BY-STEP TROUBLESHOOTING PROCEDURE

Knowing what should be done and when it should be done is a major concern for many technicians trying to repair an electrical problem. The following field-tested procedure provides a step-by-step guide for troubleshooting an electrical fault.

STEP 1 Determine the customer concern (complaint) and get as much information as possible from the customer or service advisor.
- **a.** When did the problem start?
- **b.** Under what conditions does the problem occur?
- **c.** Have there been any recent previous repairs to the vehicle which could have created the problem?

STEP 2 Verify the customer's concern by actually observing the fault.

STEP 3 Perform a thorough visual inspection and be sure to check everything that does and does not work.

STEP 4 Check for technical service bulletins (TSBs).

STEP 5 Locate the wiring schematic for the circuit being diagnosed.

STEP 6 Check the factory service information and follow the troubleshooting procedure.
- **a.** Determine how the circuit works.
- **b.** Determine which part of the circuit is good, based on what works and what does not work.
- **c.** Isolate the problem area.

NOTE: Split the circuit in half to help isolate the problem and start at the relay (if the circuit has a relay).



FIGURE 45–39 Antistatic spray can be used by customers to prevent being shocked when they touch a metal object like the door handle.

REAL WORLD FIX

Shocking Experience

A customer complained that after driving for a while, he got a static shock whenever he grabbed the door handle when exiting the vehicle. The customer thought that there must be an electrical fault and that the shock was coming from the vehicle itself. In a way, the shock was caused by the vehicle, but it was not a fault. The service technician sprayed the cloth seats with an antistatic spray and the problem did not reoccur. Obviously, a static charge was being created by the movement of the driver's clothing on the seats and then discharged when the driver touched the metal door handle. ● **SEE FIGURE 45–39**.

STEP 7 Determine the root cause and repair the vehicle.

STEP 8 Verify the repair and complete the work order by listing the three Cs (complaint, cause, and correction).

REVIEW QUESTIONS

1. List the numbers used on schematics to indicate grounds, splices, and connectors and where they are used in the vehicle.
2. List and identify the terminals of a typical ISO type relay.
3. List three methods that can be used to help locate a short circuit.
4. How can a tone generator be used to locate a short circuit?

CHAPTER QUIZ

1. On a wiring diagram, S110 with a ".8 BRN/BLK" means _____.
   - **a.** Circuit #.8, spliced under the hood
   - **b.** A connector with 0.8 mm^2 wire
   - **c.** A splice of a brown with black stripe, wire size being 0.8 mm^2 (18 gauge AWG)
   - **d.** Both a and b
2. Where is connector C250?
   - **a.** Under the hood
   - **b.** Under the dash
   - **c.** In the passenger compartment
   - **d.** In the trunk

3. All switches illustrated in schematics are _____.
   a. Shown in their normal position
   b. Always shown in their on position
   c. Always shown in their off position
   d. Shown in their on position except for lighting switches

4. When testing a relay using an ohmmeter, which two terminals should be touched to measure the coil resistance?
   a. 87 and 30
   b. 86 and 85
   c. 87a and 87
   d. 86 and 87

5. Technician A says that a good relay should measure between 60 and 100 ohms across the coil terminals. Technician B says that OL should be displayed on an ohmmeter when touching terminals 30 and 87. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

6. Which relay terminal is the normally closed (N.C.) terminal?
   a. 30
   b. 85
   c. 87
   d. 87a

7. Technician A says that there is often more than one circuit being protected by each fuse. Technician B says that more than one circuit often shares a single ground connector. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

8. Two technicians are discussing finding a short-to-ground using a test light. Technician A says that the test light, connected in place of the fuse, will light when the circuit that has the short is disconnected. Technician B says that the test light should be connected to the positive (+) and negative (−) terminals of the battery during this test. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

9. A short circuit can be located using a _____.
   a. Test light
   b. Gauss gauge
   c. Tone generator
   d. All of the above

10. For an electrical device to operate, it must have _____.
    a. Power and a ground
    b. A switch and a fuse
    c. A ground and fusible link
    d. A relay to transfer the current to the device

chapter 46 CAPACITANCE AND CAPACITORS

OBJECTIVES: **After studying Chapter 46, the reader should be able to:** • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "A" (General Electrical/Electronic Systems). • Explain capacitance. • Describe how a capacitor can be used to filter electrical noise. • Describe how a capacitor can store an electrical charge. • Explain how a capacitor circuit can be used as a timer circuit.

KEY TERMS: Capacitance 493 • Condenser 493 • Dielectric 494 • Farads 495 • Leyden jar 493

CAPACITANCE

DEFINITION **Capacitance** is the ability of an object or surface to store an electrical charge. Around 1745, Ewald Christian von Kliest and Pieter van Musschenbroek independently discovered capacitance in an electric circuit. While engaged in separate studies of electrostatics, they discovered that an electric charge could be stored for a period of time. They used a device, now called a **Leyden jar**, for their experimentation, which consisted of a glass jar filled with water, with a nail piercing the stopper and dipping into the water.

The two scientists connected the nail to an electrostatic charge. After disconnecting the nail from the source of the charge, they felt a shock by touching the nail, demonstrating that the device had stored the charge.

In 1747, John Bevis lined both the inside and outside of the jar with foil. This created a capacitor with two conductors (the inside and outside metal foil layers) equally separated by the insulating glass. ● **SEE FIGURE 46–1**. The Leyden jar was also used by Benjamin Franklin to store the charge from lightning as well as in other experiments. The natural phenomenon of lightning includes capacitance, because huge electrical fields develop between cloud layers or between clouds and the earth prior to a lightning strike.

NOTE: Capacitors are also called condensers. This term developed because electric charges collect, or condense, on the plates of a capacitor much like water vapor collects and condenses on a cold bottle or glass.

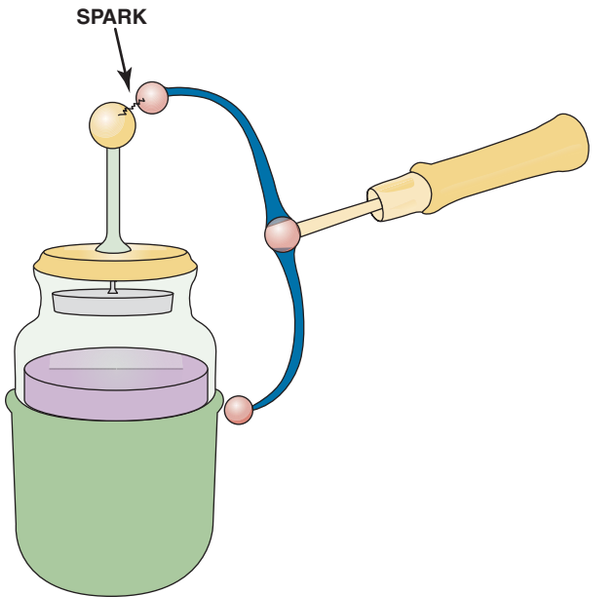


FIGURE 46–1 A Leyden jar can be used to store an electrical charge.

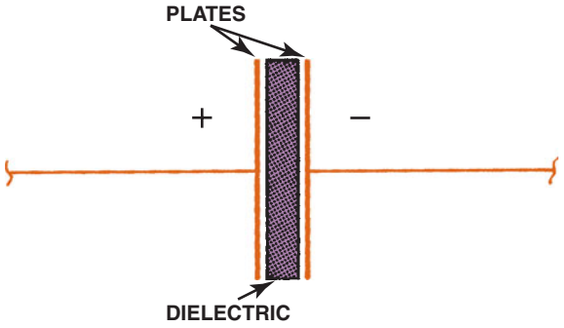


FIGURE 46–2 This simple capacitor, made of two plates separated by an insulating material, is called a dielectric.

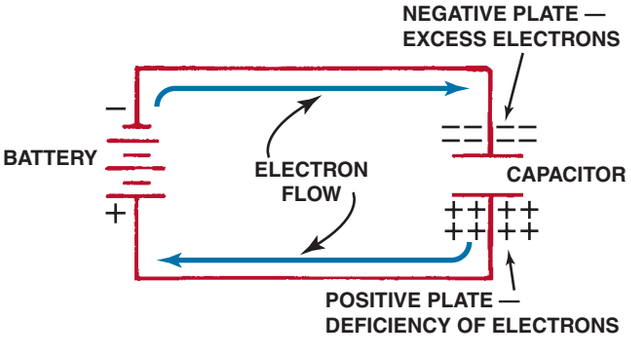


FIGURE 46–3 As the capacitor is charging, the battery forces electrons through the circuit.

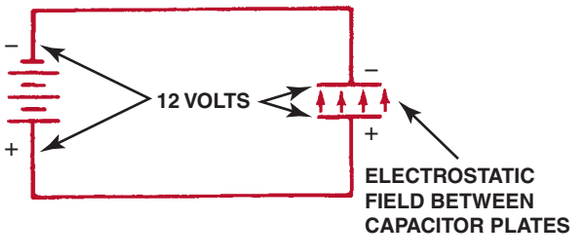


FIGURE 46–4 When the capacitor is charged, there is equal voltage across the capacitor and the battery. An electrostatic field exists between the capacitor plates. No current flows in the circuit.

MATERIAL	DIELECTRIC CONSTANT
Vacuum	1
Air	1.00059
Polystyrene	2.5
Paper	3.5
Mica	5.4
Flint glass	9.9
Methyl alcohol	35
Glycerin	56.2
Pure water	81

CHART 46–1

The higher the dielectric constant is, the better the insulating properties between the plates of the capacitor.

CAPACITOR CONSTRUCTION AND OPERATION

CONSTRUCTION A capacitor (also called a condenser) consists of two conductive plates with an insulating material between them. The insulating material is commonly called a **dielectric**. This substance is a poor conductor of electricity and can include air, mica, ceramic, glass, paper, plastic, or any similar nonconductive material. The dielectric constant is the relative strength of a material against the flow of electrical current. The higher the number is, the better the insulating properties. ● **SEE CHART 46–1**.

OPERATION When a capacitor is placed in a closed circuit, the voltage source (battery) forces electrons around the circuit. Because electrons cannot flow through the dielectric of the capacitor, excess electrons collect on what becomes the negatively charged plate. At the same time, the other plate loses electrons and, therefore, becomes positively charged. ● **SEE FIGURE 46–2**.

Current continues until the voltage charge across the capacitor plates becomes the same as the source voltage. At that time, the negative plate of the capacitor and the negative terminal of the battery are at the same negative potential. ● **SEE FIGURE 46–3**.

The positive plate of the capacitor and the positive terminal of the battery are also at equal positive potentials. There is then a voltage charge across the battery terminals and an equal voltage charge across the capacitor plates. The circuit is in balance, and there is no current. An electrostatic field now exists between the capacitor plates because of their opposite charges. It is this field that stores energy. In other words, a charged capacitor is similar to a charged battery. ● **SEE FIGURE 46–4**.

If the circuit is opened, the capacitor will hold its charge until it is connected into an external circuit through which it can discharge. When the charged capacitor is connected to an external circuit, it discharges. After discharging, both plates of the capacitor are neutral because all the energy from a circuit stored in a capacitor is returned when it is discharged. ● **SEE FIGURE 46–5**.

Theoretically, a capacitor holds its charge indefinitely. Actually, the charge slowly leaks off the capacitor through the dielectric. The better the dielectric, the longer the capacitor holds its charge. To avoid an electrical shock, any capacitor should be treated as if it were charged until it is proven to be discharged. To safely discharge a capacitor, use a test light with the clip attached to a good ground, and touch the pigtail or terminal with the point of the test light. ● **SEE FIGURE 46–6** for the symbol for capacitors as used in electrical schematics.

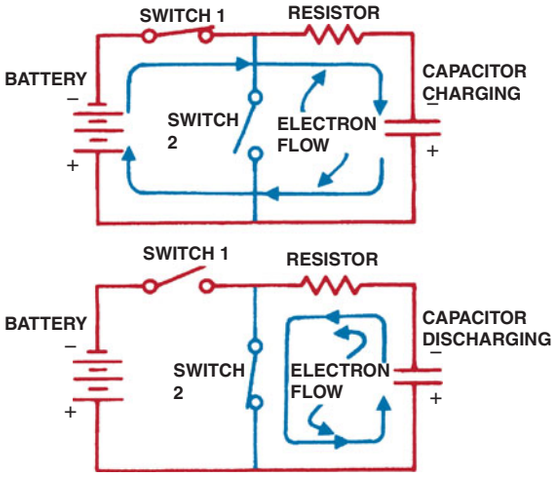


FIGURE 46–5 The capacitor is charged through one circuit (top) and discharged through another (bottom).

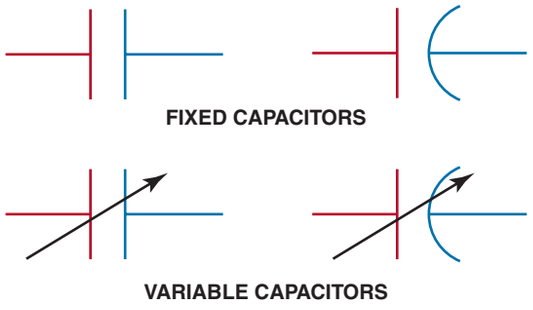


FIGURE 46–6 Capacitor symbols are shown in electrical diagrams. The negative plate is often shown curved.

FACTORS OF CAPACITANCE

Capacitance is governed by three factors.

- The surface area of the plates
- The distance between the plates
- The dielectric material

The larger the surface area of the plates is, the greater the capacitance, because more electrons collect on a larger plate area than on a small one. The closer the plates are to each other, the greater the capacitance, because a stronger electrostatic field exists between charged bodies that are close together. The insulating qualities of the dielectric material also affect capacitance. The capacitance of a capacitor is higher if the dielectric is a very good insulator.

MEASUREMENT OF CAPACITANCE

Capacitance is measured in **farads,** which is named after Michael Faraday (1791–1867), an English physicist. The symbol for farads is the letter *F*. If a charge of 1 coulomb is placed on the plates of a capacitor and the potential difference between them is 1 volt, then the capacitance is defined to be 1 farad, or 1 F. One coulomb is equal to the charge of 6.25×10^{18} electrons. One farad is an extremely large quantity of capacitance. Microfarads (0.000001 farad), or μF, are more commonly used.

The capacitance of a capacitor is proportional to the quantity of charge that can be stored in it for each volt difference in potential.

FREQUENTLY ASKED QUESTION

What Are "Points and Condenser"?

Points and condenser are used in point-type ignition systems.

Points. A set of points uses one stationary contact and a movable contact that is opened by a cam lobe inside the ignition distributor. When the points are closed, current flows through the primary windings of the ignition coil and creates a strong magnetic field. As the engine rotates, the distributor can open the contact points, which opens the circuit to the coil. The stored magnetic field in the coil collapses and generates a high-voltage arc from the secondary winding of the coil. It is this spark that is sent to the spark plugs that ignites the air-fuel mixture inside the engine.

Condenser. The condenser (capacitor) is attached to the points and the case of the condenser is grounded. When the points start to open, the charge built up in the primary winding of the coil would likely start to arc across the opening points. To prevent the points from arcing and to increase how rapidly the current is turned off, the condenser stores the current temporarily.

Points and condenser were used in vehicles and small gasoline engines until the mid-1970s. ● **SEE FIGURE 46–7.**

USES FOR CAPACITORS

SPIKE SUPPRESSION

A capacitor can be used in parallel to a coil to reduce the resulting voltage spike that occurs when the circuit is opened. The energy stored to the magnet field of the coil is rapidly released at this time. The capacitor acts to absorb the high voltage produced and stop it from interfering with other electronic devices, such as automotive radio and video equipment.

NOISE FILTERING

Interference in a sound system or radio is usually due to alternating current (AC) voltage created somewhere in the vehicle, such as in the alternator. A capacitor does the following:

- Blocks the flow of direct current (DC)
- Allows alternating current (AC) to pass

By connecting a capacitor (condenser) to the power lead of the radio or sound system amplifier, the AC voltage passes through the capacitor to the ground where the other end of the capacitor is connected. Therefore, the capacitor provides a path for the AC without affecting the DC power circuit. ● **SEE FIGURE 46–8.**

Because a capacitor stores a voltage charge, it opposes or slows any voltage change in a circuit. Therefore, capacitors are often used as voltage "shock absorbers." You sometimes find a capacitor attached to one terminal of an ignition coil. In this application, the capacitor absorbs and dampens changes in ignition voltage that interfere with radio reception.

SUPPLEMENTAL POWER SOURCE

A capacitor can be used to supply electrical power for short bursts in an audio system to help drive the speakers. Woofers and subwoofers require a lot of electrical current that often cannot be delivered by the amplifier itself. ● **SEE FIGURE 46–9.**

TIMER CIRCUITS

Capacitors are used in electronic circuits as part of a timer, to control window defoggers, interior lighting, pulse



FIGURE 46–7 A point-type distributor shown with the condenser from an old vehicle being tested on a distributor machine.

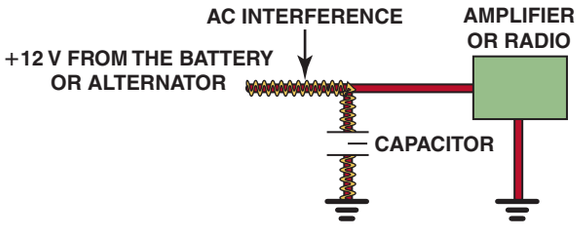


FIGURE 46–8 A capacitor blocks direct current (DC) but passes alternating current (AC). A capacitor makes a very good noise suppressor because most of the interference is AC and the capacitor will conduct this AC to ground before it can reach the radio or amplifier.



FIGURE 46–9 A 1 farad capacitor used to boost the power to large speakers.

wipers, and automatic headlights. The capacitors store energy and then are allowed to discharge through a resistance load. The greater the capacity of the capacitor and the higher the resistance load, the longer the time it takes for the capacitor to discharge.

COMPUTER MEMORY In most cases, the main memory of a computer is a high-speed random-access memory (RAM). One type of main memory, called dynamic random-access memory (DRAM), is the most commonly used type of RAM. A single memory chip is made up of several million memory cells. In a DRAM chip, each memory cell consists of a capacitor. When a capacitor is electrically charged, it is said to store the binary digit 1, and when discharged, it represents 0.

CONDENSER MICROPHONES A microphone converts sound waves into an electric signal. All microphones have a diaphragm that vibrates as sound waves strike. The vibrating diaphragm in turn causes an electrical component to create an output flow of current at a frequency proportional to the sound waves. A condenser microphone uses a capacitor for this purpose.

In a condenser microphone, the diaphragm is the negatively charged plate of a charged capacitor. When a sound wave compresses the diaphragm, the diaphragm is moved closer to the positive plate. Decreasing the distance between the plates increases the electrostatic attraction between them, which results in a flow of current to the negative plate. As the diaphragm moves out in response to sound waves, it also moves farther from the positive plate. Increasing the distance between the plates decreases the electrostatic attraction between them. This results in a flow of current back to the positive plate. These alternating flows of current provide weak electronic signals that travel to an amplifier and then to a loudspeaker.

CAPACITORS IN CIRCUITS

CAPACITORS IN PARALLEL CIRCUITS Capacitance can be increased in a circuit by connecting capacitors in parallel. For example, if a greater boost is needed for a sound system, then additional capacitors should be connected in parallel because their value adds together. ● **SEE FIGURE 46–10**.

We know that capacitance of a capacitor can be increased by increasing the size of its plates. Connecting two or more capacitors in parallel in effect increases plate size. Increasing plate area makes it possible to store more charge and therefore creates greater capacitance. To determine total capacitance of several parallel capacitors, simply add up their individual values. The following is the formula for calculating total capacitance in a circuit containing capacitors in parallel.

$$C_T = C_1 + C_2 + C_3 \ldots$$

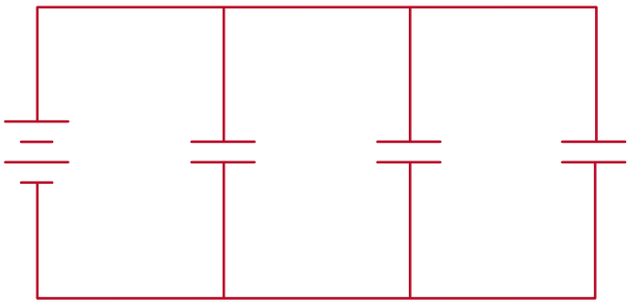


FIGURE 46–10 Capacitors in parallel effectively increase the capacitance.

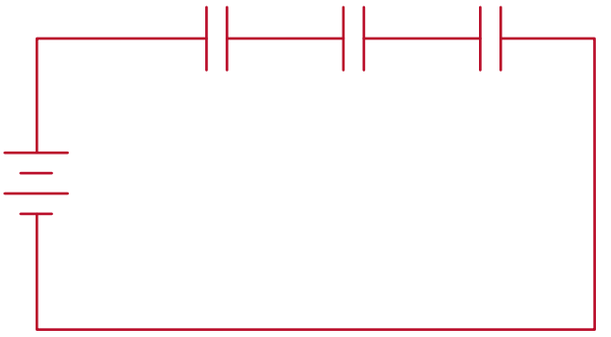


FIGURE 46–11 Capacitors in series decrease the capacitance.

For example, 220 μF + 220 μF = 440 μF when connected in parallel.

CAPACITORS IN SERIES CIRCUITS Capacitance can be decreased in a circuit by capacitors in series, as shown in ● **FIGURE 46–11**.

We know that capacitance of a capacitor can be decreased by placing the plates farther apart. Connecting two or more capacitors in series in effect increases the distance between the plates and thickness of the dielectric, thereby decreasing the amount of capacitance.

Following is the formula for calculating total capacitance in a circuit containing two capacitors in series.

$$C_T = \frac{C_1 \times C_2}{C_1 \times C_2}$$

For example, $\frac{220\,\mu F \times 220\,\mu F}{220\,\mu F \times 220\,\mu F} = \frac{48{,}400}{440} = 110\,\mu F$

NOTE: Capacitors are often used to reduce radio interference or to improve the performance of a high-power sound system. Additional capacitance can, therefore, be added by attaching another capacitor in parallel.

SUPPRESSION CAPACITORS Capacitors are installed across many circuits and switching points to absorb voltage fluctuations. Among other applications, they are used across the following:

- The primary circuit of some electronic ignition modules
- The output terminal of most alternators
- The armature circuit of some electric motors

Radio choke coils reduce current fluctuations resulting from self-induction. They are often combined with capacitors to act as electromagnetic interference (EMI) filter circuits for windshield wiper and electric fuel pump motors. Filters also may be incorporated in wiring connectors.

REVIEW QUESTIONS

1. How does a capacitor store an electrical charge?
2. How should two capacitors be electrically connected if greater capacitance is needed?
3. Where can a capacitor be used as a power source?
4. How can a capacitor be used as a noise filter?

CHAPTER QUIZ

1. A capacitor _____.
   a. Stores electrons **c.** Blocks DC
   b. Passes AC **d.** All of the above
2. A capacitor can also be called a _____.
   a. Condenser **c.** Farad
   b. Dielectric **d.** DRAM
3. Capacitors are commonly used as a _____.
   a. Voltage supply **c.** Noise filter
   b. Timer **d.** All of the above
4. A charged capacitor acts like a _____.
   a. Switch **c.** Resistor
   b. Battery **d.** Coil
5. The unit of measurement for capacitor rating is the _____.
   a. Ohm **c.** Farad
   b. Volt **d.** Ampere
6. Two technicians are discussing the operation of a capacitor. Technician A says that a capacitor can create electricity. Technician B says that a capacitor can store electricity. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
7. Capacitors block the flow of _____ current but allow _____ current to pass.
   a. Strong; weak
   b. AC; DC
   c. DC; AC
   d. Weak; strong
8. To increase the capacity, what could be done?
   a. Connect another capacitor in series.
   b. Connect another capacitor in parallel.
   c. Add a resistor between two capacitors.
   d. Both a and b
9. A capacitor can be used in what components?
   a. Microphone
   b. Radio
   c. Speaker
   d. All of the above
10. A capacitor used for spike protection will normally be placed in _____ to the load or circuit.
    a. Series
    b. Parallel
    c. Either series or parallel
    d. Parallel with a resistor in series

chapter 47

MAGNETISM AND ELECTROMAGNETISM

OBJECTIVES: After studying Chapter 47, the reader should be able to: • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "A" (General Electrical/Electronic Systems). • Explain magnetism. • Describe how magnetism and voltage are related. • Describe how an ignition coil works. • Explain how an electromagnet works.

KEY TERMS: Ampere-turns 502 • Counter electromotive force (CEMF) 504 • Electromagnet 502 • Electromagnetic induction 504 • Electromagnetic interference (EMI) 506 • Electromagnetism 500 • Flux density 499 • Flux lines 498 • Ignition control module (ICM) 505 • Left-hand rule 500 • Lenz's law 504 • Magnetic flux 498 • Magnetic induction 499 • Magnetism 498 • Mutual induction 504 • Permeability 499 • Pole 498 • Relay 502 • Reluctance 500 • Residual magnetism 499 • Right-hand rule 500 • Turns ratio 505

FUNDAMENTALS OF MAGNETISM

DEFINITION **Magnetism** is a form of energy that is caused by the motion of electrons in some materials. It is recognized by the attraction it exerts on other materials. Like electricity, magnetism cannot be seen. It can be explained in theory, however, because it is possible to see the results of magnetism and recognize the actions that it causes. Magnetite is the most naturally occurring magnet. Naturally magnetized pieces of magnetite, called *lodestone,* will attract and hold small pieces of iron. ● **SEE FIGURE 47–1.**

Many other materials can be artificially magnetized to some degree, depending on their atomic structure. Soft iron is very easy to magnetize, whereas some materials, such as aluminum, glass, wood, and plastic, cannot be magnetized at all.

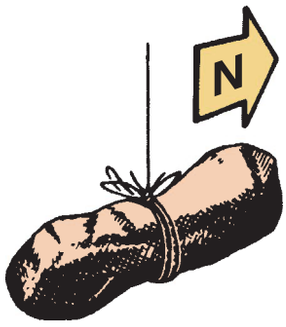


FIGURE 47–1 A freely suspended natural magnet (lodestone) will point toward the magnetic north pole.

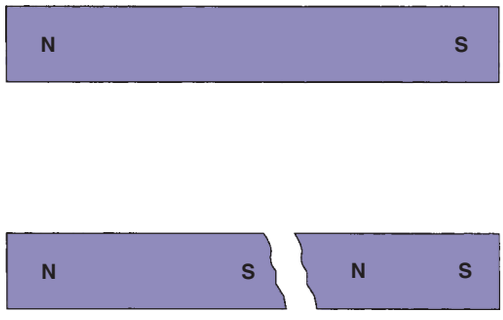


FIGURE 47–2 If a magnet breaks or is cracked, it becomes two weaker magnets.

LINES OF FORCE The lines that create a field of force around a magnet are believed to be caused by the way groups of atoms are aligned in the magnetic material. In a bar magnet, the lines are concentrated at both ends of the bar and form closed, parallel loops in three dimensions around the magnet. Force does not flow along these lines the way electrical current flows, but the lines *do* have direction. They come out of the north end, or **pole,** of the magnet and enter at the other end. ● **SEE FIGURE 47–3.**

The opposite ends of a magnet are called its north and south poles. In reality, they should be called the "north seeking" and "south seeking" poles, because they seek the earth's North Pole and South Pole, respectively.

The more lines of force that are present, the stronger the magnet becomes. The magnetic lines of force, also called **magnetic flux** or **flux lines,** form a magnetic field. The terms *magnetic field, lines of force, flux,* and *flux lines* are used interchangeably.

TECH TIP

A Cracked Magnet Becomes Two Magnets

Magnets are commonly used in vehicle crankshaft, camshaft, and wheel speed sensors. If a magnet is struck and cracks or breaks, the result is two smaller-strength magnets. Because the strength of the magnetic field is reduced, the sensor output voltage is also reduced. A typical problem occurs when a magnetic crankshaft sensor becomes cracked, resulting in a no-start condition. Sometimes the cracked sensor works well enough to start an engine that is cranking at normal speeds but will not work when the engine is cold. ● **SEE FIGURE 47–2.**

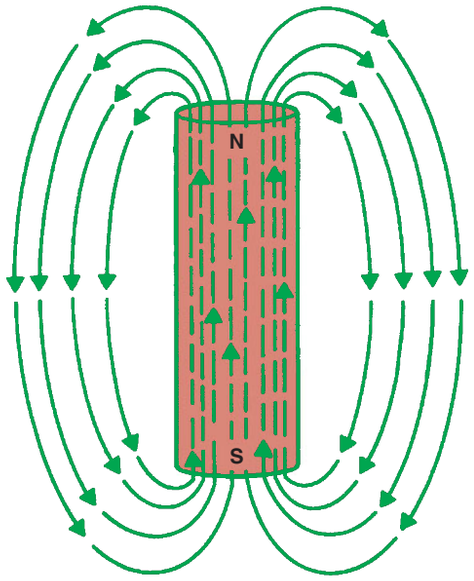


FIGURE 47–3 Magnetic lines of force leave the north pole and return to the south pole of a bar magnet.

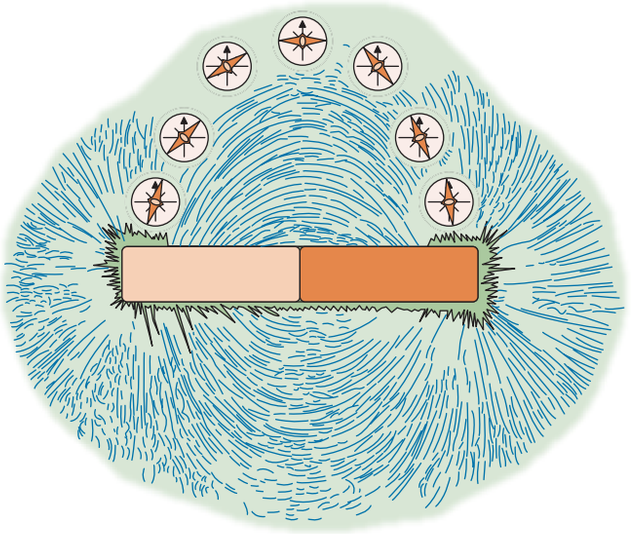


FIGURE 47–4 Iron filings and a compass can be used to observe the magnetic lines of force.

Flux density refers to the number of flux lines per unit of area. A magnetic field can be measured using a Gauss gauge, named for German scientist Johann Carl Friedrick Gauss (1777–1855).

Magnetic lines of force can be seen by spreading fine iron filings or dust on a piece of paper laid on top of a magnet. A magnetic field can also be observed by using a compass. A compass is simply a thin magnet or magnetized iron needle balanced on a pivot. The needle will rotate to point toward the opposite pole of a magnet. The needle can be very sensitive to small magnetic fields. Because it is a small magnet, a compass usually has one north end (marked N) and one south end (marked S). ● **SEE FIGURE 47–4.**

MAGNETIC INDUCTION

If a piece of iron or steel is placed in a magnetic field, it will also become magnetized. This process of creating a magnet by using a magnetic field is called **magnetic induction.**

If the metal is then removed from the magnetic field, and it retains some magnetism, this is called **residual magnetism.**

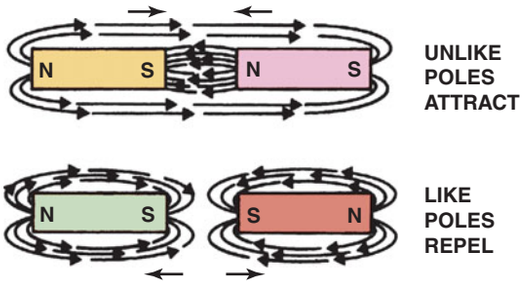


FIGURE 47–5 Magnetic poles behave like electrically charged particles—unlike poles attract and like poles repel.

TECH TIP

Magnetize a Steel Needle

A piece of steel can be magnetized by rubbing a magnet in one direction along the steel. This causes the atoms to line up in the steel, so it acts like a magnet. The steel often will not remain magnetized, whereas the true magnet is permanently magnetized.

When soft iron or steel is used, such as a paper clip, it will lose its magnetism quickly. The atoms in a magnetized needle can be disturbed by heating it or by dropping the needle on a hard object, which would cause the needle to lose its magnetism. Soft iron is used inside ignition coils because it will not keep its magnetism.

ATTRACTING OR REPELLING

The poles of a magnet are called north (N) and south (S) because, when a magnet is suspended freely, the poles tend to point toward the earth's North Pole and South Pole. Magnetic flux lines exit from the north pole and bend around to enter the south pole. An equal number of lines exit and enter, so magnetic force is equal at both poles of a magnet. Flux lines are concentrated at the poles, and therefore magnetic force (flux density) is stronger at the ends.

Magnetic poles behave like positively and negatively charged particles. When unlike poles are placed close together, the lines exit from one magnet and enter the other. The two magnets are pulled together by flux lines. If like poles are placed close together, the curving flux lines meet head on, forcing the magnets apart. Therefore, like poles of a magnet repel and unlike poles attract. ● **SEE FIGURE 47–5.**

PERMEABILITY

Magnetic flux lines cannot be insulated. There is no known material through which magnetic force does not pass, if the force is strong enough. However, some materials allow the force to pass through more easily than others. This degree of passage is called **permeability.** Iron allows magnetic flux lines to pass through much more easily than air, so iron is highly permeable.

An example of this characteristic is the use of a reluctor wheel in magnetic-type camshaft position (CMP) and crankshaft position (CKP) sensors. The teeth on a reluctor cause the magnetic field to increase as each tooth gets closer to the sensor and decrease as the tooth moves away, thus creating an AC voltage signal. ● **SEE FIGURE 47–6.**

RELUCTANCE

Although there is no absolute insulation for magnetism, certain materials resist the passage of magnetic force. This can be compared to resistance without an electrical circuit. Air does

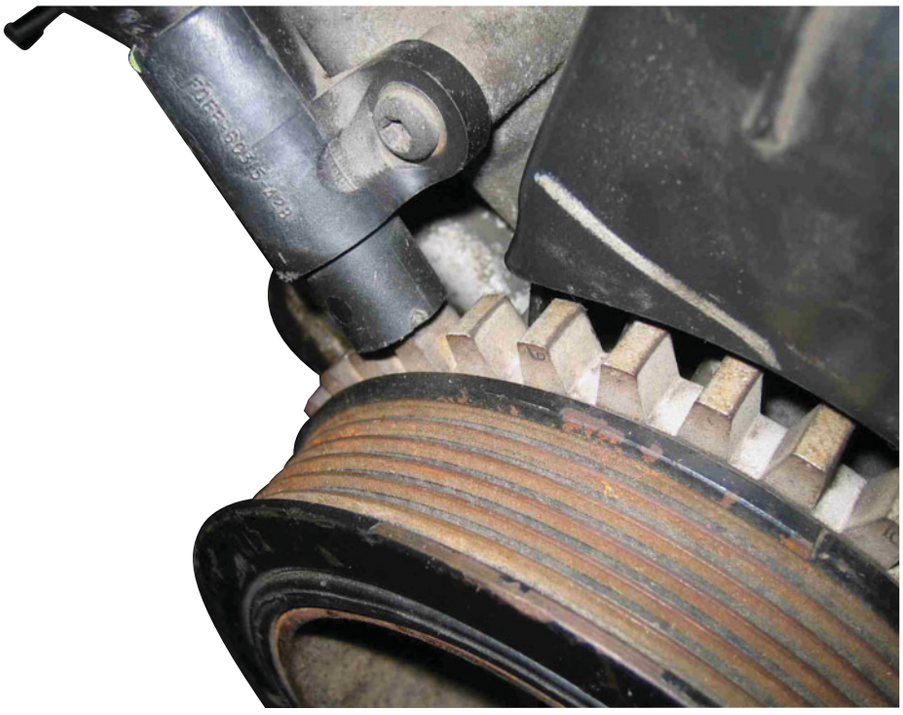


FIGURE 47–6 A crankshaft position sensor and reluctor (notched wheel).

not allow easy passage, so air has a high **reluctance.** Magnetic flux lines tend to concentrate in permeable materials and avoid materials with high reluctance. As with electricity, magnetic force follows the path of least resistance.

ELECTROMAGNETISM

DEFINITION Scientists did not discover that current-carrying conductors also are surrounded by a magnetic field until 1820. These fields may be made many times stronger than those surrounding conventional magnets. Also, the magnetic field strength around a conductor may be controlled by changing the current.

- As current increases, more flux lines are created and the magnetic field expands.
- As current decreases, the magnetic field contracts. The magnetic field collapses when the current is shut off.
- The interaction and relationship between magnetism and electricity is known as **electromagnetism.**

TECH TIP

Electricity and Magnetism

Electricity and magnetism are closely related because any electrical current flowing through a conductor creates a magnetic field. Any conductor moving through a magnetic field creates an electrical current. This relationship can be summarized as follows:

- Electricity creates magnetism.
- Magnetism creates electricity.

From a service technician's point of view, this relationship is important because wires carrying current should always be routed as the factory intended to avoid causing interference with another circuit or electronic component. This is especially important when installing or servicing spark plug wires, which carry high voltages and can cause high electromagnetic interference.

CREATING AN ELECTROMAGNET An easy way to create an electromagnet is to wrap a nail with 20 turns of insulated wire and connect the ends to the terminals of a 1.5 volt dry cell battery. When energized, the nail will become a magnet and will be able to pick up tacks or other small steel objects.

STRAIGHT CONDUCTOR The magnetic field surrounding a straight, current-carrying conductor consists of several concentric cylinders of flux that are the length of the wire. The amount of current flow (amperes) determines how many flux lines (cylinders) there will be and how far out they extend from the surface of the wire. ● **SEE FIGURE 47–7.**

LEFT-HAND AND RIGHT-HAND RULES Magnetic flux cylinders have direction, just as the flux lines surrounding a bar magnet have direction. The **left-hand rule** is a simple way to determine this direction. When you grasp a conductor with your left hand so that your thumb points in the direction of electron flow (− to +) through the conductor, your fingers curl around the wire in the direction of the magnetic flux lines. ● **SEE FIGURE 47–8.**

Most automotive circuits use the conventional theory of current (− to +) and, therefore, the **right-hand rule** is used to determine the direction of the magnetic flux lines. ● **SEE FIGURE 47–9.**

FIELD INTERACTION The cylinders of flux surrounding current-carrying conductors interact with other magnetic fields. In the following illustrations, the cross symbol (+) indicates current moving inward, or away from you. It represents the tail of an arrow. The dot symbol (•) represents an arrowhead and indicates current moving outward. If two conductors carry current in opposite directions, their magnetic fields also carry current in opposite directions

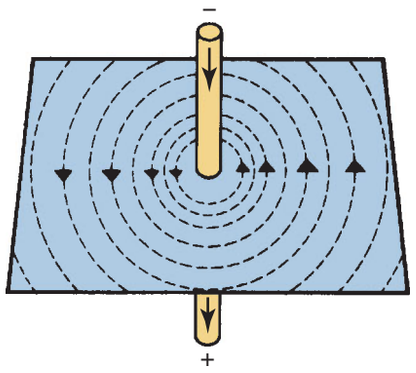


FIGURE 47–7 A magnetic field surrounds a straight, current-carrying conductor.

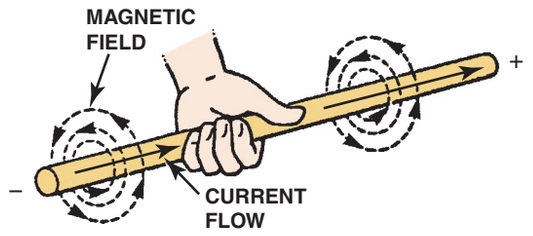


FIGURE 47–8 The left-hand rule for magnetic field direction is used with the electron flow theory.



FIGURE 47–9 The right-hand rule for magnetic field direction is used with the conventional theory of electron flow.

(according to the left-hand rule). If they are placed side by side, then the opposing flux lines between the conductors create a strong magnetic field. Current-carrying conductors tend to move out of a strong field into a weak field, so the conductors move away from each other. ● **SEE FIGURE 47–10.**

If the two conductors carry current in the same direction, then their fields are in the same direction. The flux lines between the two conductors cancel each other out, leaving a very weak field between them. The conductors are drawn into this weak field, and they tend to move toward each other.

MOTOR PRINCIPLE Electric motors, such as vehicle starter motors, use this magnetic field interaction to convert electrical energy into mechanical energy. If two conductors carrying current in opposite directions are placed between strong north and south poles, the magnetic field of the conductor interacts with the magnetic fields of the poles. The counterclockwise field of the top conductor adds to the fields of the poles and creates a strong field beneath the conductor. The conductor then tries to move up to get out of this strong field. The clockwise field of the lower conductor adds to the field of the poles and creates a strong field above the conductor. The conductor then tries to move down to get out of this strong field. These forces cause the center of the motor, where the conductors are mounted, to turn clockwise. ● **SEE FIGURE 47–11.**

COIL CONDUCTOR If several loops of wire are made into a coil, then the magnetic flux density is strengthened. Flux lines around a coil are the same as the flux lines around a bar magnet. ● **SEE FIGURE 47–12.**

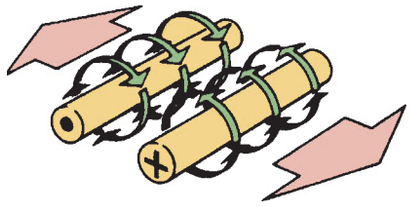


FIGURE 47–10 Conductors with opposing magnetic fields will move apart into weaker fields.

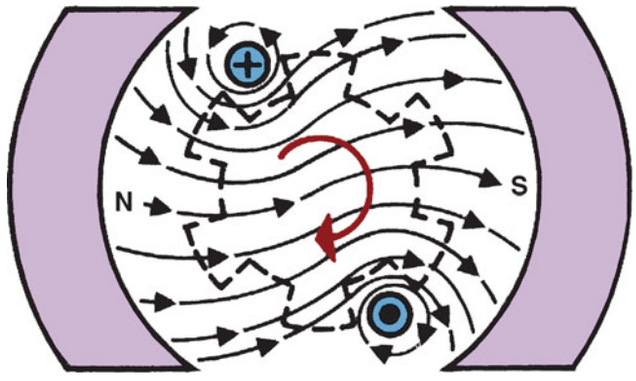


FIGURE 47–11 Electric motors use the interaction of magnetic fields to produce mechanical energy.

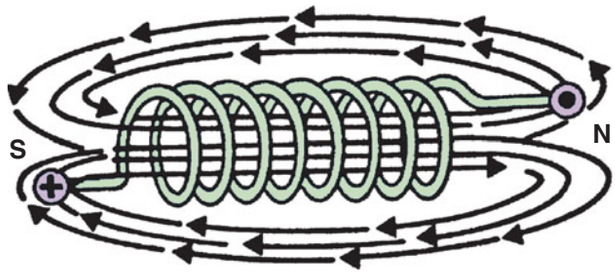


FIGURE 47–12 The magnetic lines of flux surrounding a coil look similar to those surrounding a bar magnet.

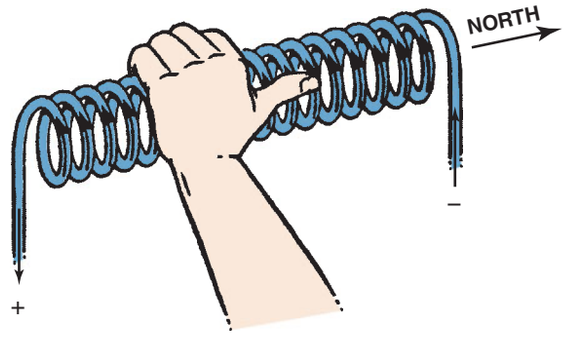


FIGURE 47–13 The left-hand rule for coils is shown.

They exit from the north pole and enter at the south pole. Use the left-hand rule to determine the north pole of a coil, as shown in ● **FIGURE 47–13.**

Grasp the coil with your left hand so that your fingers point in the direction of electron flow; your thumb will point toward the north pole of the coil.

ELECTROMAGNETIC STRENGTH The magnetic field surrounding a current-carrying conductor can be strengthened (increased) three ways.

- Place a soft iron core in the center of the coil.
- Increase the number of turns of wire in the coil.
- Increase the current flow through the coil windings.

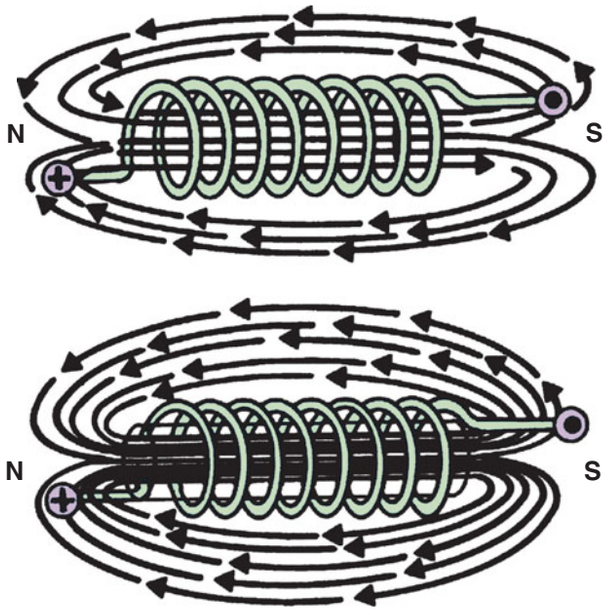


FIGURE 47–14 An iron core concentrates the magnetic lines of force surrounding a coil.

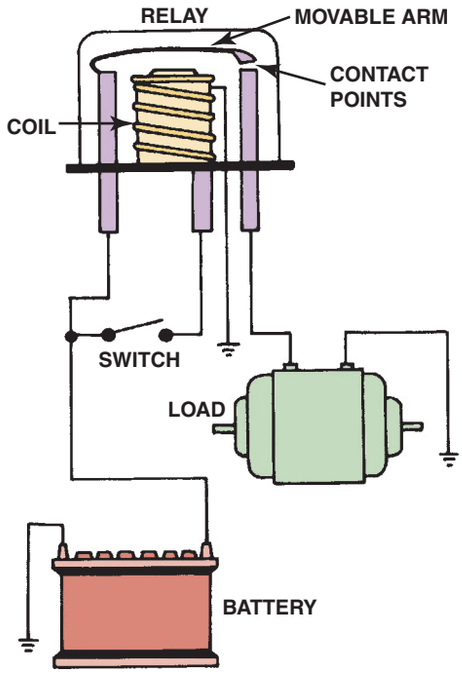


FIGURE 47–15 An electromagnetic switch that has a movable arm is referred to as a relay.

	CONSTRUCTION	AMPERAGE RATING	USES	CALLED IN SERVICE INFORMATION
Relay	Uses a movable arm Coil: 60 to 100 ohms requiring 0.12 to 0.20 A to energize	1 to 30 A	Lower current switching, lower cost, more commonly used	Electromagnetic switch or relay
Solenoid	Uses a movable core Coil(s): 0.2 to 0.6 ohm requiring 20 to 60 A to energize	30 to 400 A	Higher cost, used in starter motor circuits and other high-amperage applications	Solenoid, relay, or electromagnetic switch

CHART 47–1

Comparison between a relay and a solenoid.

Because soft iron is highly permeable, magnetic flux lines pass through it easily. If a piece of soft iron is placed inside a coiled conductor, the flux lines concentrate in the iron core, rather than pass through the air, which is less permeable. The concentration of force greatly increases the strength of the magnetic field inside the coil. Increasing the number of turns in a coil and/or increasing the current flow through the coil results in greater field strength and is proportional to the number of turns. The magnetic field strength is often expressed in the units called **ampere-turns.** Coils with an iron core are called **electromagnets.** ● **SEE FIGURE 47–14.**

USES OF ELECTROMAGNETISM

RELAYS As mentioned in the previous chapter, a **relay** is a control device that allows a small amount of current to control a large amount of current in another circuit. A simple relay contains an electromagnetic coil in series with a battery and a switch. Near the electromagnet is a movable flat arm, called an *armature*, of some material that is attracted by a magnetic field. ● **SEE FIGURE 47–15.**

The armature pivots at one end and is held a small distance away from the electromagnet by a spring (or by the spring steel of the movable arm itself). A contact point, made of a good conductor, is attached to the free end of the armature. Another contact point is fixed a small distance away. The two contact points are wired in series with an electrical load and the battery.

When the switch is closed, the following occurs.

1. Current travels from the battery through a coil, creating an electromagnet.
2. The magnetic field created by the current attracts the armature, pulling it down until the contact points close.
3. Closing the contacts allows current in the heavy current circuit from the battery to the load.

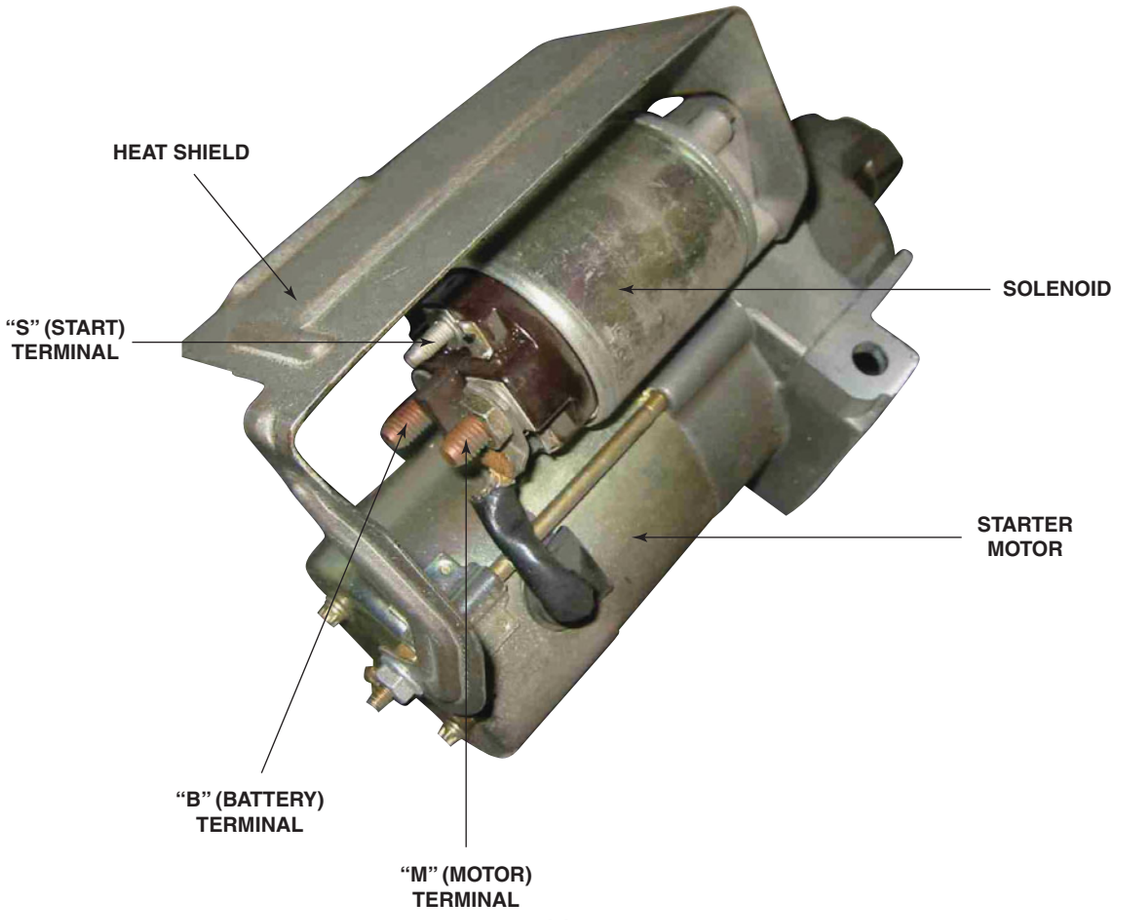
When the switch is open, the following occurs.

1. The electromagnet loses its magnetism when the current is shut off.

? FREQUENTLY ASKED QUESTION

Solenoid or Relay?

Often, either term is used to describe the same part in service information. ● **SEE CHART 47–1** for a summary of the differences.



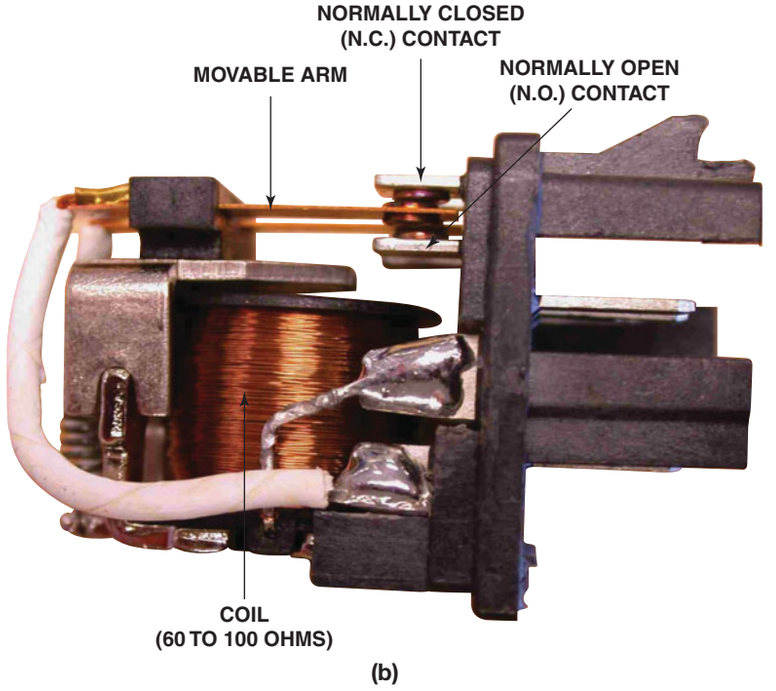


FIGURE 47–16 (a) A starter with attached solenoid. All of the current needed by the starter flows through the two large terminals of the solenoid and through the solenoid contacts inside. (b) A relay is designed to carry lower current compared to a solenoid and uses a movable arm.

2. Spring pressure lifts the arm back up.
3. The heavy current circuit is broken by the opening of the contact points.

Relays also may be designed with normally closed contacts that open when current passes through the electromagnetic coil.

SOLENOID A solenoid is an example of an electromagnetic switch. A solenoid uses a movable core rather than a movable arm and is generally used in higher-amperage applications. A solenoid can be a separate unit or attached to a starter such as a starter solenoid. ● **SEE FIGURE 47–16.**

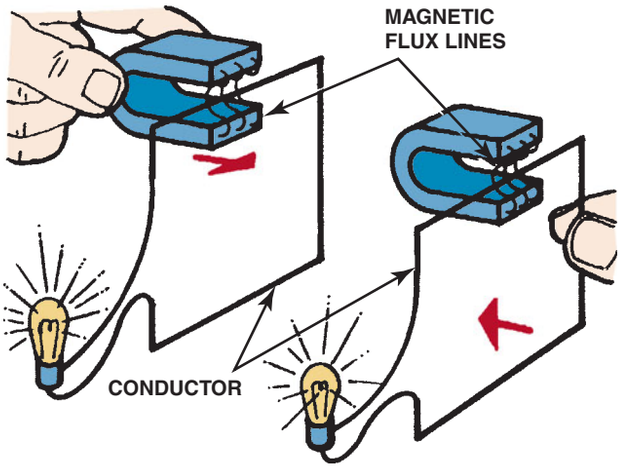


FIGURE 47–17 Voltage can be induced by the relative motion between a conductor and magnetic lines of force.

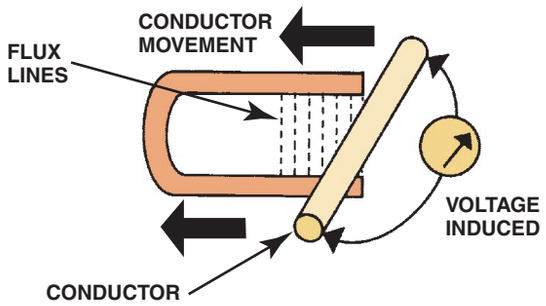


FIGURE 47–18 Maximum voltage is induced when conductors cut across the magnetic lines of force (flux lines) at a 90-degree angle.

ELECTROMAGNETIC INDUCTION

PRINCIPLES INVOLVED Electricity can be produced by using the relative movement of an electrical conductor and a magnetic field. There are three items necessary to produce electricity (voltage) from magnetism.

1. Electrical conductor (usually a coil of wire)
2. Magnetic field
3. Movement of either the conductor or the magnetic field

Therefore:

- Electricity creates magnetism.
- Magnetism can create electricity.

Magnetic flux lines create an electromotive force, or voltage, in a conductor if either the flux lines or the conductor is moving. This movement is called *relative motion*. This process is called induction, and the resulting electromotive force is called *induced voltage*. This creation of a voltage (electricity) in a conductor by a moving magnetic field is called **electromagnetic induction.** ● **SEE FIGURE 47–17.**

VOLTAGE INTENSITY Voltage is induced when a conductor cuts across magnetic flux lines. The amount of the voltage depends on the rate at which the flux lines are broken. The more flux lines that are broken per unit of time, the greater the induced voltage. If a single conductor breaks 1 million flux lines per second, 1 volt is induced.

There are four ways to increase induced voltage.

- Increase the strength of the magnetic field, so there are more flux lines.
- Increase the number of conductors that are breaking the flux lines.
- Increase the speed of the relative motion between the conductor and the flux lines so that more lines are broken per time unit.
- Increase the angle between the flux lines and the conductor to a maximum of 90 degrees. There is no voltage induced if the conductors move parallel to, and do not break, any flux lines.

Maximum voltage is induced if the conductors break flux lines at 90 degrees. Induced voltage varies proportionately at angles between 0 and 90 degrees. ● **SEE FIGURE 47–18.**

Voltage can be electromagnetically induced and can be measured. Induced voltage creates current. The direction of induced voltage (and the direction in which current moves) is called *polarity* and depends upon the direction of the flux lines, as well as the direction of relative motion.

LENZ'S LAW An induced current moves so that its magnetic field opposes the motion that induced the current. This principle is called **Lenz's law.** The relative motion of a conductor and a magnetic field is opposed by the magnetic field of the current it has induced.

SELF-INDUCTION When current begins to flow in a coil, the flux lines expand as the magnetic field forms and strengthens. As current increases, the flux lines continue to expand, cutting across the wires of the coil and actually inducing another voltage within the same coil. Following Lenz's law, this self-induced voltage tends to *oppose* the current that produces it. If the current continues to increase, the second voltage opposes the increase. When the current stabilizes, the countervoltage is no longer induced because there are no more expanding flux lines (no relative motion). When current to the coil is shut off, the collapsing magnetic flux lines self-induce a voltage in the coil that tries to maintain the original current. The self-induced voltage *opposes* and *slows* the *decrease* in the original current. The self-induced voltage that opposes changes in current flow is an inductor called **counter electromotive force (CEMF).**

MUTUAL INDUCTION When two coils are close together, energy may be transferred from one to the other by magnetic coupling called mutual induction. **Mutual induction** means that the expansion or collapse of the magnetic field around one coil induces a voltage in the second coil.

IGNITION COILS

IGNITION COIL WINDINGS Ignition coils use two windings and are wound on the same iron core.

- One coil winding is connected to a battery through a switch and is called the *primary winding*.
- The other coil winding is connected to an external circuit and is called the *secondary winding*.

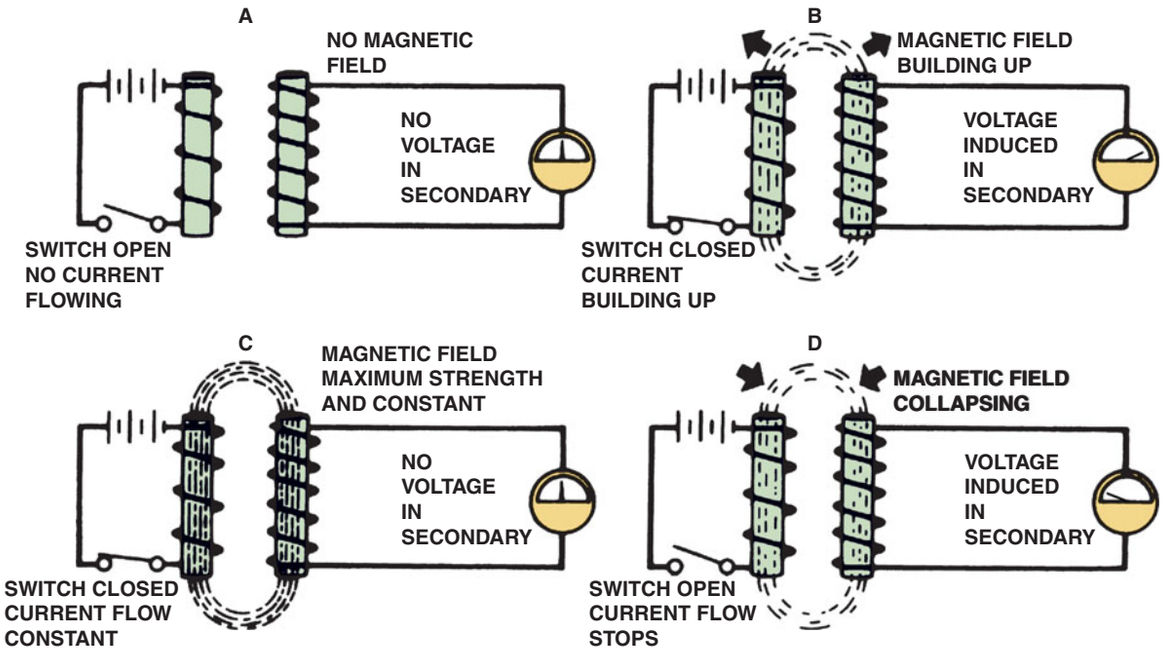


FIGURE 47–19 Mutual induction occurs when the expansion or collapse of a magnetic field around one coil induces a voltage in a second coil.

When the switch is open, there is no current in the primary winding. There is no magnetic field and, therefore, no voltage in the secondary winding. When the switch is closed, current is introduced and a magnetic field builds up around both windings. The primary winding thus changes electrical energy from the battery into magnetic energy of the expanding field. As the field expands, it cuts across the secondary winding and induces a voltage in it. A meter connected to the secondary circuit shows current. ● **SEE FIGURE 47–19.**

When the magnetic field has expanded to its full strength, it remains steady as long as the same amount of current exists. The flux lines have stopped their cutting action. There is no relative motion and no voltage in the secondary winding, as shown on the meter.

When the switch is opened, primary current stops and the field collapses. As it does, flux lines cut across the secondary winding but in the opposite direction. This induces a secondary voltage with current in the opposite direction, as shown on the meter.

Mutual induction is used in ignition coils. In an ignition coil, low-voltage primary current induces a very high secondary voltage because of the different number of turns in the primary and secondary windings. Because the voltage is increased, an ignition coil is also called a *step-up transformer*.

- **Electrically connected windings.** Many ignition coils contain two separate but electrically connected windings of copper wire. This type of coil is called a "married" type and is used in older distributor-type ignition systems and in many coil-on-plug (COP) designs.
- **Electrically insulated windings.** Other coils are true transformers in which the primary and secondary windings are not electrically connected. This type of coil is often called a "divorced" type and is used in all waste-spark-type ignition systems.

● **SEE FIGURE 47–20.**

IGNITION COIL CONSTRUCTION

The center of an ignition coil contains a core of laminated soft iron (thin strips of soft iron). This core increases the magnetic strength of the coil. Surrounding the laminated core are approximately 20,000 turns of fine wire (approximately 42 gauge). These windings are called the secondary coil windings. Surrounding the secondary windings are approximately 150 turns of heavy wire (approximately 21 gauge). These windings are called the primary coil windings. The secondary winding has about 100 times the number of turns of the primary winding, referred to as the **turns ratio** (approximately 100:1). In many coils, these windings are surrounded with a thin metal shield and insulating paper, and placed into a metal container. The metal container and shield help retain the magnetic field produced in the coil windings. The primary and secondary windings produce heat because of the electrical resistance in the turns of wire. Many coils contain oil to help cool the ignition coil. Other coil designs include the following:

- **Air-cooled, epoxy-sealed E coil.** The *E coil* is so named because the laminated, soft iron core is E shaped, with the coil wire turns wrapped around the center "finger" of the E and the primary winding wrapped inside the secondary winding. ● **SEE FIGURE 47–21** on page 507.
- **Spool design.** Used mostly for coil-on plug design, the coil windings are wrapped around a nylon or plastic spool or bobbin. ● **SEE FIGURE 47–22** on page 507.

IGNITION COIL OPERATION

The negative terminal is attached to an **ignition control module** (**ICM**, or **igniter**), which opens and closes the primary ignition circuit by opening or closing the ground return path of the circuit. When the ignition switch is on, voltage should be available at *both* the positive terminal and the negative terminal of the coil if the primary windings of the coil have continuity.

A spark is created by the following sequence of events.

- A magnetic field is created in the primary winding of the coil when there is 12 volts applied to the primary coil winding and the ignition control module grounds the other end on the coil.
- When the ignition control module (or powertrain control module) opens the ground circuit, the stored magnetic field collapses and creates a high voltage (up to 40,000 volts or more) in the secondary winding.

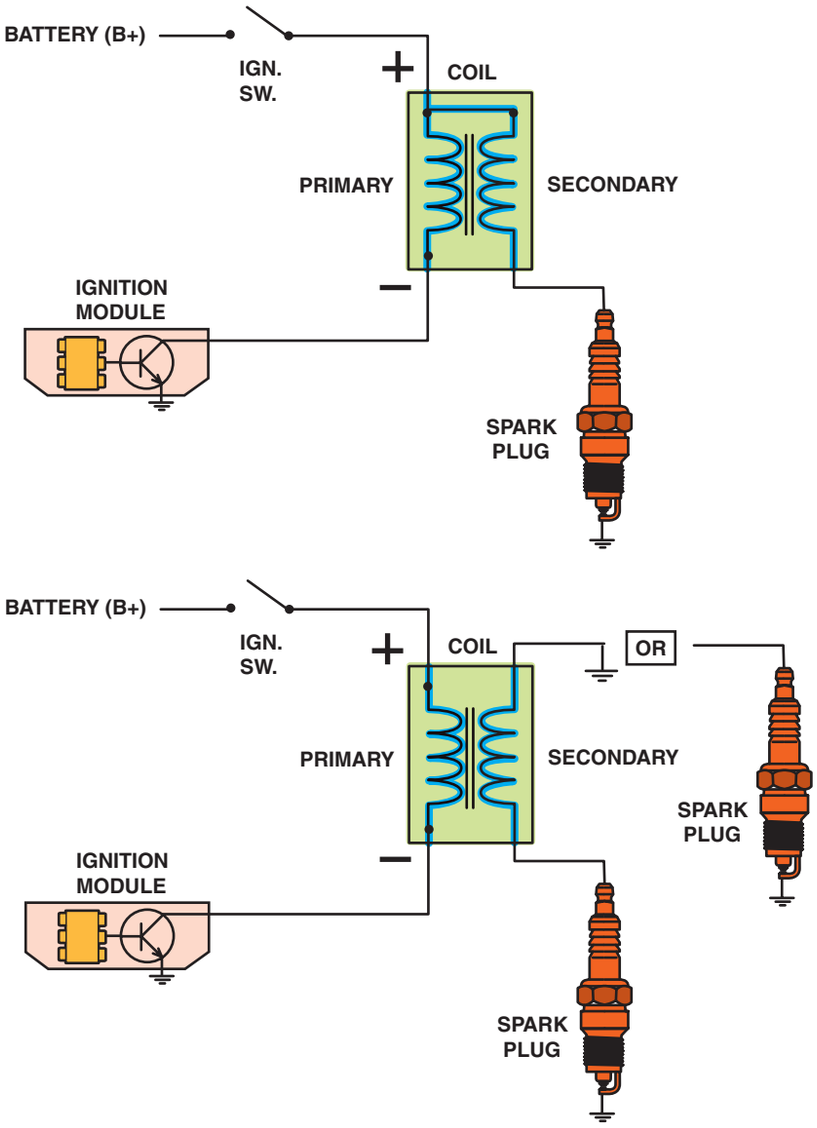


FIGURE 47–20 Some ignition coils are electrically connected, called married (top figure) whereas others use separated primary and secondary windings, called divorced (lower figure).

- The high-voltage pulse then flows to the spark plug and creates a spark at the ground electrode inside the engine that ignites the air-fuel mixture inside the cylinder.

ELECTROMAGNETIC INTERFERENCE

DEFINITION Until the advent of the onboard computer, **electromagnetic interference (EMI)** was not a source of real concern to automotive engineers. The problem was mainly one of *radio-frequency interference (RFI)*, caused primarily by the use of secondary ignition cables. Using spark plug wires that contained a high-resistance, nonmetallic core made of carbon, linen, or fiberglass strands impregnated with graphite mostly solved RFI from the secondary ignition system. RFI is a part of electromagnetic interference, which deals with interference that affects radio reception. All electronic devices used in vehicles are affected by EMI/RFI.

HOW EMI IS CREATED Whenever there is current in a conductor, an electromagnetic field is created. When current stops and starts, as in a spark plug cable or a switch that opens and closes, the field strength changes. Each time this happens, it creates an electromagnetic signal wave. If it happens rapidly enough, the resulting high-frequency signal waves, or EMI, interfere with radio and television transmission or with other electronic systems such as those under the hood. This is an undesirable side effect of the phenomenon of electromagnetism.

Static electric charges caused by friction of the tires with the road, or the friction of engine drive belts contacting their pulleys, also produce EMI. Drive axles, driveshafts, and clutch or brake lining surfaces are other sources of static electric charges.

There are four ways of transmitting EMI, all of which can be found in a vehicle.

- Conductive coupling is actual physical contact through circuit conductors.
- Capacitive coupling is the transfer of energy from one circuit to another through an electrostatic field between two conductors.



FIGURE 47–21 A GM waste-spark ignition coil showing the section of laminations that is shaped like the letter *E*. These mild steel laminations improve the efficiency of the coil.



FIGURE 47–22 The coil-on-plug (COP) design typically uses a bobbin-type coil.

TECH TIP

Cell Phone Interference

A cellular phone emits a weak signal if it is turned on, even though it is not being used. This signal is picked up and tracked by cell phone towers. When the cell phone is called, it emits a stronger signal to notify the tower that it is on and capable of receiving a phone call. It is this "handshake" signal that can cause interference in the vehicle. Often this signal causes some static in the radio speakers even though the radio is off, but it can also cause a false antilock brake (ABS) trouble code to set. These signals from the cell phone create a voltage that is induced in the wires of the vehicle. Because the cell phone usually leaves with the customer, the service technician is often unable to verify the customer concern.

Remember, the interference occurs right *before* the cell phone rings. To fix the problem, connect an external antenna to the cell phone. This step will prevent the induction of a voltage in the wiring of the vehicle.

- Inductive coupling is the transfer of energy from one circuit to another as the magnetic fields between two conductors form and collapse.
- Electromagnetic radiation is the transfer of energy by the use of radio waves from one circuit or component to another.

EMI SUPPRESSION DEVICES

There are four general ways in which EMI is reduced.

- **Resistance suppression.** Adding resistance to a circuit to suppress RFI works only for high-voltage systems. This has been done by the use of resistance spark plug cables, resistor spark plugs, and the silicone grease used on the distributor cap and rotor of some electronic ignitions.
- **Suppression capacitors and coils.** Capacitors are installed across many circuits and switching points to absorb voltage fluctuations. Among other applications, they are used across the following:
  - The primary circuit of some electronic ignition modules
  - The output terminal of most alternators
  - The armature circuit of some electric motors

  Coils reduce current fluctuations resulting from self-induction. They are often combined with capacitors to act as EMI filter circuits for windshield wiper and electric fuel pump motors. Filters also may be incorporated in wiring connectors.
- **Shielding.** The circuits of onboard computers are protected to some degree from external electromagnetic waves by their metal housings.
- **Ground wires or straps.** Ground wires or braided straps between the engine and chassis of an automobile help suppress EMI conduction and radiation by providing a low-resistance circuit ground path. Such suppression ground straps are often installed between rubber-mounted components and body parts. On some models, ground straps are installed between body parts, such as between the hood and a fender panel, where no electrical circuit exists. The strap has no other job than to suppress EMI. Without it, the sheet-metal body and hood could function as a large capacitor. The space between the fender and hood could form an electrostatic field and couple with the computer circuits in the wiring harness routed near the fender panel. ● **SEE FIGURE 47–23.**



FIGURE 47–23 To help prevent underhood electromagnetic devices from interfering with the antenna input, it is important that all ground wires, including the one from this power antenna, be properly grounded.

REVIEW QUESTIONS

1. What is the relationship between electricity and magnetism?
2. What is the difference between mutual induction and self-induction?
3. What is the result if a magnet cracks?
4. How can EMI be reduced or controlled?

CHAPTER QUIZ

1. Technician A says that magnetic lines of force can be seen by placing iron filings on a piece of paper and then holding them over a magnet. Technician B says that the effects of magnetic lines of force can be seen using a compass. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
2. Unlike magnetic poles _____, and like magnetic poles _____.
   a. Repel; attract **c.** Repel; repel
   b. Attract; repel **d.** Attract; attract
3. The conventional theory for current flow is being used to determine the direction of magnetic lines of force. Technician A says that the left-hand rule should be used. Technician B says that the right-hand rule should be used. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
4. Technician A says that a relay is an electromagnetic switch. Technician B says that a solenoid uses a movable core. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
5. Two technicians are discussing electromagnetic induction. Technician A says that the induced voltage can be increased if the speed is increased between the conductor and the magnetic lines of force. Technician B says that the induced voltage can be increased by increasing the strength of the magnetic field. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
6. An ignition coil operates using the principle(s) of _____.
   a. Electromagnetic induction
   b. Self-induction
   c. Mutual induction
   d. All of the above
7. Electromagnetic interference can be reduced by using a _____.
   a. Resistance
   b. Capacitor
   c. Coil
   d. All of the above
8. An ignition coil is an example of a _____.
   a. Solenoid
   b. Step-down transformer
   c. Step-up transformer
   d. Relay
9. Magnetic field strength is measured in _____.
   a. Ampere-turns
   b. Flux
   c. Density
   d. Coil strength
10. Two technicians are discussing ignition coils. Technician A says that some ignition coils have the primary and secondary windings electrically connected. Technician B says that some coils have totally separate primary and secondary windings that are not electrically connected. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

chapter 48

ELECTRONIC FUNDAMENTALS

OBJECTIVES: **After studying Chapter 48, the reader should be able to:** • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "A" (General Electrical/Electronic Systems Diagnosis). • Identify semiconductor components. • Explain precautions necessary when working with semiconductor circuits. • Discuss where various electronic and semiconductor devices are used in vehicles. • Explain how diodes and transistors work. • Describe how to test diodes and transistors. • List the precautions that a service technician should follow to avoid damage to electronic components from electrostatic discharge.

KEY TERMS: Anode 510 • Base 516 • Bipolar transistor 516 • Burn in 511 • Cathode 510 • CHMSL 515 • Clamping diode 512 • Collector 516 • Control current 517 • Darlington pair 517 • Despiking diode 512 • Diode 510 • Doping 509 • Dual inline pins (DIP) 518 • Emitter 516 • ESD 523 • FET 517 • Forward bias 511 • Gate 518 • Germanium 509 • Heat sink 518 • Holes 510 • Hole theory 510 • Impurities 509 • Integrated circuit (IC) 518 • Inverter 522 • Junction 510 • Light emitting diode (LED) 513 • MOSFET 517 • NPN transistor 516 • NTC 515 • N-type material 509 • Op-amps 519 • Photodiodes 514 • Photons 514 • Photoresistor 514 • Phototransistor 518 • Peak inverse voltage (PIV) 513 • Peak reverse voltage (PRV) 513 • PNP transistor 516 • P-type material 510 • PWM 520 • Rectifier bridge 515 • Reverse bias 511 • SCR 515 • Semiconductors 509 • Silicon 509 • Spike protection resistor 513 • Suppression diode 512 • Thermistor 515 • Threshold voltage 517 • Transistor 516 • Zener diode 511

Electronic components are the heart of computers. Knowing how electronic components work helps take the mystery out of automotive electronics.

SEMICONDUCTORS

DEFINITION Semiconductors are neither conductors nor insulators. The flow of electrical current is caused by the movement of electrons in materials, known as conductors having *fewer* than four electrons in their atom's outer orbit. Insulators contain *more* than four electrons in their outer orbit and cannot conduct electricity because their atomic structure is stable (no free electrons).

Semiconductors are materials that contain exactly four electrons in the outer orbit of their atom structure and are, therefore, neither good conductors nor good insulators.

EXAMPLES OF SEMICONDUCTORS Two examples of semiconductor materials are **germanium** and **silicon,** which have exactly four electrons in their valance ring and no free electrons to provide current flow. However, both of these semiconductor materials can be made to conduct current if another material is added to provide the necessary conditions for electron movement.

CONSTRUCTION When another material is added to a semiconductor material in very small amounts, it is called **doping.** The doping elements are called **impurities;** therefore, after their addition, the germanium and silicon are no longer considered *pure* elements. The material added to pure silicon or germanium to make it electrically conductive represents only one atom of impurity for every *100 million* atoms of the pure semiconductor material. The resulting

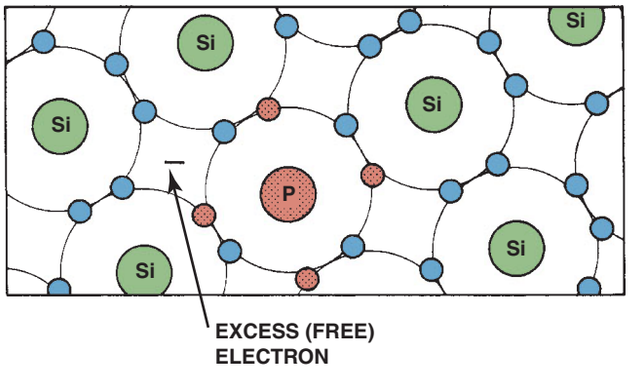


FIGURE 48–1 N-type material. Silicon (Si) doped with a material (such as phosphorus) with five electrons in the outer orbit results in an extra free electron.

atoms are still electrically *neutral,* because the number of electrons still equals the number of protons of the combined materials. These combined materials are classified into two groups depending on the number of electrons in the bonding between the two materials.

- N-type materials
- P-type materials

N-TYPE MATERIAL **N-type material** is silicon or germanium that is doped with an element such as *phosphorus*, *arsenic*, or *antimony*, each having five electrons in its outer orbit. These five electrons are combined with the four electrons of the silicon or germanium to total nine electrons. There is room for only eight electrons in the bonding between the semiconductor material and the doping material. This leaves extra electrons, and even though the material is still electrically neutral, these extra electrons tend to repel other electrons outside the material. ● **SEE FIGURE 48–1.**

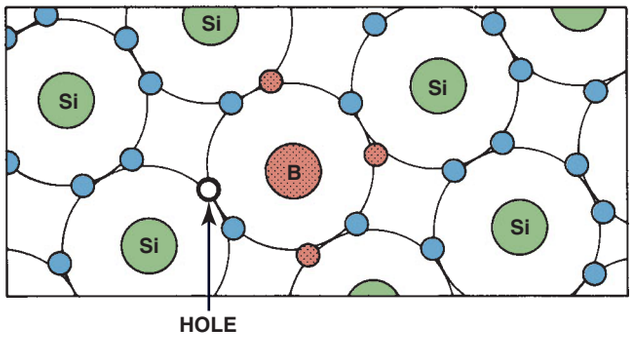


FIGURE 48–2 P-type material. Silicon (Si) doped with a material, such as boron (B), with three electrons in the outer orbit results in a hole capable of attracting an electron.

P-TYPE MATERIAL **P-type material** is produced by doping silicon or germanium with the element *boron* or the element *indium*. These impurities have only three electrons in their outer shell and, when combined with the semiconductor material, result in a material with seven electrons, one electron *less* than is required for atom bonding. This lack of one electron makes the material able to attract electrons, even though the material still has a neutral charge. This material tends to attract electrons to fill the **holes** for the missing eighth electron in the bonding of the materials. ● **SEE FIGURE 48–2.**

SUMMARY OF SEMICONDUCTORS

The following is a summary of semiconductor fundamentals.

1. The two types of semiconductor materials are P type and N type. N-type material contains extra electrons; P-type material contains holes due to missing electrons. The number of excess electrons in an N-type material must remain constant, and the number of holes in the P-type material must also remain constant. Because electrons are interchangeable, movement of electrons in or out of the material is possible to maintain a balanced material.
2. In P-type semiconductors, electrical conduction occurs mainly as the result of holes (absence of electrons). In N-type semiconductors, electrical conduction occurs mainly as the result of electrons (excess of electrons).
3. Hole movement results from the jumping of electrons into new positions.
4. Under the effect of a voltage applied to the semiconductor, electrons travel toward the positive terminal and holes move toward the negative terminal. The direction of hole current agrees with the conventional direction of current flow.

DIODES

CONSTRUCTION A **diode** is an electrical one-way check valve made by combining a P-type material and an N-type material. The word *diode* means "having two electrodes." Electrodes

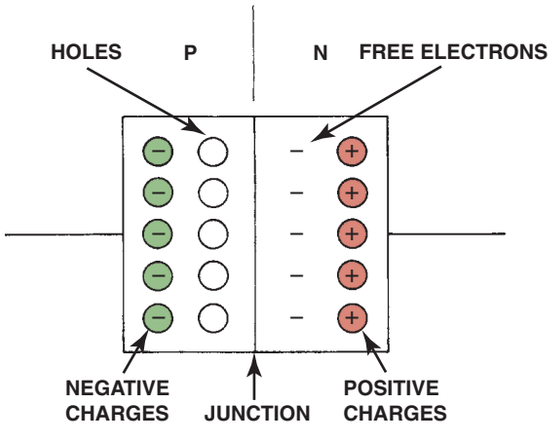


FIGURE 48–3 Unlike charges attract and the current carriers (electrons and holes) move toward the junction.

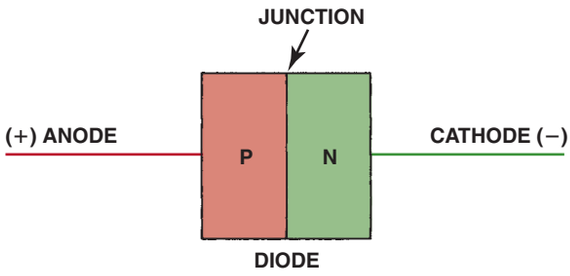


FIGURE 48–4 A diode is a component with P-type and N-type materials together. The negative electrode is called the cathode and the positive electrode is called the anode.

? FREQUENTLY ASKED QUESTION

What Is the Hole Theory?

Current flow is expressed as the movement of electrons from one atom to another. In semiconductor and electronic terms, the movement of electrons fills the holes of the P-type material. Therefore, as the holes are filled with electrons, the unfilled holes move opposite to the flow of the electrons. This concept of hole movement is called the **hole theory** of current flow. The holes move in the direction opposite that of electron flow. For example, think of an egg carton, where if an egg is moved in one direction, the holes created move in the opposite direction. ● **SEE FIGURE 48–3.**

are electrical connections: The positive electrode is called the **anode;** the negative electrode is called the **cathode.** The point where the two types of materials join is called the **junction.** ● **SEE FIGURE 48–4.**

OPERATION The N-type material has one extra electron, which can flow into the P-type material. The P type has a need for electrons to fill its holes. If a battery were connected to the diode positive (+) to P-type material and negative (−) to N-type material, then the electrons that left the N-type material and flowed into the P-type material to fill the holes would be quickly replaced by the electron

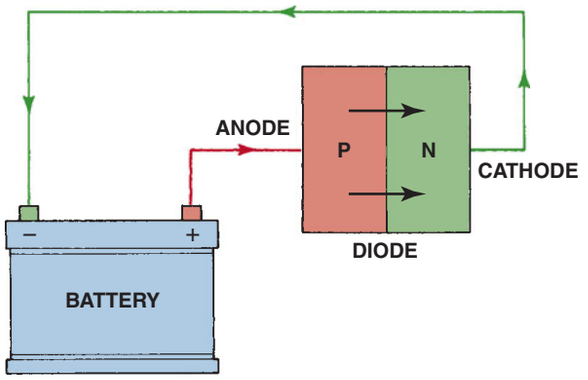


FIGURE 48–5 Diode connected to a battery with correct polarity (battery positive to P type and battery negative to N-type). Current flows through the diode. This condition is called forward bias.

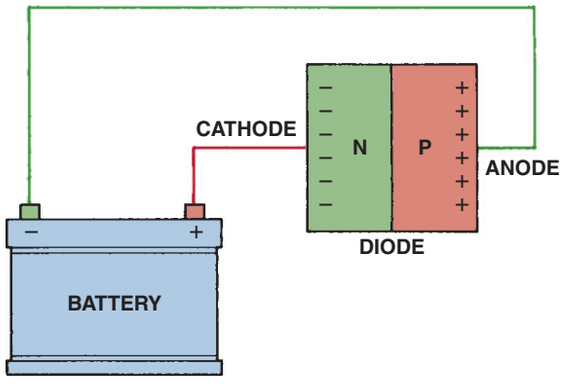


FIGURE 48–6 Diode connected with reversed polarity. No current flows across the junction between the P-type and N-type materials. This connection is called reverse bias.

flow from the battery. Current flows through a forward-bias diode for the following reasons.

- Electrons move toward the holes (P-type material).
- Holes move toward the electrons (N-type material). ● **SEE FIGURE 48–5.**

As a result, current would flow through the diode with low resistance. This condition is called **forward bias.**

If the battery connections were reversed and the positive side of the battery was connected to the N-type material, the electrons would be pulled toward the battery and away from the junction of the N-type and P-type materials. (Remember, unlike charges attract, whereas like charges repel.) Because electrical conduction requires the flow of electrons across the junction of the N-type and P-type materials and because the battery connections are actually reversed, the diode offers very high resistance to current flow. This condition is called **reverse bias.** ● **SEE FIGURE 48–6.**

Therefore, diodes allow current flow only when current of the correct polarity is connected to the circuit.

- Diodes are used in alternators to control current flow in one direction, which changes the AC voltage generated into DC voltage.
- Diodes are also used in computer controls, relays, air-conditioning circuits, and many other circuits to prevent possible damage due to reverse current flows that may be generated within the circuit. ● **SEE FIGURE 48–7.**

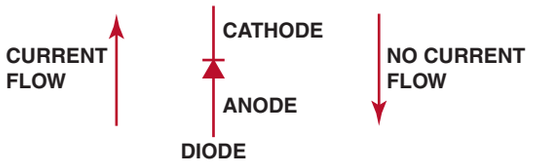


FIGURE 48–7 Diode symbol and electrode names. The stripe on one end of a diode represents the cathode end of the diode.

FREQUENTLY ASKED QUESTION

What Is the Difference Between Electricity and Electronics?

Electronics usually means that solid-state devices are used in the electrical circuits. Electricity as used in automotive applications usually means electrical current flow through resistance and loads without the use of diodes, transistors, or other electronic devices.

TECH TIP

"Burn In" to Be Sure

A common term heard in the electronic and computer industry is **burn in,** which means to operate an electronic device, such as a computer, for a period from several hours to several days.

Most electronic devices fail in infancy, or during the first few hours of operation. This early failure occurs if there is a manufacturing defect, especially at the P-N junction of any semiconductor device. The junction will usually fail after only a few operating cycles.

What does this information mean to the average person? When purchasing a personal or business computer, have the computer burned in before delivery. This step helps ensure that all of the circuits have survived infancy and that the chances of chip failure are greatly reduced. Purchasing sound or television equipment that has been on display may be a good value, because during its operation as a display model, the burn-in process has been completed. The automotive service technician should be aware that if a replacement electronic device fails shortly after installation, the problem may be a case of early electronic failure.

NOTE: Whenever there is a failure of a replacement part, the technician should always check for excessive voltage or heat to and around the problem component.

ZENER DIODES

CONSTRUCTION A **zener diode** is a specially constructed diode designed to operate with a reverse-bias current. Zener diodes were named in 1934 for their inventor, Clarence Melvin Zener, an American professor of physics.

OPERATION A zener diode acts as any diode in that it blocks reverse-bias current, but only up to a certain voltage. Above this



ZENER DIODE SYMBOL

FIGURE 48–8 A zener diode blocks current flow until a certain voltage is reached, then it permits current to flow.

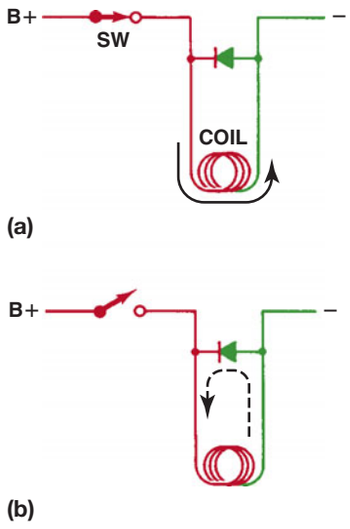


FIGURE 48–9 (a) Notice that when the coil is being energized, the diode is reverse biased and the current is blocked from passing through the diode. The current flows through the coil in the normal direction. (b) When the switch is opened, the magnetic field surrounding the coil collapses, producing a high-voltage surge in the reverse polarity of the applied voltage. This voltage surge forward biases the diode, and the surge is dissipated harmlessly back through the windings of the coil.

certain voltage (called the *breakdown voltage* or the zener region), a zener diode will conduct current in the opposite direction without damage to the diode. A zener diode is heavily doped, and the reverse-bias voltage does not harm the material. The voltage drop across a zener diode remains practically the same before and after the breakdown voltage, and this factor makes a zener diode perfect for voltage regulation. Zener diodes can be constructed for various breakdown voltages and can be used in a variety of automotive and electronic applications, especially for electronic voltage regulators used in the charging system. ● **SEE FIGURE 48–8.**

HIGH-VOLTAGE SPIKE PROTECTION

CLAMPING DIODES Diodes can be used as a high-voltage clamping device when the power (+) is connected to the cathode (–) of the diode. If a coil is pulsed on and off, a high-voltage spike is produced whenever the coil is turned off. To control and direct this possibly damaging high-voltage spike, a diode can be installed across the leads to the coil to redirect the high-voltage spike back through the coil windings to prevent possible damage to the rest of the vehicle's electrical or electronic circuits. A diode connected across the terminals of a coil to control voltage spikes is called a **clamping diode.** Clamping diodes can also be called **despiking** or **suppression diodes.** ● **SEE FIGURE 48–9.**

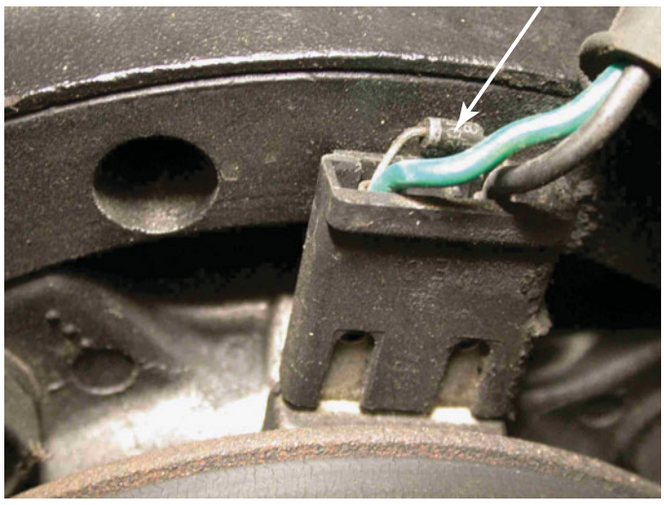


FIGURE 48–10 A diode connected to both terminals of the air-conditioning compressor clutch used to reduce the high-voltage spike that results when a coil (compressor clutch coil) is de-energized.

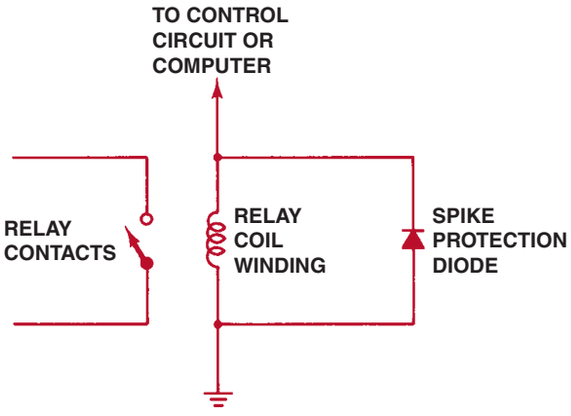


FIGURE 48–11 Spike protection diodes are commonly used in computer-controlled circuits to prevent damaging high-voltage surges that occur any time current flowing through a coil is stopped.

CLAMPING DIODE APPLICATION Diodes were first used on A/C compressor clutch coils at the same time electronic devices were first used. The diode was used to help prevent the high voltage spike generated inside the A/C clutch coil from damaging delicate to delicate electronic circuits anywhere in the vehicle's electrical system. ● **SEE FIGURE 48–10.**

Because most automotive circuits eventually are electrically connected to each other in parallel, a high-voltage surge anywhere in the vehicle could damage electronic components in other circuits.

The circuits most likely to be affected by the high-voltage surge, if the diode fails, are the circuits controlling the operation of the A/C compressor clutch and any component that uses a coil, such as those of the blower motor and climate control units.

Many relays are equipped with a diode to prevent a voltage spike when the contact points open and the magnetic field in the coil winding collapses. ● **SEE FIGURE 48–11.**

DESPIKING ZENER DIODES Zener diodes can also be used to control high-voltage spikes and keep them from damaging delicate electronic circuits. Zener diodes are most commonly used in electronic fuel-injection circuits that control the firing of the injectors. If clamping diodes were used in parallel with the injection coil, the resulting clamping action would tend to delay the closing of the

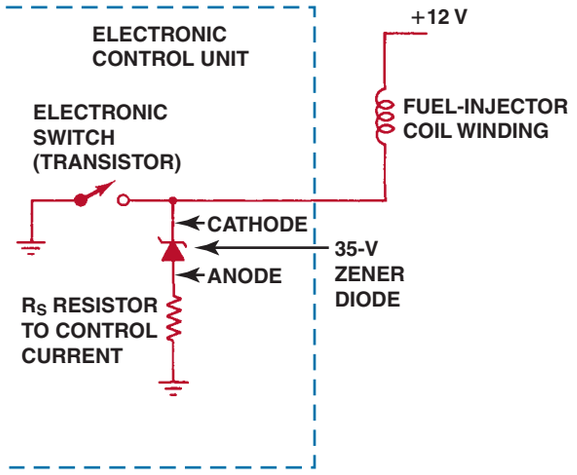


FIGURE 48–12 A zener diode is commonly used inside automotive computers to protect delicate electronic circuits from high-voltage spikes. A 35 volt zener diode will conduct any voltage spike higher than 35 voltage resulting from the discharge of the fuel injector coil safely to ground through a current-limiting resistor in series with the zener diode.

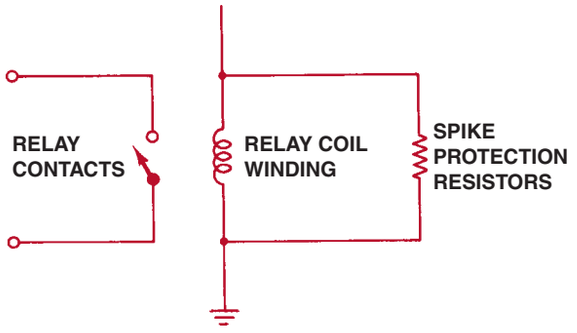


FIGURE 48–13 A despiking resistor is used in many automotive applications to help prevent harmful high-voltage surges from being created when the magnetic field surrounding a coil collapses when the coil circuit is opened.

fuel injector nozzle. A zener diode is commonly used to clamp only the higher voltage portion of the resulting voltage spike without affecting the operation of the injector. ● **SEE FIGURE 48–12.**

DESPIKING RESISTORS All coils must use some protection against high-voltage spikes that occur when the voltage is removed from any coil. Instead of a diode installed in parallel with the coil windings, a resistor can be used, called a **spike protection resistor.** ● **SEE FIGURE 48–13.**

Resistors are often preferred for two reasons.

Reason 1	Coils will usually fail when shorted rather than open, as this shorted condition results in greater current flow in the circuit. A diode installed in the reverse-bias direction cannot control this extra current, whereas a resistor in parallel can help reduce potentially damaging current flow if the coil becomes shorted.
Reason 2	The protective diode can also fail, and diodes usually fail by shorting before they blow open. If a diode becomes shorted, excessive current can flow through the coil circuit, perhaps causing damage. A resistor usually fails open and, therefore, even in failure could not in itself cause a problem.

Resistors on coils are often used in relays and in climate-control circuit solenoids to control vacuum to the various air management system doors as well as other electronically controlled applications.

DIODE RATINGS

SPECIFICATIONS Most diodes are rated according to the following:

- Maximum current flow in the forward-bias direction. Diodes are sized and rated according to the amount of current they are designed to handle in the forward-bias direction. This rating is normally from 1 to 5 amperes for most automotive applications.
- This rating of resistance to reverse-bias voltage is called the **peak inverse voltage (PIV)** rating, or the **peak reverse voltage (PRV)** rating. It is important that the service technician specifies and uses only a replacement diode that has the same or a higher rating than specified by the vehicle manufacturer for both amperage and PIV rating. Typical 1 A diodes use an industry numbering code that indicates the PIV rating. For example:

  1N 4001-50 V PIV

  1N 4002-100 V PIV

  1N 4003-200 V PIV (most commonly used)

  1N 4004-400 V PIV

  1N 4005-600 V PIV
- The "1N" means that the diode has one P-N junction. A higher rating diode can be used with no problems (except for slightly higher cost, even though the highest rated diode generally costs less than $1). Never substitute a *lower* rated diode than is specified.

DIODE VOLTAGE DROP The voltage drop across a diode is about the same voltage as that required to forward bias the diode. If the diode is made from germanium, the forward voltage is 0.3 to 0.5 volt. If the diode is made from silicon, the forward voltage is 0.5 to 0.7 volt.

NOTE: When diodes are tested using a digital multimeter, the meter will display the voltage drop across the P-N junction (about 0.5 to 0.7 volt) when the meter is set to the *diode-check* position.

LIGHT-EMITTING DIODES

OPERATION All diodes radiate some energy during normal operation. Most diodes radiate heat because of the junction barrier voltage drop (typically 0.6 volt for silicon diodes). **Light emitting diode (LED)** radiate light when current flows through the diode in the forward-bias direction. ● **SEE FIGURE 48–14.**

The forward-bias voltage required for an LED ranges between 1.5 and 2.2 volts.

An LED will only light if the voltage at the anode (positive electrode) is at least 1.5 to 2.2 volts higher than the voltage at the cathode (negative electrode).

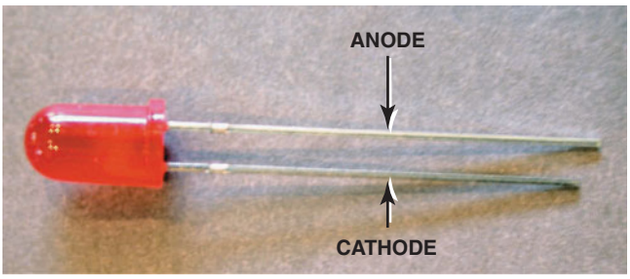


FIGURE 48–14 A typical light-emitting diode (LED). This particular LED is designed with a built-in resistor so that 12 volts DC may be applied directly to the leads without an external resistor. Normally a 300 to 500 ohm, 0.5 watt resistor is required to be attached in series with the LED, to control current flow to about 0.020 A (20 mA) or damage to the P-N junction may occur.

? FREQUENTLY ASKED QUESTION

How Does an LED Emit Light?

An LED contains a chip that houses P-type and N-type materials. The junction between these regions acts as a barrier to the flow of electrons between the two materials. When a voltage of 1.5 to 2.2 volts of the correct polarity is applied, current will flow across the junction. As the electrons enter the P-type material, it combines with the holes in the material and releases energy in the form of light (called **photons**). The amount and color the light produces depends on materials used in the creation of the semiconductor material.

LEDs are very efficient compared to conventional incandescent bulbs, which depend on heat to create light. LEDs generate very little heat, with most of the energy consumed converted directly to light. LEDs are reliable and are being used for taillights, brake lights, daytime running lights, and headlights in some vehicles.

NEED FOR CURRENT LIMITING If an LED were connected across a 12 volt automotive battery, the LED would light brightly, but only for a second or two. Excessive current (amperes) that flows across the P-N junction of any electronic device can destroy the junction. A resistor *must* be connected in series with every diode (including LEDs) to control current flow across the P-N junction. This protection should include the following:

1. The value of the resistor should be from 300 to 500 ohms for each P-N junction. Commonly available resistors in this range include 470, 390, and 330 ohm resistors.
2. The resistors can be connected to either the anode or the cathode end. (Polarity of the resistor does not matter.) Current flows through the LED in series with the resistor, and the resistor will control the current flow through the LED regardless of its position in the circuit.
3. Resistors protecting diodes can be actual resistors or other current-limiting loads such as lamps or coils. With the current-limiting devices to control the current, the average LED will require about 20 to 30 milliamperes (mA), or 0.020 to 0.030 ampere.

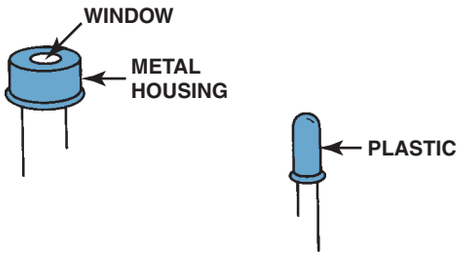


FIGURE 48–15 Typical photodiodes. They are usually built into a plastic housing so that the photodiode itself may not be visible.



FIGURE 48–16 Symbol for a photodiode. The arrows represent light striking the P-N junction of the photodiode.

PHOTODIODES

PURPOSE AND FUNCTION All semiconductor P-N junctions emit energy, mostly in the form of heat or light such as with an LED. In fact, if an LED is exposed to bright light, a voltage potential is established between the anode and the cathode. **Photodiodes** are specially constructed to respond to various wavelengths of light with a "window" built into the housing. ● **SEE FIGURE 48–15.**

Photodiodes are frequently used in steering wheel controls for transmitting tuning, volume, and other information from the steering wheel to the data link and the unit being controlled. If several photodiodes are placed on the steering column end and LEDs or phototransistors are placed on the steering wheel side, then data can be transmitted between the two moving points without the interference that could be caused by physical contact types of units.

CONSTRUCTION A photodiode is sensitive to light. When light energy strikes the diode, electrons are released and the diode will conduct in the forward-bias direction. (The light energy is used to overcome the barrier voltage.)

The resistance across the photodiode decreases as the intensity of the light increases. This characteristic makes the photodiode a useful electronic device for controlling some automotive lighting systems such as automatic headlights. The symbol for a photodiode is shown in ● **FIGURE 48–16.**

PHOTORESISTORS

A **photoresistor** is a semiconductor material (usually cadmium sulfide) that changes resistance with the presence or absence of light.

Dark = High resistance

Light = Low resistance

Because resistance is reduced when the photoresistor is exposed to light, the photoresistor can be used to control headlight dimmer relays and for automotive headlights. ● **SEE FIGURE 48–17.**

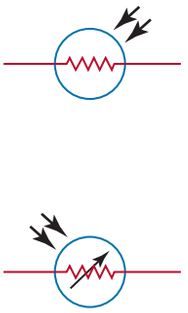


FIGURE 48–17 Either symbol may be used to represent a photoresistor.

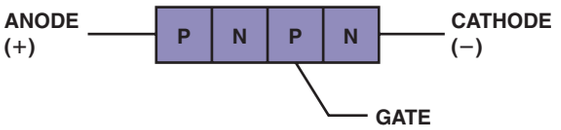


FIGURE 48–18 Symbol and terminal identification of an SCR.

SILICON-CONTROLLED RECTIFIERS

CONSTRUCTION A **silicon-controlled rectifier (SCR)** is commonly used in the electronic circuits of various automotive applications. An SCR is a semiconductor device that looks like two diodes connected end to end. ● **SEE FIGURE 48–18.**

If the anode is connected to a higher voltage source than the cathode in a circuit, no current will flow as would occur with a diode. If, however, a positive voltage source is connected to the gate of the SCR, then current can flow from anode to cathode with a typical voltage drop of 1.2 volts (double the voltage drop of a typical diode, at 0.6 volt).

Voltage applied to the gate is used to turn the SCR on. However, if the voltage source at the gate is shut off, the current will still continue to flow through the SCR until the source current is stopped.

USES OF AN SCR SCRs can be used to construct a circuit for a **center high-mounted stoplight (CHMSL)**. If this third stoplight were wired into either the left- or the right-side brake light circuit, the CHMSL would also flash whenever the turn signals were used for the side that was connected to the CHMSL. When two SCRs are used, both brake lights must be activated to supply current to the CHMSL. The current to the CHMSL is shut off when both SCRs lose their power source (when the brake pedal is released, which stops the current flow to the brake lights). ● **SEE FIGURE 48–19.**

THERMISTORS

CONSTRUCTION A **thermistor** is a semiconductor material such as silicon that has been doped to provide a given resistance. When the thermistor is heated, the electrons within the crystal gain energy and electrons are released. This means that a thermistor actually produces a small voltage when heated. If voltage is applied

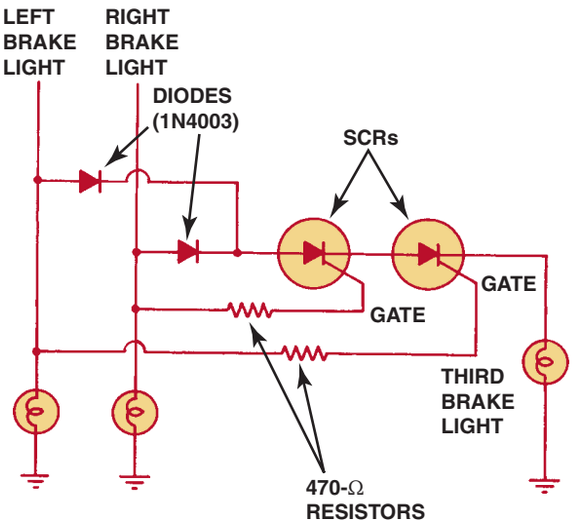


FIGURE 48–19 Wiring diagram for a center high-mounted stoplight (CHMSL) using SCRs.

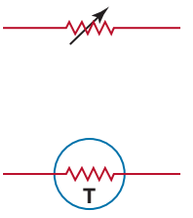


FIGURE 48–20 Symbols used to represent a thermistor.

	COPPER WIRE	NTC THERMISTOR
Cold	Lower resistance	Higher resistance
Hot	Higher resistance	Lower resistance

CHART 48–1

The resistance changes opposite that of a copper wire with changes in temperature.

to a thermistor, its resistance decreases because the thermistor itself is acting as a current carrier rather than as a resistor at higher temperatures.

USES OF THERMISTORS A thermistor is commonly used as a temperature-sensing device for coolant temperature and intake manifold air temperature. Because thermistors operate in a manner opposite to that of a typical conductor, they are called **negative temperature coefficient (NTC)** thermistors; their resistance decreases as the temperature increases. ● **SEE CHART 48–1.**

Thermistor symbols are shown in ● **FIGURE 48–20.**

RECTIFIER BRIDGES

DEFINITION The word *rectify* means "to set straight"; therefore, a rectifier is an electronic device (such as a diode) used to convert a changing voltage into a straight or constant voltage. A **rectifier bridge** is a group of diodes that is used to change alternating current

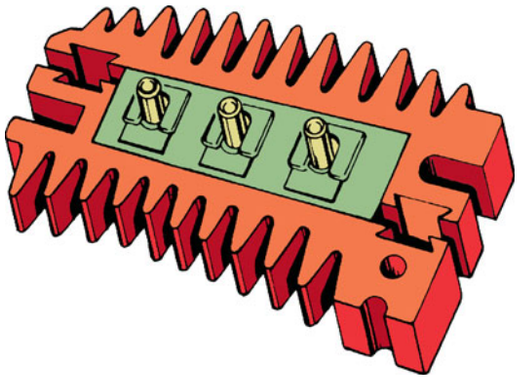


FIGURE 48–21 This rectifier bridge contains six diodes; the three on each side are mounted in an aluminum-finned unit to help keep the diode cool during alternator operation.

(AC) into direct current (DC). A rectifier bridge is used in alternators to rectify the AC voltage produced in the stator (stationary windings) of the alternator into DC voltage. These rectifier bridges contain six diodes: one pair of diodes (one positive and one negative) for each of the three stator windings. ● **SEE FIGURE 48–21.**

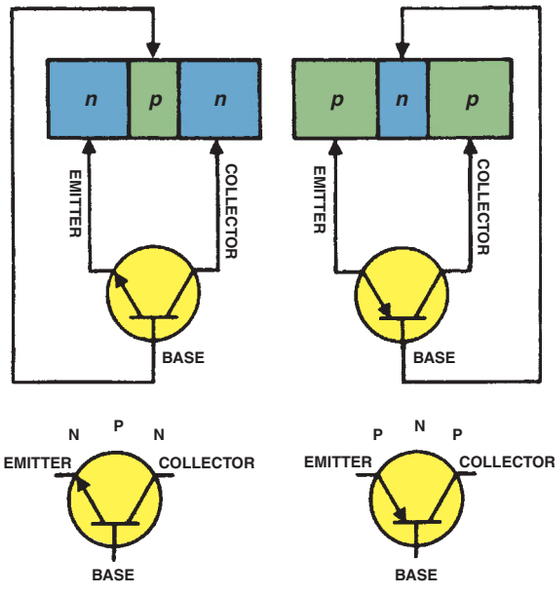


FIGURE 48–22 Basic transistor operation. A small current flowing through the base and emitter of the transistor turns on the transistor and permits a higher amperage current to flow from the collector and the emitter.

TRANSISTORS

PURPOSE AND FUNCTION A **transistor** is a semiconductor device that can perform the following electrical functions.

1. Act as an electrical switch in a circuit
2. Act as an amplifier of current in a circuit
3. Regulate the current in a circuit

The word *transistor,* derived from the words *transfer* and *resistor,* is used to describe the transfer of current across a resistor. A transistor is made of three alternating sections or layers of P-type and N-type materials. This type of transistor is usually called a **bipolar transistor.**

CONSTRUCTION A transistor that has P-type material on each end, with N-type material in the center, is called a **PNP transistor.** Another type, with the exact opposite arrangement, is called an **NPN transistor.**

The material at one end of a transistor is called the **emitter** and the material at the other end is called the **collector.** The **base** is in the center and the voltage applied to the base is used to control current through a transistor.

TRANSISTOR SYMBOLS All transistor symbols contain an arrow indicating the emitter part of the transistor. The arrow points in the direction of current flow (conventional theory).

When an arrowhead appears in any semiconductor symbol, it stands for a P-N junction and it points from the P-type material toward the N-type material. The arrow on a transistor is always attached to the *emitter* side of the transistor. ● **SEE FIGURE 48–22.**

HOW A TRANSISTOR WORKS A transistor is similar to two back-to-back diodes that can conduct current in only one direction. As in a diode, N-type material can conduct electricity by means of its supply of free electrons, and P-type material conducts by means of its supply of positive holes.

	RELAY	TRANSISTOR
Low-current circuit	Coil (terminals 85 and 86)	Base and emitter
High-current circuit	Contacts terminals 30 and 87	Collector and emitter

CHART 48–2

Comparison between the control (low-current) and high-current circuits of a transistor compared to a mechanical relay.

? FREQUENTLY ASKED QUESTION

Is a Transistor Similar to a Relay?

Yes, in many cases a transistor is similar to a relay.

Both use a low current to control a higher current circuit. ● **SEE CHART 48–2.**

A relay can only be on or off. A transistor can provide a variable output if the base is supplied a variable current input.

? FREQUENTLY ASKED QUESTION

What Does the Arrow Mean on a Transistor Symbol?

The arrow on a transistor symbol is always on the emitter and points toward the N-type material. The arrow on a diode also points toward the N-type material. To know which type of transistor is being shown, note which direction the arrow points.

- PNP: pointing in
- NPN: not pointing in

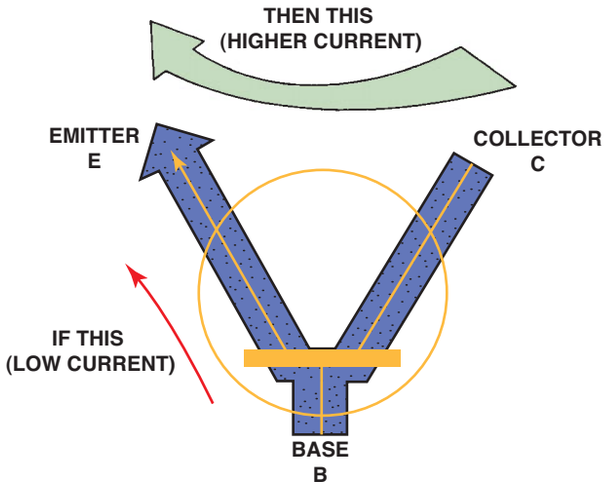


FIGURE 48–23 Basic transistor operation. A small current flowing through the base and emitter of the transistor turns on the transistor and permits a higher amperage current to flow from the collector and the emitter.

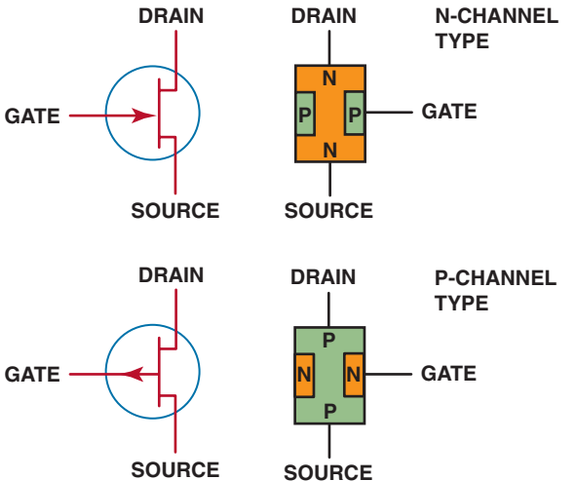


FIGURE 48–24 The three terminals of a field-effect transistor (FET) are called the source, gate, and drain.

A transistor will allow current flow if the electrical conditions allow it to switch on, in a manner similar to the working of an electromagnetic relay. The electrical conditions are determined, or switched, by means of the base, or *B*. The base will carry current only when the proper voltage and polarity are applied. The main circuit current flow travels through the other two parts of the transistor: the emitter *E* and the collector *C.* ● **SEE FIGURE 48–23.**

If the base current is turned off or on, the current flow from collector to emitter is turned off or on. The current controlling the base is called the **control current.** The control current must be high enough to switch the transistor on or off. (This control voltage, called the **threshold voltage,** must be above approximately 0.3 volt for germanium and 0.6 volt for silicon transistors.) This control current can also "throttle" or regulate the main circuit, in a manner similar to the operation of a water faucet.

HOW A TRANSISTOR AMPLIFIES

A transistor can amplify a signal if the signal is strong enough to trigger the base of a transistor on and off. The resulting on-off current flow through the transistor can be connected to a higher powered electrical circuit. This results in a higher powered circuit being controlled by a lower powered circuit. This low-powered circuit's cycling is exactly duplicated in the higher powered circuit, and therefore any transistor can be used to amplify a signal. However, because some transistors are better than others for amplification, specialized types of transistors are used for each specialized circuit function.

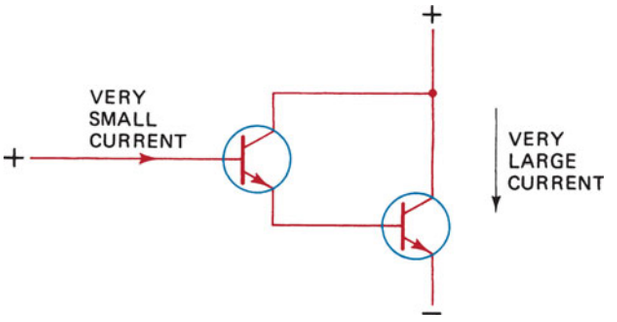


FIGURE 48–25 A Darlington pair consists of two transistors wired together, allowing for a very small current to control a larger current flow circuit.

FREQUENTLY ASKED QUESTION

What Is a Darlington Pair?

A **Darlington pair** consists of two transistors wired together. This arrangement permits a very small current flow to control a large current flow. The Darlington pair is named for Sidney Darlington, an American physicist for Bell Laboratories from 1929 to 1971. Darlington amplifier circuits are commonly used in electronic ignition systems, computer engine control circuits, and many other electronic applications. ● **SEE FIGURE 48–25.**

FIELD-EFFECT TRANSISTORS

Field-effect transistors (FETs) have been used in most automotive applications since the mid-1980s. They use less electrical current and rely mostly on the strength of a small voltage signal to control the output. The parts of a typical FET include the *source, gate,* and *drain.* ● **SEE FIGURE 48–24.**

Many field-effect transistors are constructed of metal oxide semiconductor (MOS) materials, called **MOSFETs.** MOSFETs are highly sensitive to static electricity and can be easily damaged if exposed to excessive current or high-voltage surges (spikes). Most automotive electronic circuits use MOSFETs, which explains why it is vital for the service technician to use caution to avoid doing anything that could result in a high-voltage spike, and perhaps destroy an expensive computer module. Some vehicle manufacturers recommend that technicians wear an antistatic wristband when working with modules that contain MOSFETs. Always follow the vehicle manufacturer's instructions found in service information to avoid damaging electronic modules or circuits.



FIGURE 48–26 Symbols for a phototransistor. (a) This symbol uses the line for the base; (b) this symbol does not.

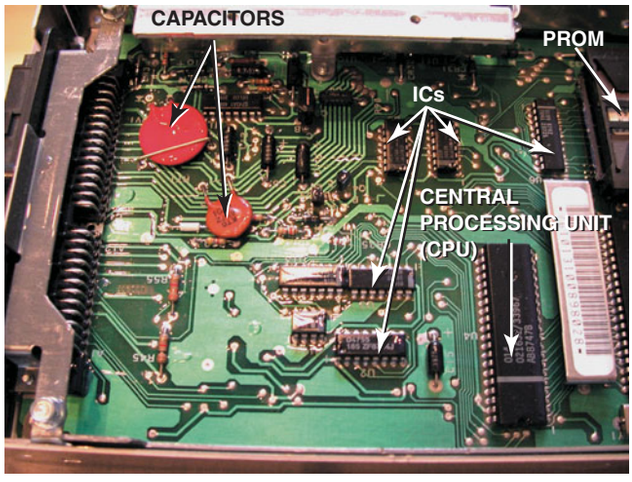


FIGURE 48–27 A typical automotive computer with the case removed to show all of the various electronic devices and integrated circuits (ICs). The CPU is an example of a DIP chip and the large red and orange devices are ceramic capacitors.

PHOTOTRANSISTORS

Similar in operation to a photodiode, a **phototransistor** uses light energy to turn on the base of a transistor. A phototransistor is an NPN transistor that has a large exposed base area to permit light to act as the control for the transistor. Therefore, a phototransistor may or may not have a base lead. If not, then it has only a collector and emitter lead. When the phototransistor is connected to a powered circuit, the light intensity is amplified by the gain of the transistor. Phototransistors, along with photo diodes, are frequently used in steering wheel controls. ● **SEE FIGURE 48–26.**

INTEGRATED CIRCUITS

PURPOSE AND FUNCTION Solid-state components are used in many electronic semiconductors and/or circuits. They are called "solid state" because they have no moving parts, just higher or lower voltage levels within the circuit. Discrete (individual) diodes, transistors, and other semiconductor devices were often used to construct early electronic ignition and electronic voltage regulators. Newer style electronic devices use the same components, but they are now combined (integrated) into one group of circuits, and are thus called an **integrated circuit (IC).**

CONSTRUCTION Integrated circuits are usually encased in a plastic housing called a CHIP with two rows of inline pins. This arrangement is called the **dual inline pins (DIP)** chips. ● **SEE FIGURE 48–27.**

FREQUENTLY ASKED QUESTION

What Causes a Transistor or Diode to Blow?

Every automotive diode and transistor is designed to operate within certain voltage and amperage ranges for individual applications. For example, transistors used for switching are designed and constructed differently from transistors used for amplifying signals.

Because each electronic component is designed to operate satisfactorily for its particular application, any severe change in operating current (amperes), voltage, or heat can destroy the *junction.* This failure can cause either an open circuit (no current flows) or a short (current flows through the component all the time when the component should be blocking the current flow).

Therefore, most computer circuits are housed as an integrated circuit in a DIP chip.

HEAT SINK **Heat sink** is a term used to describe any area around an electronic component that, because of its shape or design, can conduct damaging heat away from electronic parts. Examples of heat sinks include the following:

1. Ribbed electronic ignition control units
2. Cooling slits and cooling fan attached to an alternator
3. Special heat-conducting grease under the electronic ignition module in General Motors HEI distributor ignition systems and other electronic systems

Heat sinks are necessary to prevent damage to diodes, transistors, and other electronic components due to heat buildup. Excessive heat can damage the junction between the N-type and P-type materials used in diodes and transistors.

TRANSISTOR GATES

PURPOSE AND FUNCTION An understanding of the basic operation of electronic gates is important to understanding how computers work. A **gate** is an electronic circuit whose output depends on the location and voltage of two inputs.

CONSTRUCTION Whether a transistor is on or off depends on the voltage at the base of the transistor. If the voltage is at least a 0.6 volt difference from that of the emitter, the transistor is turned on. Most electronic and computer circuits use 5 volts as a power source. If two transistors are wired together, several different outputs can be received depending on how the two transistors are wired. ● **SEE FIGURE 48–28.**

OPERATION If the voltage at *A* is higher than that of the emitter, the top transistor is turned on; however, the bottom transistor is off unless the voltage at *B* is also higher. If both transistors are turned on, the output signal voltage will be high. If only one of the two transistors is on, the output will be zero (off or no voltage). Because it requires both *A* and *B* to be on to result in a voltage output, this circuit is called an *AND gate*. In other words, both transistors have

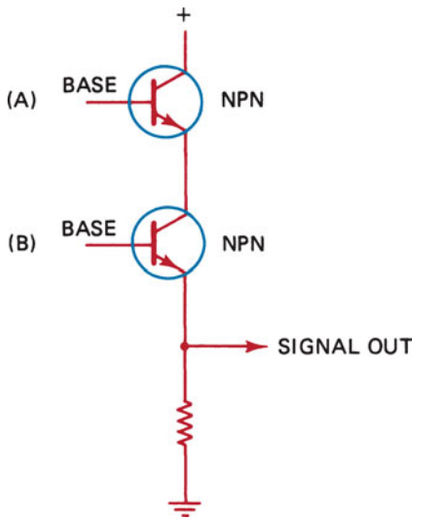


FIGURE 48–28 Typical transistor AND gate circuit using two transistors. The emitter is always the line with the arrow. Notice that both transistors must be turned on before there will be voltage present at the point labeled "signal out."

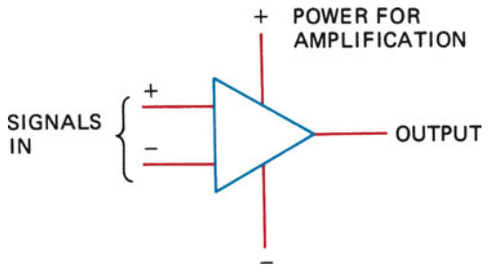


FIGURE 48–29 Symbol for an operational amplifier (op-amp).

on when the following events occur, to cause the control module to turn it on.

1. The ignition must be on (input).
2. The air conditioning is commanded on.
3. The engine coolant temperature is within a predetermined limit.

If all of these conditions are met, then the control module will command the blower motor on. If any of the input signals are incorrect, the control module will not be able to perform the correct command.

? FREQUENTLY ASKED QUESTION

What Are Logic Highs and Lows?

All computer circuits and most electronic circuits (such as gates) use various combinations of high and low voltages. High voltages are typically those above 5 volts, and low is generally considered zero (ground). However, high voltages do not *have* to begin at 5 volts. *High, or the number 1, to a computer is the presence of voltage above a certain level.* For example, a circuit could be constructed where any voltage higher than 3.8 volts would be considered high. *Low, or the number 0, to a computer is the absence of voltage or a voltage lower than a certain value.* For example, a voltage of 0.62 may be considered low. Various associated names and terms can be summarized.

- Logic low = Low voltage = Number 0 = Reference low
- Logic high = Higher voltage = Number 1 = Reference high

to be on before the gate opens and allows a voltage output. Other types of gates can be constructed using various connections to the two transistors. For example:

AND gate. Requires both transistors to be on to get an output.

OR gate. Requires either transistor to be on to get an output.

NAND (NOT-AND) gate. Output is on unless both transistors are on.

NOR (NOT-OR) gate. Output is on only when both transistors are off.

Gates represent logic circuits that can be constructed so that the output depends on the voltage (on or off; high or low) of the inputs to the bases of transistors. Their inputs can come from sensors or other circuits that monitor sensors, and their outputs can be used to operate an output device if amplified and controlled by other circuits. For example, the blower motor will be commanded

OPERATIONAL AMPLIFIERS

Operational amplifiers (op-amps) are used in circuits to control and amplify digital signals. Op-amps are frequently used for motor control in climate control systems (heating and air conditioning) airflow control door operation. Op-amps can provide the proper voltage polarity and current (amperes) to control the direction of permanent magnetic (PM) motors. The symbol for an op-amp is shown in ● **FIGURE 48–29.**

ELECTRONIC COMPONENT FAILURE CAUSES

Electronic components such as electronic ignition modules, electronic voltage regulators, onboard computers, and any other electronic circuit are generally quite reliable; however, failure can occur. Frequent causes of premature failure include the following:

- **Poor connections.** It has been estimated that most engine computers returned as defective have simply had poor connections at the wiring harness terminal ends. These faults are often intermittent and hard to find.

  NOTE: When cleaning electronic contacts, use a pencil eraser. This cleans the contacts without harming the thin, protective coating used on most electronic terminals.

- **Heat.** The operation and resistance of electronic components and circuits are affected by heat. Electronic components should be kept as cool as possible and never hotter than 260°F (127°C).
- **Voltage spikes.** A high-voltage spike can literally burn a hole through semiconductor material. The source of these high-voltage spikes is often the discharge of a coil without proper (or with defective) despiking protection. A poor electrical

TECH TIP

Blinking LED Theft Deterrent

A blinking (flashing) LED consumes only about 5 milliamperes (5/1,000 of 1 ampere or 0.005 A). Most alarm systems use a blinking red LED to indicate that the system is armed. A fake alarm indicator is easy to make and install.

A 470 ohm, 0.5 watt resistor limits current flow to prevent battery drain. The positive terminal (anode) of the diode is connected to a fuse that is hot at all times, such as the cigarette lighter. The negative terminal (cathode) of the LED is connected to any ignition-controlled fuse. **SEE FIGURE 48–30.**

When the ignition is turned off, the power flows through the LED to ground and the LED flashes. To prevent distraction during driving, the LED goes out when the ignition is on. Therefore, this fake theft deterrent is "auto setting" and no other action is required to activate it when you leave your vehicle except to turn off the ignition and remove the key as usual.

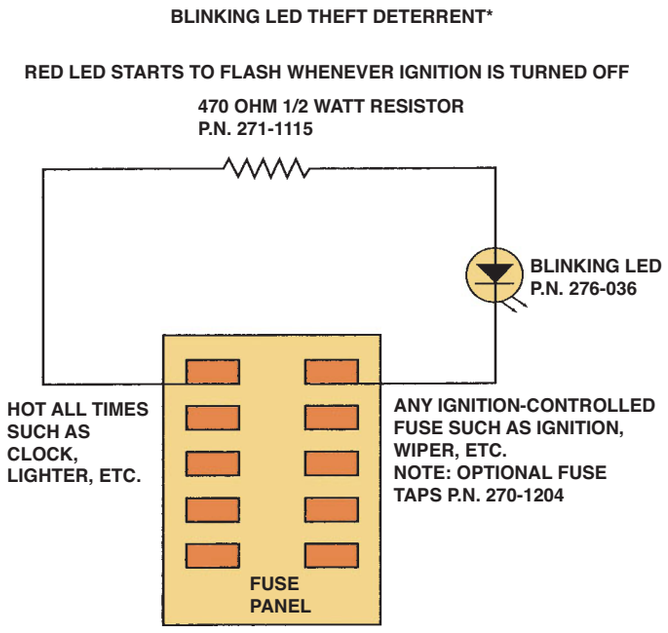


FIGURE 48–30 Schematic for a blinking LED theft deterrent.

connection at the battery or other major electrical connection can cause high-voltage spikes to occur, because the *entire wiring harness creates its own magnetic field*, similar to that formed around a coil. If the connection is loose and momentary loss of contact occurs, a high-voltage surge can occur through the entire electrical system. To help prevent this type of damage, ensure that all electrical connections, including grounds, are properly clean and tight.

CAUTION: One of the major causes of electronic failure occurs during jump starting a vehicle. Always check that the ignition switch is off on both vehicles when making the connection. Always double check that the correct battery polarity (+ to + and − to −) is being performed.

- **Excessive current.** All electronic circuits are designed to operate within a designated range of current (amperes). If a solenoid or relay is controlled by a computer circuit, the resistance of that solenoid or relay becomes part of that control circuit. If a coil winding inside the solenoid or relay becomes shorted, the resulting lower resistance will increase the current through the circuit. Even though individual components are used with current-limiting resistors in series, the coil winding resistance is also used as a current-control component in the circuit. If a computer fails, always measure the resistance across all computer-controlled relays and solenoids. The resistance should be within specifications (generally *over* 20 ohms) for each component that is computer controlled.

NOTE: Some computer-controlled solenoids are pulsed on and off rapidly. This type of solenoid is used in many electronically shifted transmissions. Their resistance is usually about half of the resistance of a simple on-off solenoid—usually between 10 and 15 ohms. Because the computer controls the on-time of the solenoid, the solenoid and its circuit control are called pulse-width modulated (PWM).

HOW TO TEST DIODES AND TRANSISTORS

TESTERS Diodes and transistors can be tested with an ohmmeter. The diode or transistor being tested must be disconnected from the circuit for the results to be meaningful.

- Use the *diode-check* position on a digital multimeter.
- In the diode-check position on a digital multimeter, the meter applies a higher voltage than when the ohms test function is selected.
- This slightly higher voltage (about 2 to 3 volts) is enough to forward bias a diode or the P-N junction of transistors.

DIODES Using the diode test position, the meter applies a voltage. The display will show the voltage drop across the diode P-N junction. A good diode should give an over limit (OL) reading with the test leads attached to each lead of the diode in one way, and a voltage reading of 0.400 to 0.600 V when the leads are reversed. This reading is the voltage drop or the barrier voltage across the P-N junction of the diode.

1. A low-voltage reading with the meter leads attached both ways across a diode means that the diode is *shorted* and must be replaced.
2. An OL reading with the meter leads attached both ways across a diode means that the diode is *open* and must be replaced. **SEE FIGURE 48–31.**

TRANSISTORS Using a digital meter set to the diode-check position, a good transistor should show a voltage drop of 0.400 to 0.600 volt between the following:

- The emitter (*E*) and the base (*B*) and between the base (*B*) and the collector (*C*) with a meter connected one way, and OL when the meter test leads are reversed.

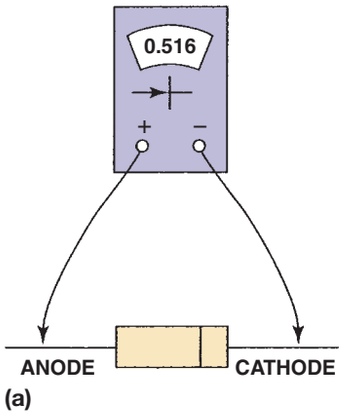


FIGURE 48–31 To check a diode, select "diode check" on a digital multimeter. The display will indicate the voltage drop (difference) between the meter leads. The meter itself applies a low-voltage signal (usually about 3 volts) and displays the difference on the display. (a) When the diode is forward biased, the meter should display a voltage between 0.500 and 0.700 V (500 to 700 mV). (b) When the meter leads are reversed, the meter should read OL (over limit) because the diode is reverse biased and blocking current flow.

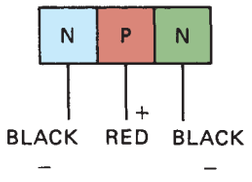


FIGURE 48–32 If the red (positive) lead of the ohmmeter (or a multimeter set to diode check) is touched to the center and the black (negative lead) touched to either end of the electrode, the meter should forward bias the P-N junction and indicate on the meter as low resistance. If the meter reads high resistance, reverse the meter leads, putting the black on the center lead and the red on either end lead. If the meter indicates low resistance, the transistor is a good PNP type. Check all P-N junctions in the same way.

- An OL reading (no continuity) in both directions when a transistor is tested between the emitter (*E*) and the collector (*C*) (A transistor tester can also be used if available.). ● **SEE FIGURE 48–32.**

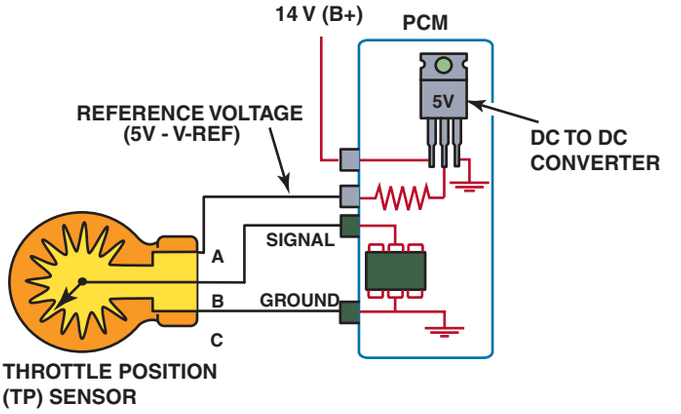


FIGURE 48–33 A DC to DC converter is built into most power-train control modules (PCMs) and is used to supply the 5 volt reference called V-ref to many sensors used to control the internal combustion engine.

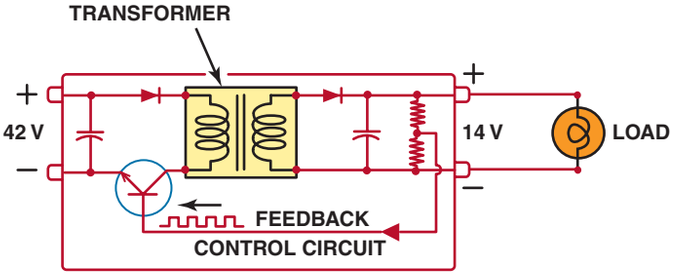


FIGURE 48–34 This DC-DC converter is designed to convert 42 volts to 14 volts, to provide 14 V power to accessories on a hybrid electric vehicle operating with a 42 volt electrical system.

CONVERTERS AND INVERTERS

CONVERTERS DC to DC converters (usually written as DC-DC converter) are electronic devices used to transform DC voltage from one level of DC voltage to another higher or lower level. They are used to distribute various levels of DC voltage throughout a vehicle from a single power bus (or voltage source).

EXAMPLES OF USE One example of a DC-DC converter circuit is the circuit the PCM uses to convert 14 V to 5 V. The 5 volts is called the reference voltage, abbreviated V-ref, and is used to power many sensors in a computer-controlled engine management system. The schematic of a typical 5 volt V-ref interfacing with the TP sensor circuit is shown in ● **FIGURE 48–33.**

The PCM operates on 14 volts, using the principle of DC conversion to provide a constant 5 volts of sensor reference voltage to the TP sensor and others. The TP sensor demands little current, so the V-ref circuit is a low-power DC voltage converter in the range of 1 watt. The PCM uses a DC-DC converter, which is a small semiconductor device called a voltage regulator, and is designed to convert battery voltage to a constant 5 volts regardless of changes in the charging voltage.

Hybrid electric vehicles use DC-DC converters to provide higher or lower DC voltage levels and current requirements.

A high-power DC-DC converter schematic is shown in ● **FIGURE 48–34** and represents how a nonelectronic DC-DC converter works.

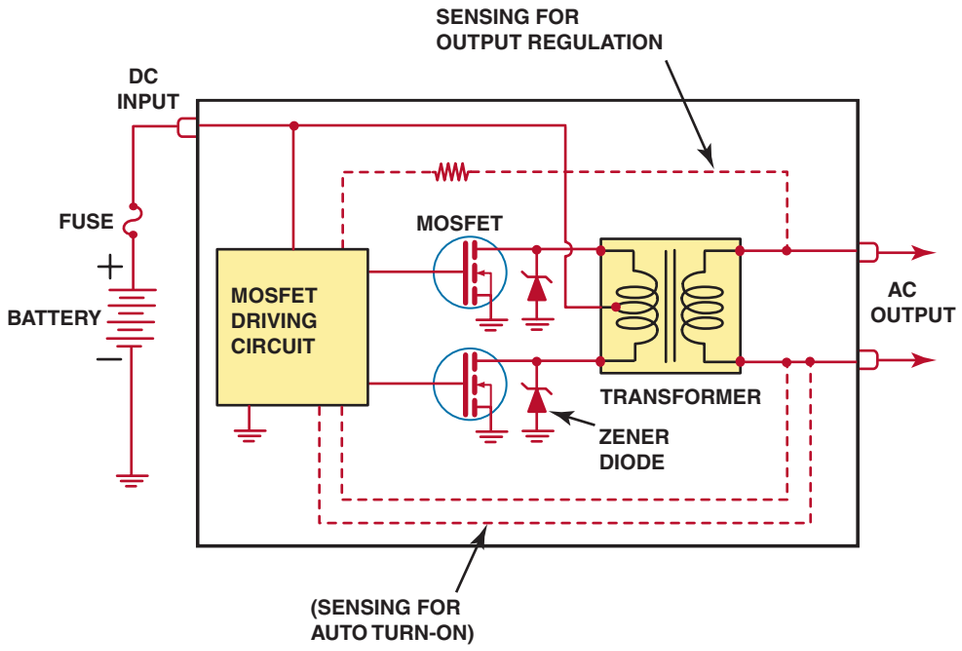


FIGURE 48–35 A typical circuit for an inverter designed to change direct current from a battery to alternating current for use by the electric motors used in a hybrid electric vehicle.

The central component of a converter is a transformer that physically isolates the input (42 V) from the output (14 V). The power transistor pulses the high-voltage coil of the transformer, and the resulting changing magnetic field induces a voltage in the coil windings of the lower voltage side of the transformer. The diodes and capacitors help control and limit the voltage and frequency of the circuit.

DC-DC CONVERTER CIRCUIT TESTING

Usually a DC control voltage is used, which is supplied by a digital logic circuit to shift the voltage level to control the converter. A voltage test can indicate if the correct voltages are present when the converter is on and off.

WARNING

Always follow the manufacturer's safety precautions for discharging capacitors in DC-DC converter circuits.

Voltage measurements are usually specified to diagnose a DC-DC converter system. A digital multimeter (DMM) that is CAT III rated should be used.

1. Always follow the manufacturer's safety precautions when working with high-voltage circuits. These circuits are usually indicated by orange wiring.
2. Never tap into wires in a DC-DC converter circuit to access power for another circuit.
3. Never tap into wires in a DC-DC converter circuit to access a ground for another circuit.
4. Never block airflow to a DC-DC converter heat sink.
5. Never use a heat sink for a ground connection for a meter, scope, or accessory connection.
6. Never connect or disconnect a DC-DC converter while the converter is powered up.
7. Never connect a DC-DC converter to a larger voltage source than specified.

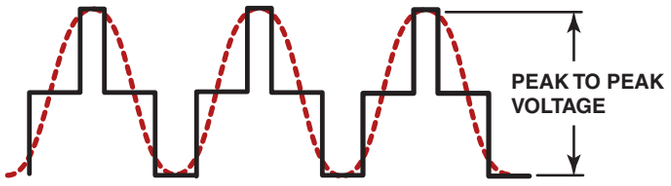


FIGURE 48–36 The switching (pulsing) MOSFETs create a waveform called a modified sine wave (solid lines) compared to a true sine wave (dotted lines).

INVERTERS

An **inverter** is an electronic circuit that changes direct current (DC) into alternating current (AC). In most DC-AC inverters, the switching transistors, which are usually MOSFETs, are turned on alternately for short pulses. As a result, the transformer produces a modified sine wave output, rather than a true sine wave. ● **SEE FIGURE 48–35.**

The waveform produced by an inverter is not the perfect sine wave of household AC, but is rather more like a pulsing DC that reacts similar to sine wave AC in transformers and in induction motors. ● **SEE FIGURE 48–36.**

Inverters power AC motors. An inverter converts DC power to AC power at the required frequency and amplitude. The inverter consists of three half-bridge units, and the output voltage is mostly created by a pulse-width modulation (PWM) technique. The three-phase voltage waves are shifted 120 degrees to each other, to power each of the three phases.

WARNING

Do not touch the terminals of a battery that are being used to power an inverter. There is always a risk that those battery terminals could deliver a much greater shock than from batteries alone, if a motor or inverter should develop a fault.

ELECTROSTATIC DISCHARGE

DEFINITION **Electrostatic discharge (ESD)** is created when static charges build up on the human body when movement occurs. The friction of the clothing and the movement of shoes against carpet or vinyl floors cause a high voltage to build. Then when we touch a conductive material, such as a doorknob, the static charge is rapidly discharged. These charges, although just slightly painful to us, can cause severe damage to delicate electronic components. The following are typical static voltages.

- If you can feel it, it is at least 3,000 volts.
- If you can hear it, it is at least 5,000 volts.
- If you can see it, it is at least 10,000 volts.

Although these voltages seem high, the current, in amperes, is extremely low. However, sensitive electronic components such as vehicle computers, radios, and instrument panel clusters can be ruined if exposed to as little as 30 volts. This is a problem, because harm can occur to components at voltages lower than we can feel.

AVOIDING ESD To help prevent damage to components, follow these easy steps.

1. Keep the replacement electronic component in the protective wrapping until just before installation.
2. Before handling any electronic component, ground yourself by touching a metal surface to drain away any static charge.
3. Do not touch the terminals of electronic components.
4. If working in an area where touching terminals may occur, wear a static electrically grounding wrist strap available at most electronic parts stores, such as Radio Shack.

If these precautions are observed, ESD damage can be eliminated or reduced. Remember, just because the component works after being touched does not mean that damage has not occurred. Often, a section of the electronic component may be damaged, yet will not fail until several days or weeks later.

REVIEW QUESTIONS

1. What is the difference between P-type material and N-type material?
2. How can a diode be used to suppress high-voltage surges in automotive components or circuits containing a coil?
3. How does a transistor work?
4. To what precautions should all service technicians adhere, to avoid damage to electronic and computer circuits?

CHAPTER QUIZ

1. A semiconductor is a material _____.
   a. With fewer than four electrons in the outer orbit of its atoms
   b. With more than four electrons in the outer orbit of its atoms
   c. With exactly four electrons in the outer orbit of its atoms
   d. Determined by other factors besides the number of electrons
2. The arrow in a symbol for a semiconductor device _____.
   a. Points toward the negative
   b. Points away from the negative
   c. Is attached to the emitter on a transistor
   d. Both a and c
3. A diode installed across a coil with the cathode toward the battery positive is called a(n) _____.
   a. Clamping diode **c.** SCR
   b. Forward-bias diode **d.** Transistor
4. A transistor is controlled by the polarity and current at the _____.
   a. Collector **c.** Base
   b. Emitter **d.** Both a and b
5. A transistor can _____.
   a. Switch on and off **c.** Throttle
   b. Amplify **d.** All of the above
6. Clamping diodes _____.
   a. Are connected into a circuit with the positive (+) voltage source to the cathode and the negative (−) voltage to the anode
   b. Are also called despiking diodes
   c. Can suppress transient voltages
   d. All of the above
7. A zener diode is normally used for voltage regulation. A zener diode, however, can also be used for high-voltage spike protection if connected _____.
   a. Positive to anode, negative to cathode
   b. Positive to cathode, ground to anode
   c. Negative to anode, cathode to a resistor then to a lower voltage terminal
   d. Both a and c
8. The forward-bias voltage required for an LED is _____.
   a. 0.3 to 0.5 volt **c.** 1.5 to 2.2 volts
   b. 0.5 to 0.7 volt **d.** 4.5 to 5.1 volts
9. An LED can be used in a _____.
   a. Headlight **c.** Brake light
   b. Taillight **d.** All of the above
10. Another name for a ground is _____.
    a. Logic low **c.** Reference low
    b. Zero **d.** All of the above

chapter 49

CAN AND NETWORK COMMUNICATIONS

OBJECTIVES: **After studying Chapter 49, the reader should be able to:** • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "A" (General Electrical/Electronic Systems Diagnosis). • Describe the types of networks and serial communications used on vehicles. • Discuss how the networks connect to the data link connector and to other modules. • Explain how to diagnose module communication faults.

KEY TERMS: Breakout box (BOB) 533 • BUS 526 • CAN 527 • Chrysler Collision Detection (CCD) 530 • Class 2 528 • E & C 528 • GMLAN 528 • Keyword 528 • Multiplexing 524 • Network 524 • Node 524 • Plastic optical fiber (POF) 534 • Programmable controller interface (PCI) 530 • Protocol 527 • Serial communications interface (SCI) 530 • Serial data 524 • Splice pack 525 • Standard corporate protocol (SCP) 529 • State of health (SOH) 534 • SWCAN 529 • Terminating resistors 534 • Twisted pair 524 • UART 527 • UART-based protocol (UBP) 530

MODULE COMMUNICATIONS AND NETWORKS

NEED FOR NETWORK

Since the 1990s, vehicles have used modules to control the operation of most electrical components. A typical vehicle will have 10 or more modules and they communicate with each other over data lines or hard wiring, depending on the application.

ADVANTAGES

Most modules are connected together in a network because of the following advantages.

- A decreased number of wires are needed, thereby saving weight and cost, as well as helping with installation at the factory and decreased complexity, making servicing easier.
- Common sensor data can be shared with those modules that may need the information, such as vehicle speed, outside air temperature, and engine coolant temperature.

● **SEE FIGURE 49–1.**

NETWORK FUNDAMENTALS

MODULES AND NODES

Each module, also called a **node,** must communicate to other modules. For example, if the driver depresses the window-down switch, the power window switch sends a window-down message to the body control module. The body control module then sends the request to the driver's side window module. This module is responsible for actually performing the task by supplying power and ground to the window lift motor in the current polarity to cause the window to go down. The module also contains a circuit that monitors the current flow through the motor and will stop and/or reverse the window motor if an obstruction causes the window motor to draw more than the normal amount of current.

TYPES OF COMMUNICATION

The types of communications include the following:

- **Differential.** In the differential form of module communication, a difference in voltage is applied to two wires, which are twisted to help reduce electromagnetic interference (EMI). These transfer wires are called a **twisted pair.**
- **Parallel.** In the parallel type of module communication, the send and receive signals are on different wires.
- **Serial data.** The **serial data** is data transmitted over one wire by a series of rapidly changing voltage signals pulsed from low to high or from high to low.
- **Multiplexing.** The process of **multiplexing** involves the sending of multiple signals of information at the same time over a signal wire and then separating the signals at the receiving end.

This system of intercommunication of computers or processors is referred to as a **network.** ● **SEE FIGURE 49–2.**

By connecting the computers together on a communications network, they can easily share information back and forth. This multiplexing has the following advantages.

- Elimination of redundant sensors and dedicated wiring for these multiple sensors
- Reduction of the number of wires, connectors, and circuits
- Addition of more features and option content to new vehicles

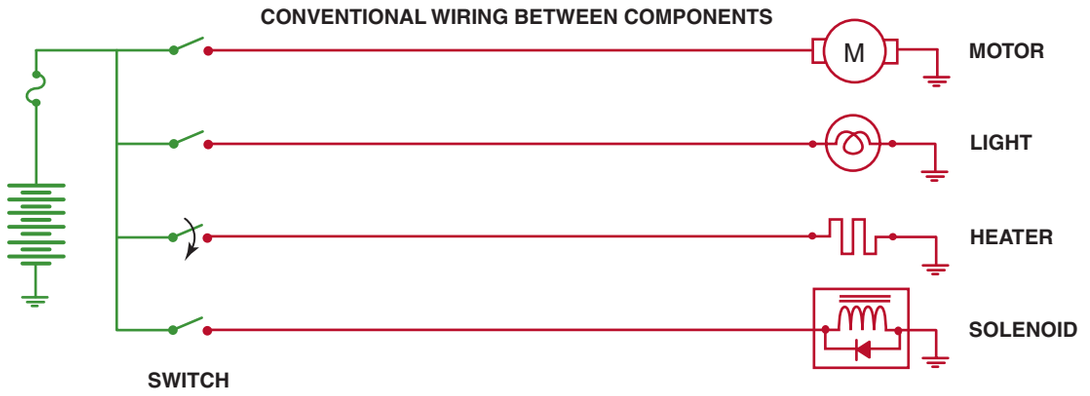
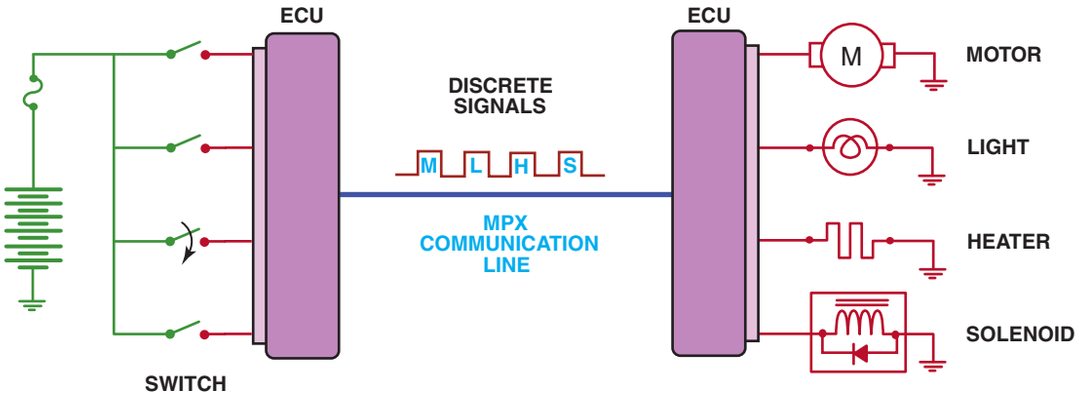


FIGURE 49–1 Module communications makes controlling multiple electrical devices and accessories easier by utilizing simple low-current switches to signal another module, which does the actual switching of the current to the device.



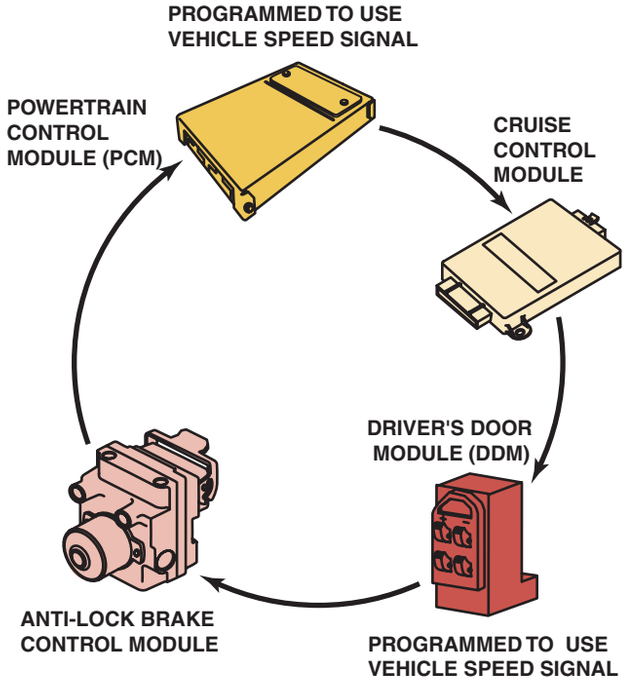


FIGURE 49–2 A network allows all modules to communicate with other modules.

- Weight reduction due to fewer components, wires, and connectors, thereby increasing fuel economy
- Changeable features with software upgrades versus component replacement

MODULE COMMUNICATIONS CONFIGURATION

The three most common types of networks used on vehicles include:

1. **Ring link networks.** In a ring-type network, all modules are connected to each other by a serial data line (in a line) until all are connected in a ring. ● **SEE FIGURE 49–3.**
2. **Star link networks.** In a star link network, a serial data line attaches to each module and then each is connected to a central point. This central point is called a **splice pack,** abbreviated SP such as in "SP 306." The splice pack uses a bar to splice all of the serial lines together. Some GM vehicles use two or more splice packs to tie the modules together. When more than one splice pack is used, a serial data line connects one splice pack to the others. In most applications, the BUS bar used in each splice pack can be removed. When the BUS bar is removed, a special tool (J 42236) can be installed in place of the removed BUS bar. Using this tool, the serial data line for each module can be isolated and tested for a possible problem. Using the special tool at the splice pack makes diagnosing this type of network easier than many others. ● **SEE FIGURE 49–4.**
3. **Ring/star hybrid.** In a ring/star network, the modules are connected using both types of network configurations. Check service information (SI) for details on how this network is connected on the vehicle being diagnosed and always follow the recommended diagnostic steps.

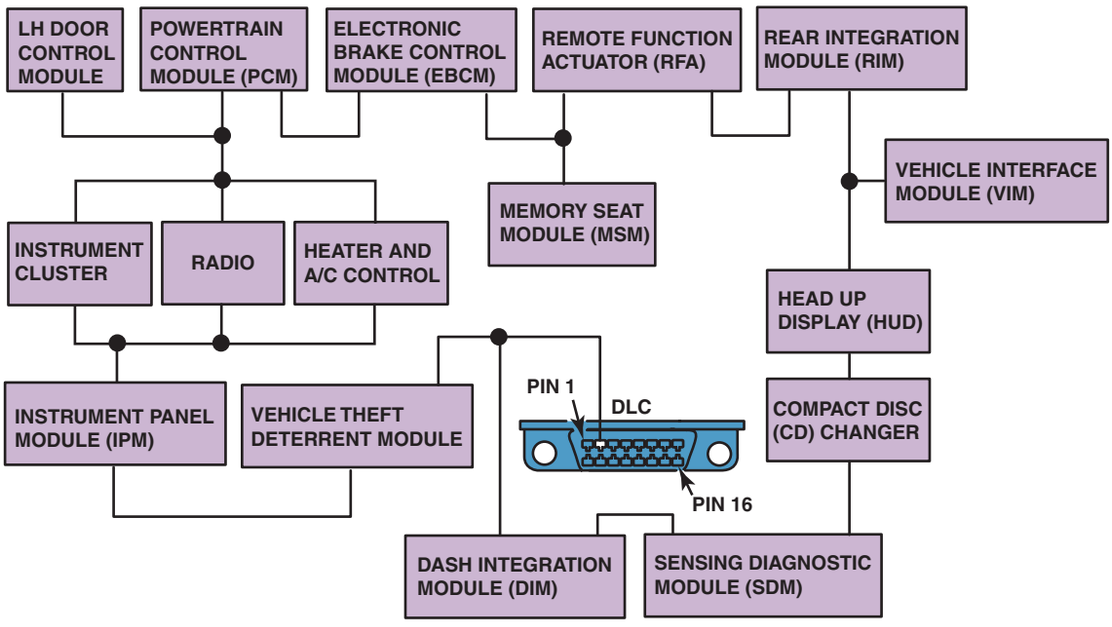


FIGURE 49–3 A ring link network reduces the number of wires it takes to interconnect all of the modules.

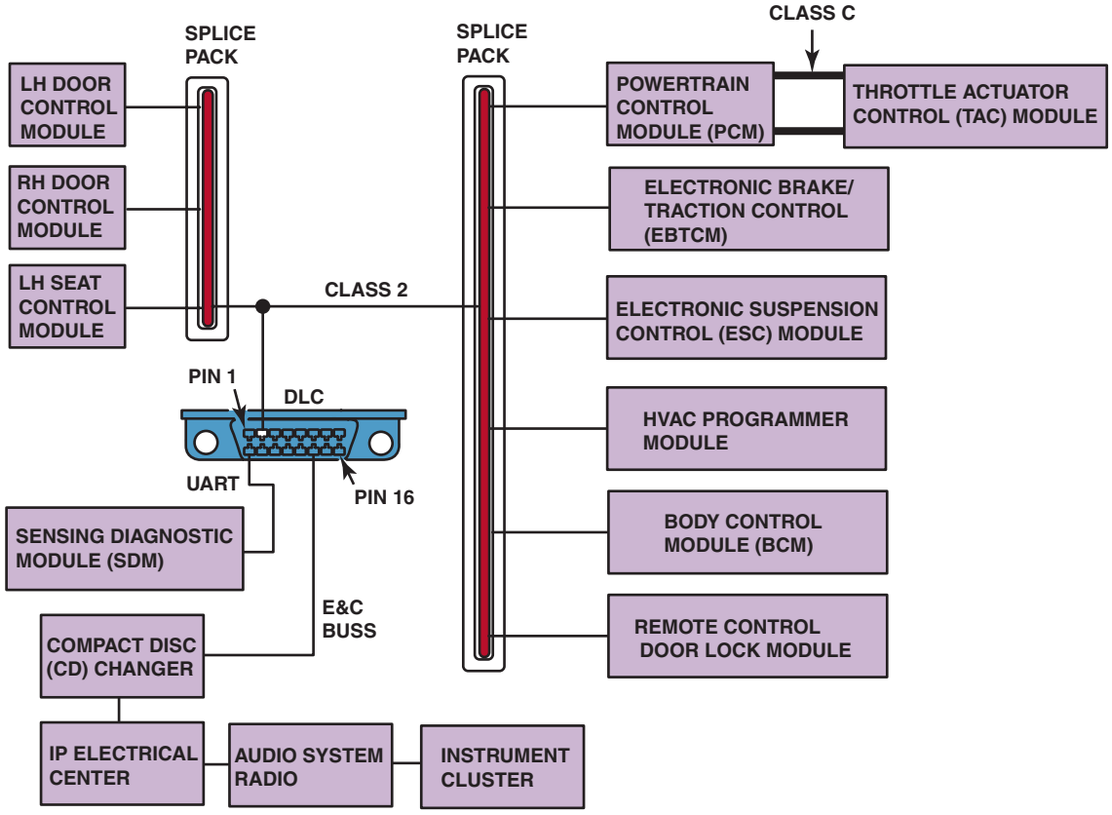


FIGURE 49–4 In a star link network, all of the modules are connected using splice packs.

NETWORK COMMUNICATIONS CLASSIFICATIONS

The Society of Automotive Engineers (SAE) standards include the following three categories of in-vehicle network communications.

CLASS A Low-speed networks, meaning less than 10,000 bits per second (bps, or 10 Kbs), are generally used for trip computers, entertainment, and other convenience features.

FREQUENTLY ASKED QUESTION

What Is a BUS?

A **BUS** is a term used to describe a communications network. Therefore, there are *connections to the BUS* and *BUS communications,* both of which refer to digital messages being transmitted among electronic modules or computers.

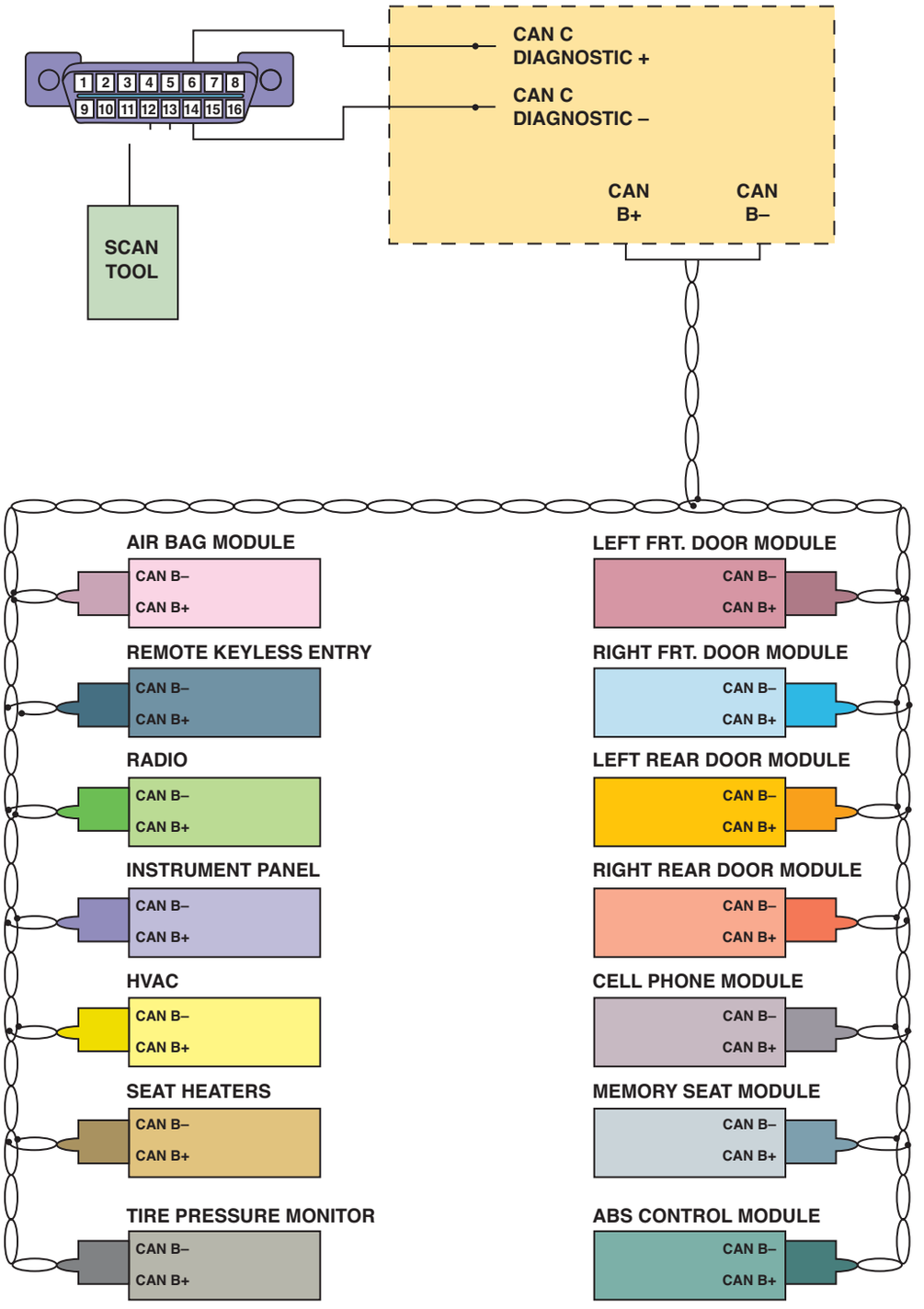


FIGURE 49–5 A typical BUS system showing module CAN communications and twisted pairs of wire.

? FREQUENTLY ASKED QUESTION

What Is a Protocol?

A **protocol** is set of rules or a standard used between computers or electronic control modules. Protocols include the type of electrical connectors, voltage levels, and frequency of the transmitted messages. Protocols, therefore, include both the hardware and software needed to communicate between modules.

CLASS B Medium-speed networks, meaning 10,000 to 125,000 bps (10 to 125 Kbs), are generally used for information transfer among modules, such as instrument clusters, temperature sensor data, and other general uses.

CLASS C High-speed networks, meaning 125,000 to 1,000,000 bps, are generally used for real-time powertrain and vehicle dynamic control. High-speed BUS communication systems now use a **controller area network (CAN).** ● **SEE FIGURE 49–5.**

GENERAL MOTORS COMMUNICATIONS PROTOCOLS

UART General Motors and others use UART communications for some electronic modules or systems. **UART** is a serial data communications protocol that stands for **universal asynchronous receive**

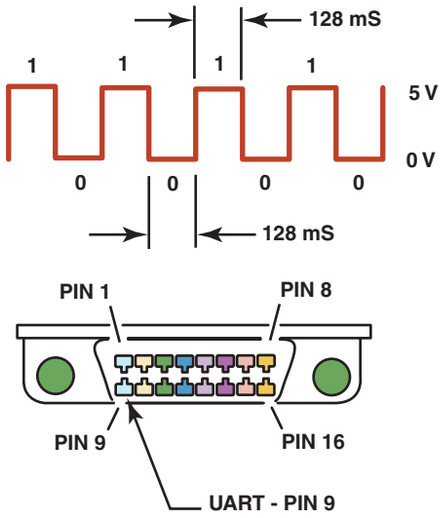


FIGURE 49–6 UART serial data master control module is connected to the data link connector at pin 9.

and transmit. UART uses a master control module connected to one or more remote modules. The master control module is used to control message traffic on the data line by poling all of the other UART modules. The remote modules send a response message back to the master module.

UART uses a fixed pulse-width switching between 0 and 5 V. The UART data BUS operates at a baud rate of 8,192 bps. ● **SEE FIGURE 49–6.**

ENTERTAINMENT AND COMFORT COMMUNICATION

The GM **entertainment and comfort (E & C)** serial data is similar to UART, but uses a 0 to 12 V toggle. Like UART, the E & C serial data uses a master control module connected to other remote modules, which could include the following:

- Compact disc (CD) player
- Instrument panel (IP) electrical center
- Audio system (radio)
- Heating, ventilation, and air-conditioning (HVAC) programmer and control head
- Steering wheel controls

● **SEE FIGURE 49–7.**

CLASS 2 COMMUNICATIONS

Class 2 is a serial communications system that operates by toggling between 0 and 7 V at a transfer rate of 10.4 Kbs. Class 2 is used for most high-speed communications between the powertrain control module (PCM) and other control modules, plus to the scan tool. Class 2 is the primary high-speed serial communications system used by GMCAN (CAN). ● **SEE FIGURE 49–8.**

KEYWORD COMMUNICATION

Keyword 81, 82, and 2000 serial data are also used for some module-to-module communication on GM vehicles. Keyword data BUS signals are toggled from 0 to 12 V when communicating. The voltage or the datastream is zero volts when not communicating. Keyword serial communication is used by the seat heater module and others, but is not connected to the data link connector (DLC). ● **SEE FIGURE 49–9.**

GMLAN

General Motors, like all vehicle manufacturers, must use high-speed serial data to communicate with scan tools on all vehicles effective with the 2008 model year. As mentioned, the standard

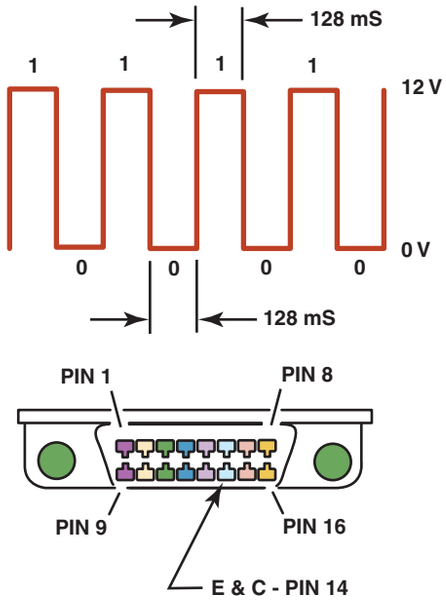


FIGURE 49–7 The E & C serial data is connected to the data link connector (DLC) at pin 14.

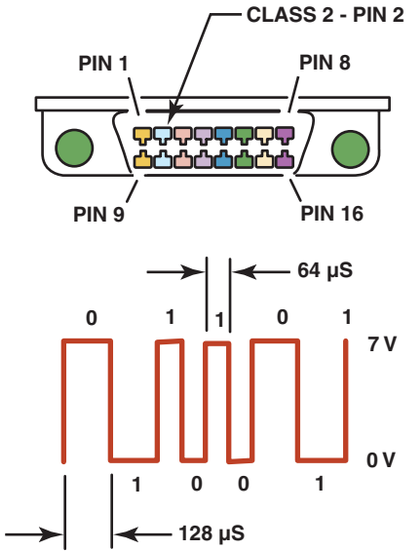


FIGURE 49–8 Class 2 serial data communication is accessible at the data link connector (DLC) at pin 2.

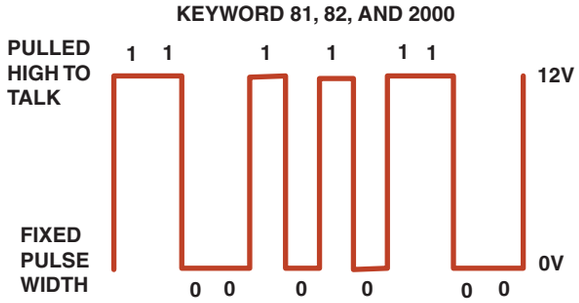


FIGURE 49–9 Keyword 82 operates at a rate of 8,192 bps, similar to UART, and keyword 2000 operates at a baud rate of 10,400 bps (the same as a Class 2 communicator).

is called controller area network (CAN), which General Motors calls **GMLAN,** which stands for **GM local area network.**

General Motors uses two versions of GMLAN.

- **Low-speed GMLAN.** The low-speed version is used for driver-controlled functions such as power windows and door locks. The baud rate for low-speed GMLAN is 33,300 bps.

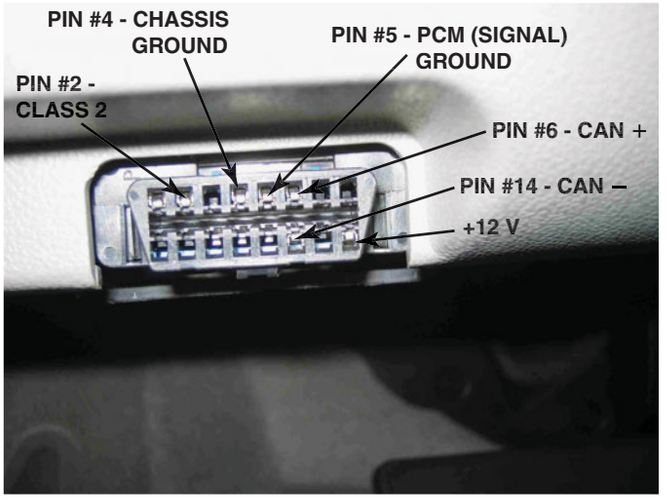


FIGURE 49–10 GMLAN uses pins at terminals 6 and 14.



FIGURE 49–12 A CANdi module will flash the green LED rapidly if communication is detected.

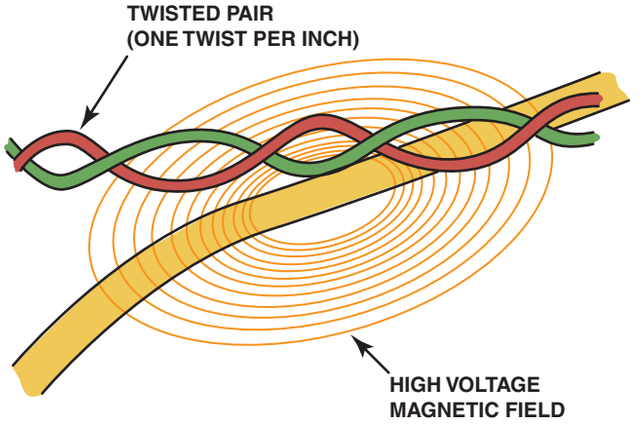


FIGURE 49–11 A twisted pair is used by several different network communications protocols to reduce interference that can be induced in the wiring from nearby electromagnetic sources.

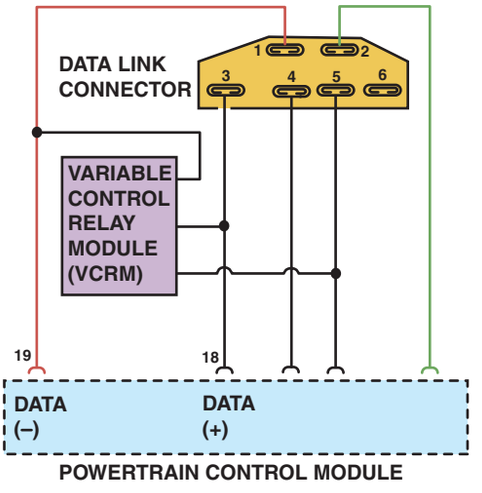


FIGURE 49–13 A Ford OBD-I diagnostic link connector showing that SCP communication uses terminals in cavities 1 (upper left) and 3 (lower left).

The GMLAN low-speed serial data is not connected directly to the data link connector and uses one wire. The voltage toggles between 0 and 5 V after an initial 12 V spike, which indicates to the modules to turn on or wake up and listen for data on the line. Low-speed GMLAN is also known as **single-wire CAN,** or **SWCAN.**

- **High-speed GMLAN.** The baud rate is almost real time at 500 Kbs. This serial data method uses a two-twisted-wire circuit which is connected to the data link connector on pins 6 and 14. ● **SEE FIGURE 49–10.**

FREQUENTLY ASKED QUESTION

Why Is a Twisted Pair Used?

A twisted pair is where two wires are twisted to prevent electromagnetic radiation from affecting the signals passing through the wires. By twisting the two wires about once every inch (9 to 16 times per foot), the interference is canceled by the adjacent wire. ● **SEE FIGURE 49–11.**

A CANdi (CAN diagnostic interface) module is required to be used with the Tech 2 to be able to connect a GM vehicle equipped with GMLAN. ● **SEE FIGURE 49–12.**

FORD NETWORK COMMUNICATIONS PROTOCOLS

STANDARD CORPORATE PROTOCOL Only a few Fords had scan tool data accessible through the OBD-I data link connector. To identify an OBD-I (1988–1995) on a Ford vehicle that is equipped with **standard corporate protocol (SCP)** and be able to communicate through a scan tool, look for terminals in cavities 1 and 3 of the DLC. ● **SEE FIGURE 49–13.**

SCP uses the J-1850 protocol and is active with the key on. The SCP signal is from 4 V negative to 4.3 V positive, and a scan tool does not have to be connected for the signal to be detected on the terminals. OBD-II (EECV) Ford vehicles use terminals 2 (positive) and 10 (negative) of the 16 pin data link connector (DLC) for network communication, using the SCP module communications.

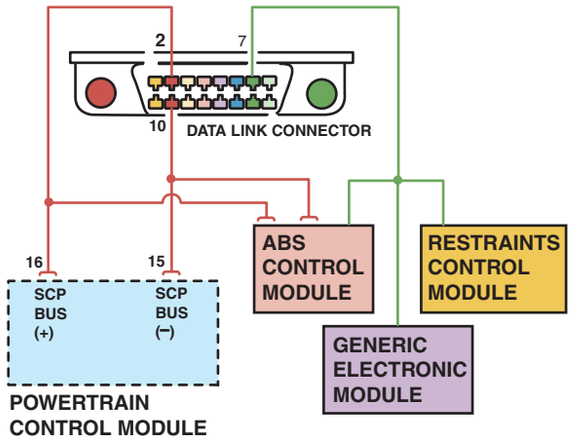


FIGURE 49–14 A scan tool can be used to check communications with the SCP BUS through terminals 2 and 10 and to the other modules connected to terminal 7 of the data link connector (DLC).

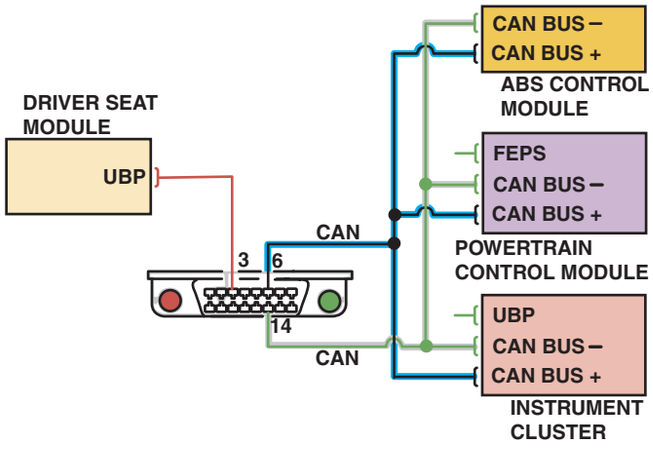


FIGURE 49–15 Many Fords use UBP module communications along with CAN.

UART-BASED PROTOCOL

Newer Fords use the CAN for scan tool diagnosis, but still retain SCP and **UART-based protocol (UBP)** for some modules. ● **SEE FIGURES 49–14 AND 49–15.**

CHRYSLER COMMUNICATIONS PROTOCOLS

CCD

Since the late 1980s, the **Chrysler Collision Detection (CCD)** multiplex network is used for scan tool and module communications. It is a differential-type communication and uses a twisted pair of wires. The modules connected to the network apply a bias voltage on each wire. CCD signals are divided into plus and minus (CCD+ and CCD−) and the voltage difference does not exceed 0.02 V. The baud rate is 7,812.5 bps.

NOTE: The "collision" in the Chrysler Collision detection BUS communications refers to the program that avoids conflicts of information exchange within the BUS, and does not refer to airbags or other accident-related circuits of the vehicle.

FREQUENTLY ASKED QUESTION

What Are U Codes?

The U diagnostic trouble codes were at first "undefined" but are now network-related codes. Use the network codes to help pinpoint the circuit or module that is not working correctly.

The circuit is active without a scan tool command. ● **SEE FIGURE 49–16.**

The modules on the CCD BUS apply a bias voltage on each wire by using termination resistors. ● **SEE FIGURE 49–17.**

The difference in voltage between CCD+ and CCD− is less than 20 mV. For example, using a digital meter with the black meter lead attached to ground and the red meter lead attached at the data link connector (DLC), a normal reading could include:

- Terminal 3 = 2.45 volts
- Terminal 11 = 2.47 volts

This is an acceptable reading because the readings are 20 mV (0.020 volt) of each other. If both had been exactly 2.5 volts, then this could indicate that the two data lines are shorted together. The module providing the bias voltage is usually the body control module on passenger cars and the front control module on Jeeps and trucks.

PROGRAMMABLE CONTROLLER INTERFACE

The Chrysler **programmable controller interface (PCI)** is a one-wire communication protocol that connects at the OBD-II DLC at terminal 2. The PCI BUS is connected to all modules on the BUS in a star configuration and operates at a baud rate of 10,200 bps. The voltage signal toggles between 7.5 and 0 V. If this voltage is checked at terminal 2 of the OBD-II DLC, a voltage of about 1 V indicates the average voltage and means that the BUS is functioning and is not shorted-to-ground. PCI and CCD are often used in the same vehicle. ● **SEE FIGURE 49–18.**

SERIAL COMMUNICATIONS INTERFACE

Chrysler used **serial communications interface (SCI)** for most scan tool and flash reprogramming functions until it was replaced with CAN. SCI is connected at the OBD-II diagnostic link connector (DLC) at terminals 6 (SCI receive) and 7 (SCI transmit). A scan tool must be connected to test the circuit.

CONTROLLER AREA NETWORK

BACKGROUND

Robert Bosch Corporation developed the CAN protocol, which was called CAN 1.2, in 1993. The CAN protocol was approved by the Environmental Protection Agency (EPA) for 2003 and newer vehicle diagnostics, and a legal requirement for all vehicles by 2008. The CAN diagnostic systems use pins 6 and 14 in the standard 16 pin OBD-II (J-1962) connector. Before CAN, the scan tool protocol had been manufacturer specific.

CAN FEATURES

The CAN protocol offers the following features.

- Faster than other BUS communication protocols
- Cost effective because it is an easier system than others to use

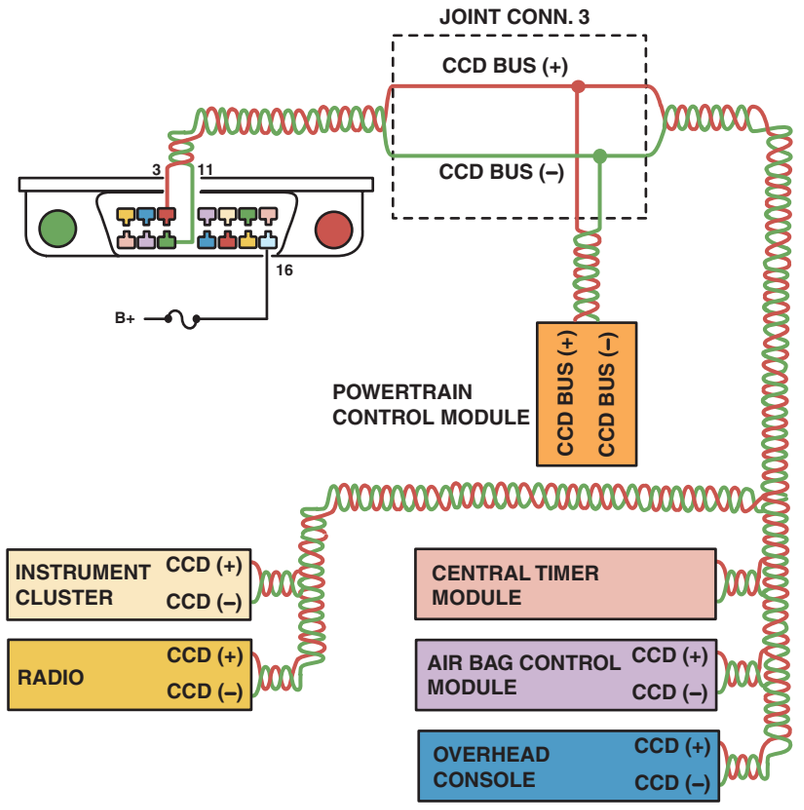


FIGURE 49–16 CCD signals are labeled plus and minus and use a twisted pair of wires. Notice that terminals 3 and 11 of the data link connector are used to access the CCD BUS from a scan tool. Pin 16 is used to supply 12 volts to the scan tool.

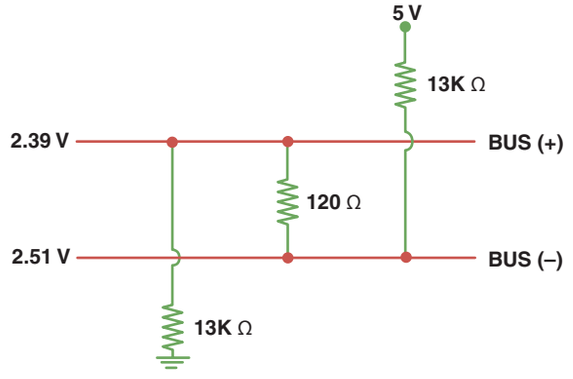


FIGURE 49–17 The differential voltage for the CCD BUS is created by using resistors in a module.

- Less effected by electromagnetic interference (Data is transferred on two wires that are twisted together, called twisted pair, to help reduce EMI interference.)
- Message based rather than address based which makes it easier to expand
- No wakeup needed because it is a two-wire system
- Supports up to15 modules plus a scan tool
- Uses a 120 ohm resistor at the ends of each pair to reduce electrical noise
- Applies 2.5 volts on both wires:
  H (high) goes to 3.5 volts when active
  L (low) goes to 1.5 volts when active
  ● **SEE FIGURE 49–19.**

CAN CLASS A, B, AND C There are three classes of CAN and they operate at different speeds. The CAN A, B, and C networks can all be linked using a gateway within the same vehicle. The gateway is usually one of the many modules in the vehicle.

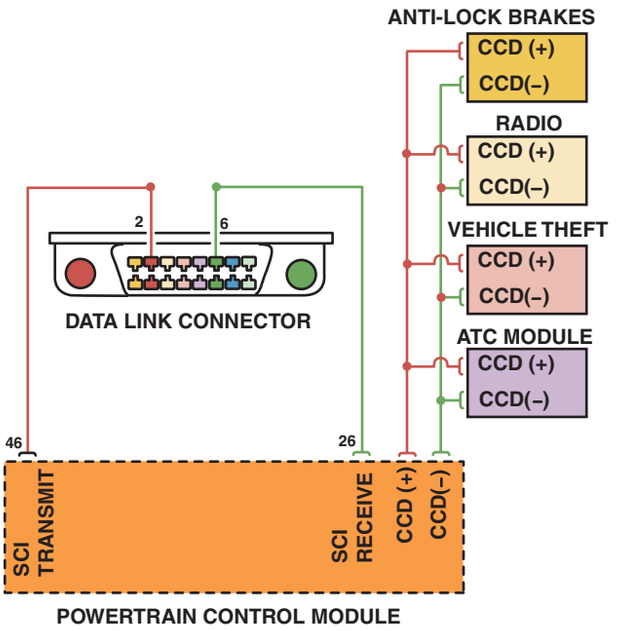


FIGURE 49–18 Many Chrysler vehicles use both SCI and CCD for module communication.

- **CAN A.** This class operates on only one wire at slow speeds and is therefore less expensive to build. CAN A operates a data transfer rate of 33.33 Kbs in normal mode and up to 83.33 Kbs during reprogramming mode. CAN A uses the vehicle ground as the signal return circuit.
- **CAN B.** This class operates on a two-wire network and does not use the vehicle ground as the signal return circuit. CAN B

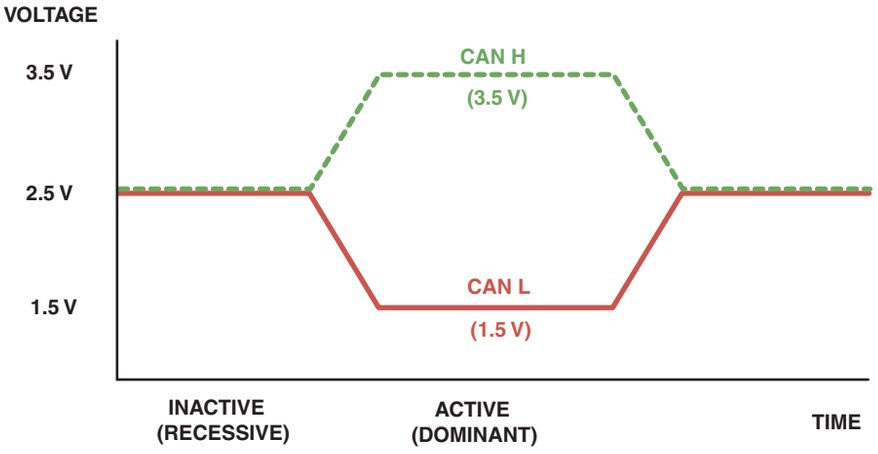


FIGURE 49–19 CAN uses a differential type of module communication where the voltage on one wire is the equal but opposite voltage on the other wire. When no communication is occurring, both wires have 2.5 volts applied. When communication is occurring, CAN H (high) goes up 1 volt to 3.5 volts and CAN L (low) goes down 1 volt to 1.5 volts.

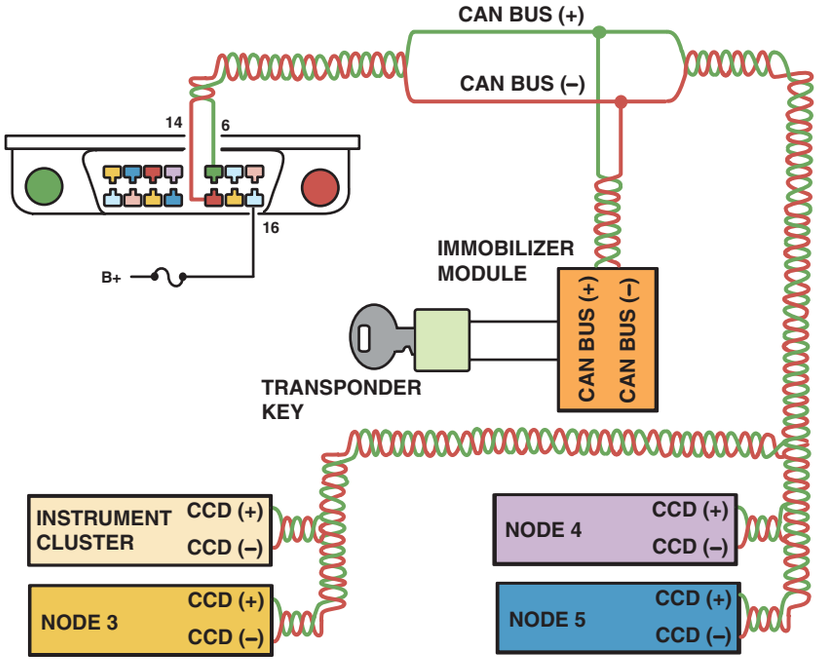


FIGURE 49–20 A typical (generic) system showing how the CAN BUS is connected to various electrical accessories and systems in the vehicle.

uses a data transfer rate of 95.2 Kbs. Instead, CAN B (and CAN C) uses two network wires for differential signaling. This means that the two data signal voltages are opposite to each other and used for error detection by constantly being compared. In this case, when the signal voltage at one of the CAN data wires goes high (CAN H), the other one goes low (CAN L), hence the name *differential signaling.* Differential signaling is also used for redundancy, in case one of the signal wires shorts out.

- **CAN C.** This class is the highest speed CAN protocol with speeds up to 500 Kbs. Beginning with 2008 models, all vehicles sold in the United States must use CAN BUS for scan tool communications. Most vehicle manufacturers started using CAN in older models; and it is easy to determine if a vehicle is equipped with CAN. The CAN BUS communicates to the scan tool through terminals 6 and 14 of the DLC indicating that the vehicle is equipped with CAN. ● **SEE FIGURE 49–20.**

The total voltage remains constant at all times and the electromagnetic field effects of the two data BUS lines cancel each other out. The data BUS line is protected against received radiation and is virtually neutral in sending radiation.

HONDA/TOYOTA COMMUNICATIONS

The primary BUS communications on pre-CAN-equipped vehicles is ISO 9141-2 using terminals 7 and 15 at the OBD-II DLC. ● **SEE FIGURE 49–21.**

A factory scan tool or an aftermarket scan tool equipped with enhanced original equipment (OE) software is needed to access many of the BUS messages. ● **SEE FIGURE 49–22.**

EUROPEAN BUS COMMUNICATIONS

UNIQUE DIAGNOSTIC CONNECTOR Many different types of module communications protocols are used on European vehicles such as Mercedes and BMW.

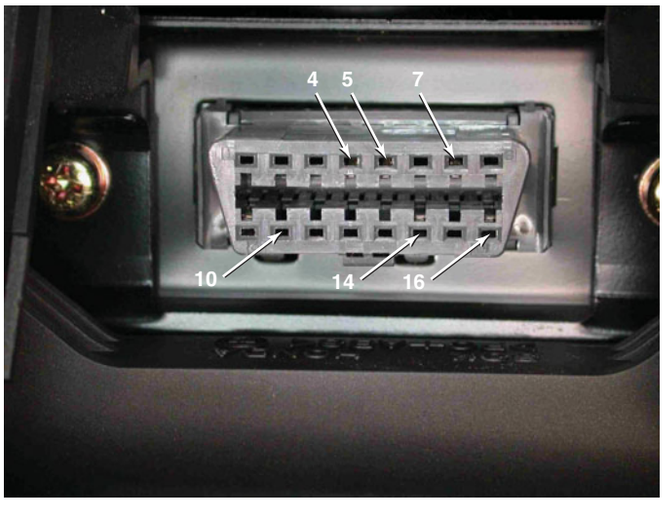


FIGURE 49–21 A DLC from a pre-CAN Acura. It shows terminals in cavities 4, 5 (grounds), 7, 10, 14, and 16 (B+).



FIGURE 49–22 A Honda scan display showing a B and two U codes, all indicating a BUS-related problem(s).

Most of these communication BUS messages cannot be accessed through the data link connector (DLC). To check the operation of the individual modules, a scan tool equipped with factory-type software will be needed to communicate with the module through the gateway module. ● **SEE FIGURE 49–23** for an alternative access method to the modules.

MEDIA ORIENTED SYSTEM TRANSPORT BUS The media oriented system transport (MOST) BUS uses fiber optics for module-to-module communications in a ring or star configuration. This BUS system is currently being used for entertainment equipment data communications for videos, CDs, and other media systems in the vehicle.

MOTOROLA INTERCONNECT BUS Motorola interconnect (MI) is a single-wire serial communications protocol, using one master control module and many slave modules. Typical application of the MI BUS protocol is with power and memory mirrors, seats, windows, and headlight levelers.

DISTRIBUTED SYSTEM INTERFACE BUS Distributed system interface (DSI) BUS protocol was developed by Motorola and uses a two-wire serial BUS. This BUS protocol is currently being used for safety-related sensors and components.



FIGURE 49–23 A typical 38-cavity diagnostic connector as found on many BMW and Mercedes vehicles under the hood. The use of a breakout box (BOB) connected to this connector can often be used to gain access to module BUS information.

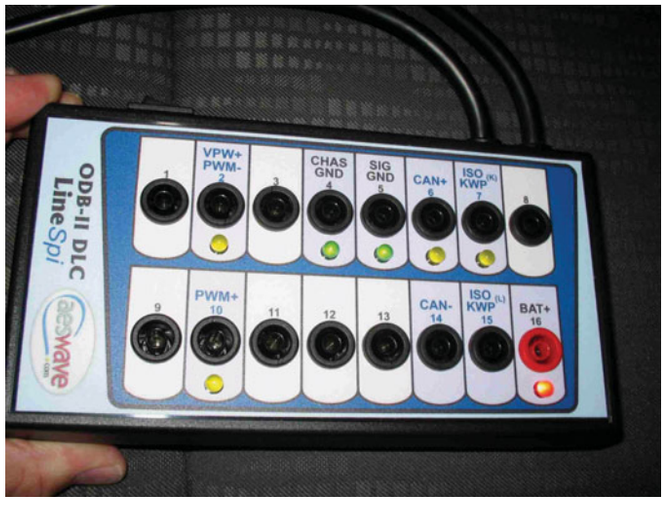


FIGURE 49–24 A breakout box (BOB) used to access the BUS terminals while using a scan tool to activate the modules. This breakout box is equipped with LEDs that light when circuits are active.

FREQUENTLY ASKED QUESTION

How Do You Know What System Is Used?

Use service information to determine which network communication protocol is used. However, due to the various systems on some vehicles, it may be easier to look at the data link connection to determine the system. All OBD-II vehicles have terminals in the following cavities.

Terminal 4: chassis ground

Terminal 5: computer (signal) ground

Terminal 16: 12 V positive

The terminals in cavities 6 and 14 mean that this vehicle is equipped with CAN as the only module communication protocol available at the DLC. To perform a test of the BUS, use a **breakout box (BOB)** to gain access to the terminals while connecting to the vehicle, using a scan tool. ● **SEE FIGURE 49–24** for a typical OBD-II connector breakout box.

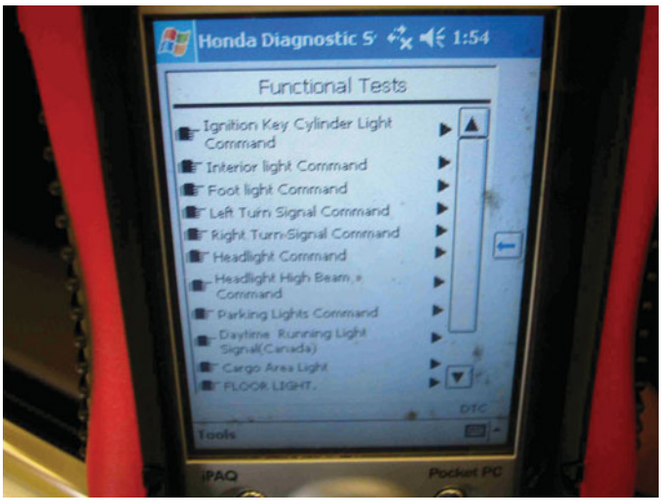


FIGURE 49–25 This Honda scan tool allows the technician to turn on individual lights and operate individual power windows and other accessories that are connected to the BUS system.

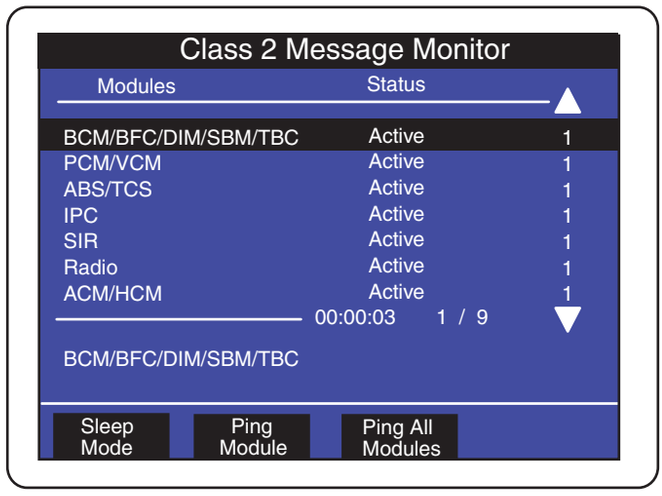


FIGURE 49–26 Modules used in a General Motors vehicle can be "pinged" using a Tech 2 scan tool.

BOSCH-SIEMANS-TEMIC BUS The Bosch-Siemans-Temic (BST) BUS is another system that is used for safety-related components and sensors in a vehicle, such as airbags. The BST BUS is a two-wire system and operates up to 250,000 bps.

BYTEFLIGHT BUS The byteflight BUS is used in safety critical systems, such as airbags, and uses the time division multiple access (TDMA) protocol, which operates at 10 million bps using a **plastic optical fiber (POF).**

FLEXRAY BUS FlexRay BUS is a version of byteflight, and is a high-speed serial communication system for in-vehicle networks. FlexRay is commonly used for steer-by-wire and brake-by-wire systems.

DOMESTIC DIGITAL BUS The domestic digital BUS, commonly designated D2B, is an optical BUS system connecting audio, video, computer, and telephone components in a single-ring structure with a speed of up to 5,600,000 bps.

LOCAL INTERCONNECT NETWORK BUS Local interconnect network (LIN) is a BUS protocol used between intelligent sensors and actuators, and has a BUS speed of 19,200 bps.

NETWORK COMMUNICATIONS DIAGNOSIS

STEPS TO FINDING A FAULT When a network communications fault is suspected, perform the following steps.

STEP 1 **Check everything that does and does not work.** Often accessories that do not seem to be connected can help identify which module or BUS circuit is at fault.

STEP 2 **Perform module status test.** Use a factory level scan tool or an aftermarket scan tool equipped with enhanced software that allows OE-like functions. Check if the components or systems can be operated through the scan tool. ● **SEE FIGURE 49–25.**

- **Ping modules.** Start the Class 2 diagnosis by using a scan tool and select *diagnostic circuit check.* If no diagnostic trouble codes (DTCs) are shown, there could be a communication problem. Select *message monitor,* which will display the status of all of the modules on the Class 2 BUS circuit. The modules that are awake will be shown as active and the scan tool can be used to ping individual modules or command all modules. The ping command should change the status from "active" to "inactive." ● **SEE FIGURE 49–26.**

  NOTE: If an excessive parasitic draw is being diagnosed, use a scan tool to ping the modules in one way to determine if one of the modules is not going to sleep and causing the excessive battery drain.

- **Check state of health.** All modules on the Class 2 BUS circuit have at least one other module responsible for reporting **state of health (SOH).** If a module fails to send a state of health message within five seconds, the companion module will set a diagnostic trouble code for the module that did not respond. The defective module is not capable of sending this message.

STEP 3 **Check the resistance of the terminating resistors.** Most high-speed BUS systems use resistors at each end, called **terminating resistors.** These resistors are used to help reduce interference into other systems in the vehicle. Usually two 120 ohm resistors are installed at each end and are therefore connected electrically in parallel. Two 120 ohm resistors connected in parallel would measure 60 ohms if being tested using an ohmmeter. ● **SEE FIGURE 49–27.**

STEP 4 **Check data BUS for voltages.** Use a digital multimeter set to DC volts, to monitor communications and check the BUS for proper operation. Some BUS conditions and possible causes include:

- **Signal is zero volt all of the time.** Check for short-to-ground by unplugging modules one at a time to check if one module is causing the problem.
- **Signal is high or 12 volts all of the time.** The BUS circuit could be shorted to 12 V. Check with the customer to see if any service or body repair work was done recently. Try unplugging each module one at a time to pin down which module is causing the communications problem.

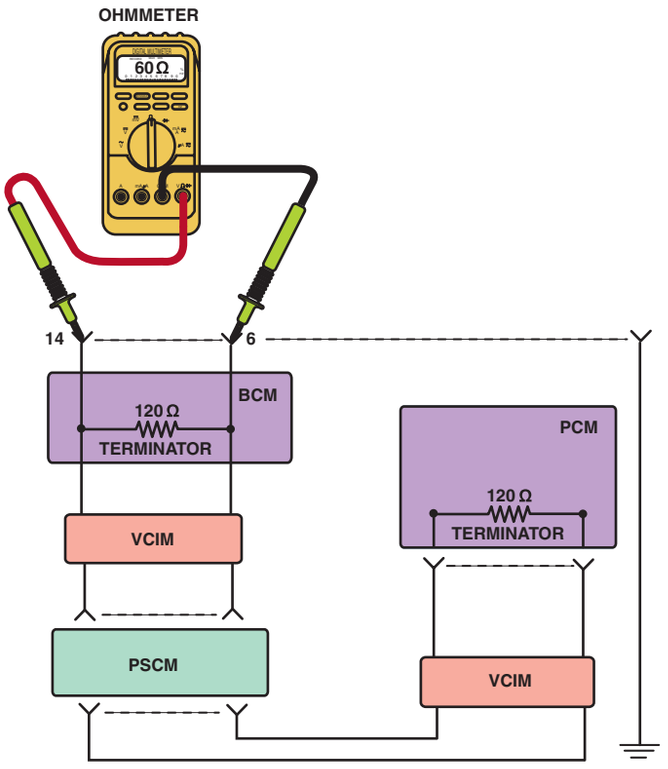


FIGURE 49–27 Checking the terminating resistors using an ohmmeter at the DLC.



FIGURE 49–28 Use front-probe terminals to access the data link connector. Always follow the specified back-probe and front-probe procedures as found in service information.

- **A variable voltage usually indicates that messages are being sent and received.** CAN and Class 2 can be identified by looking at the data link connector (DLC) for a terminal in cavity number 2. Class 2 is active all of the time the ignition is on, and therefore voltage variation between 0 and 7 V can be measured using a DMM set to read DC volts. ● **SEE FIGURE 49–28.**

STEP 5 **Use a digital storage oscilloscope to monitor the waveforms of the BUS circuit.** Using a scope on the data line terminals can show if communication is being transmitted. Typical faults and their causes include:

- **Normal operation.** Normal operation shows variable voltage signals on the data lines. It is impossible to know what information is being transmitted, but if there is activity with short sections of inactivity, this indicates normal data line transmission activity. ● **SEE FIGURE 49–29.**
- **High voltage.** If there is a constant high-voltage signal without any change, this indicates that the data line is shorted to voltage.
- **Zero or low voltage.** If the data line voltage is zero or almost zero and not showing any higher voltage signals, then the data line is short-to-ground.

TECH TIP

No Communication? Try Bypass Mode.

If a Tech 2 scan tool shows "no communication," try using the bypass mode to see what should be on the data display. To enter bypass mode, perform the following steps.

STEP 1 Select tool option (F3).

STEP 2 Set communications to bypass (F5).

STEP 3 Select enable.

STEP 4 Input make/model and year of vehicle.

STEP 5 Note all parameters that should be included, as shown. The values will not be shown.

REAL WORLD FIX

The Radio Caused No-Start Story

A 2005 Chevrolet Cobalt did not start. A technician checked with a subscription-based helpline service and discovered that a fault with the Class 2 data circuit could prevent the engine from starting. The advisor suggested that a module should be disconnected one at a time to see if one of them was taking the data line to ground. The two most common components on the Class 2 serial data line that have been known to cause a lack of communication and become shorted-to-ground are the radio and electronic brake control module (EBCM). The first one the technician disconnected was the radio. The engine started and ran. Apparently the Class 2 serial data line was shorted-to-ground inside the radio, which took the entire BUS down. When BUS communication is lost, the PCM is not able to energize the fuel pump, ignition, or fuel injectors so the engine would not start. The radio was replaced to solve the no-start condition.

FREQUENTLY ASKED QUESTION

Which Module Is the Gateway Module?

The gateway module is responsible for communicating with other modules and acts as the main communications module for scan tool data. Most General Motors vehicles use the body control module (BCM) or the instrument panel control (IPC) module as the gateway. To verify which module is the gateway, check the schematic and look for one that has voltage applied during all of the following conditions.

- Key on, engine off
- Engine cranking
- Engine running

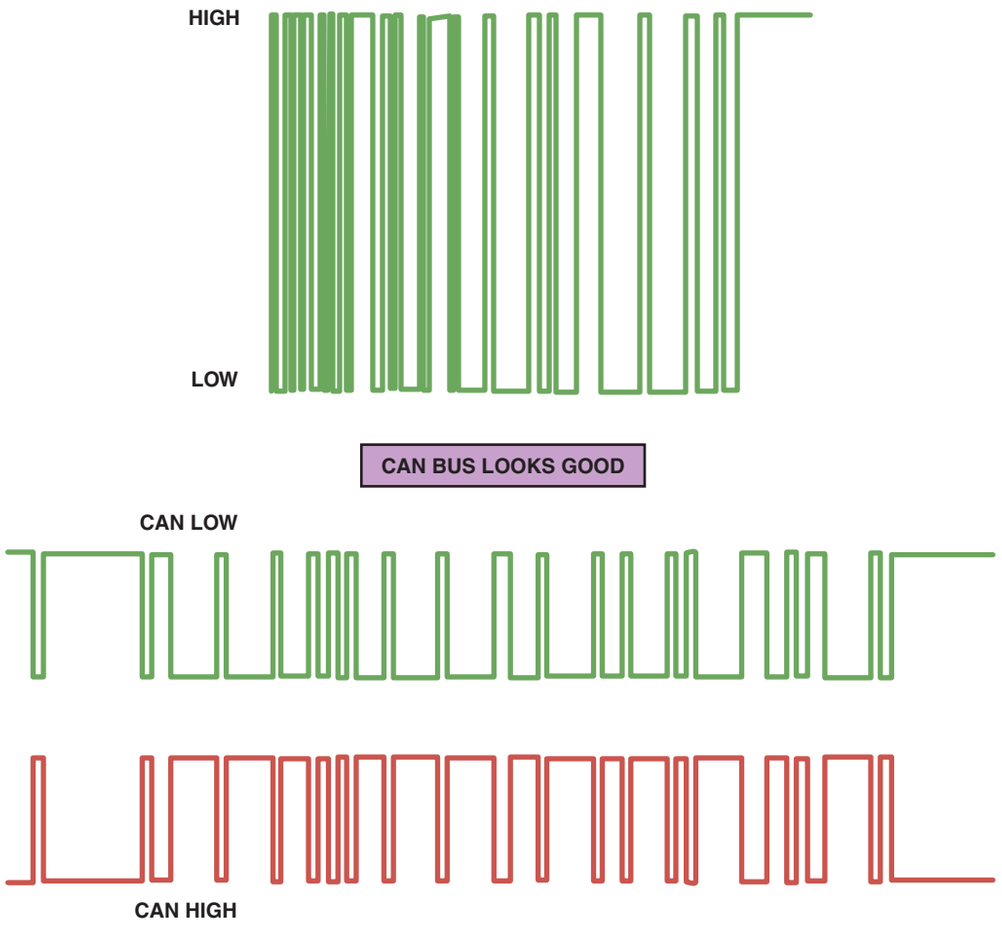


FIGURE 49–29 (a) Data is sent in packets, so it is normal to see activity then a flat line between messages. (b) A CAN BUS should show voltages that are opposite when there is normal communications. CAN H (high) circuit should go from 2.5 volts at rest to 3.5 volts when active. The CAN L (low) circuit goes from 2.5 volts at rest to 1.5 volts when active.

STEP 6 **Follow factory service information instructions to isolate the cause of the fault.** This step often involves disconnecting one module at a time to see if it is the cause of a short-to-ground or an open in the BUS circuit.

OBD-II DATA LINK CONNECTOR

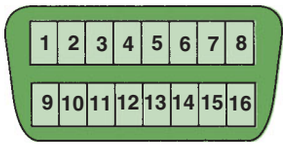
All OBD-II vehicles use a 16 pin connector that includes:

Pin 4 = chassis ground

Pin 5 = signal ground

Pin 16 = battery power (4 A max)

● **SEE FIGURE 49–30.**



OBD-II DLC

PIN NO.	ASSIGNMENTS
1.	MANUFACTURER'S DISCRETION
2.	BUS + LINE, SAE J1850
3.	MANUFACTURER'S DISCRETION
4.	CHASSIS GROUND
5.	SIGNAL GROUND
6.	MANUFACTURER'S DISCRETION
7.	K LINE, ISO 9141
8.	MANUFACTURER'S DISCRETION
9.	MANUFACTURER'S DISCRETION
10.	BUS – LINE, SAE J1850
11.	MANUFACTURER'S DISCRETION
12.	MANUFACTURER'S DISCRETION
13.	MANUFACTURER'S DISCRETION
14.	MANUFACTURER'S DISCRETION
15.	L LINE, ISO 9141
16.	VEHICLE BATTERY POSITIVE (4A MAX)

FIGURE 49–30 A 16 pin OBD-II DLC with terminals identified. Scan tools use the power pin (16) and ground pin (4) for power so that a separate cigarette lighter plug is not necessary on OBD-II vehicles.

GENERAL MOTORS VEHICLES

- SAE J-1850 (VPW, Class 2, 10.4 Kbs) standard, which uses pins 2, 4, 5, and 16, but not 10
- GM Domestic OBD-II

  Pin 1 and 9: CCM (comprehensive component monitor) slow baud rate, 8,192 UART

  Pins 2 and 10: OEM enhanced, fast rate, 40,500 baud rate

  Pins 7 and 15: generic OBD-II, ISO 9141, 10,400 baud rate

  Pins 6 and 14: GMLAN

ASIAN, CHRYSLER, AND EUROPEAN VEHICLES

- ISO 9141-2 standard, which uses pins 4, 5, 7, 15, and 16
- Chrysler Domestic Group OBD-II

  Pins 2 and 10: CCM

  Pins 3 and 14: OEM enhanced, 60,500 baud rate

  Pins 7 and 15: generic OBD-II, ISO 9141, 10,400 baud rate

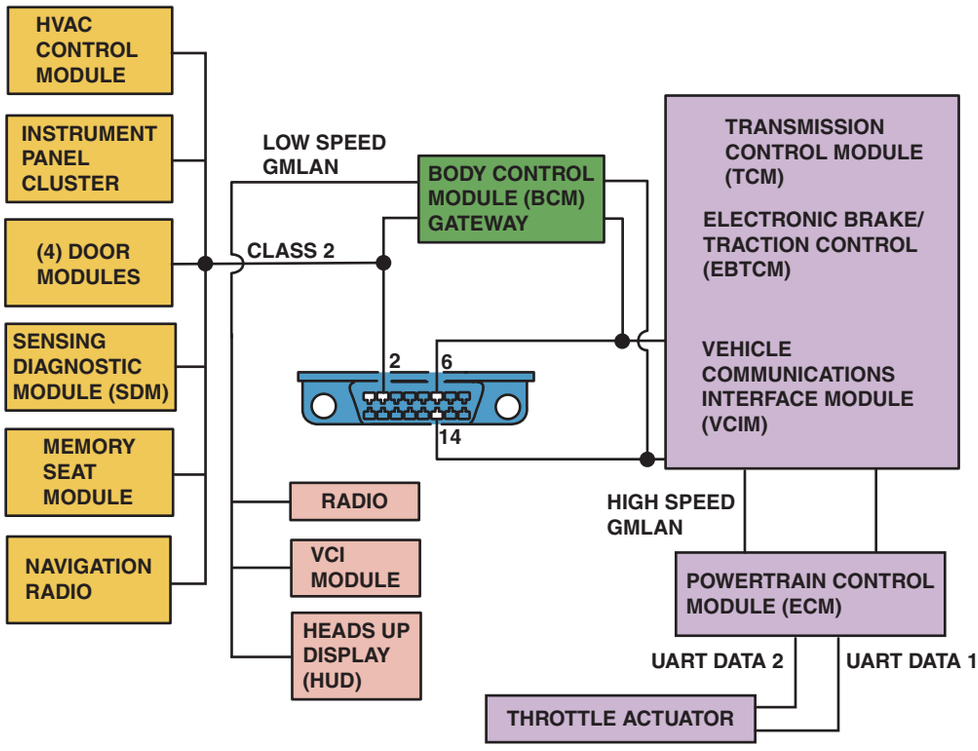


FIGURE 49–31 This schematic of a Chevrolet Equinox shows that the vehicle uses a GMLAN BUS (DLC pins 6 and 14), plus a Class 2 (pin 2) and UART.

TECH TIP

Check Computer Data Line Circuit Schematic

Many General Motors vehicles use more than one type of BUS communications protocol. Check service information (SI) and look at the schematic for computer data line circuits which should show all of the data BUSes and their connectors to the diagnostic link connector (DLC). ● **SEE FIGURE 49–31.**

FORD VEHICLES

- SAE J-1850 (PWM, 41.6 Kbs) standard, which uses pins 2, 4, 5, 10, and 16
- Ford Domestic OBD-II

  Pins 2 and 10: CCM

  Pins 6 and 14: OEM enhanced, Class C, 40,500 baud rate

  Pins 7 and 15: generic OBD-II, ISO 9141, 10,400 baud rate

REVIEW QUESTIONS

1. Why is a communication network used?
2. Why are the two wires twisted if used for network communications?
3. Why is a gateway module used?
4. What are U codes?

CHAPTER QUIZ

1. Technician A says that module communications networks are used to reduce the number of wires in a vehicle. Technician B says that a communications network is used to share data from sensors, which can be used by many different modules. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
2. A module is also known as a _____.
   a. BUS **c.** Terminator
   b. Node **d.** Resistor pack
3. A high-speed CAN BUS communicates with a scan tool through which terminal(s)?
   a. 6 and 14 **c.** 7 and 15
   b. 2 **d.** 4 and 16
4. UART uses a _____ signal that toggles 0 V.
   a. 5 V **c.** 8 V
   b. 7 V **d.** 12 V
5. GM Class 2 communication toggles between _____.
   a. 5 and 7 V **c.** 7 and 12 V
   b. 0 and 12 V **d.** 0 and 7 V

6. Which terminal of the data link connector does General Motors use for Class 2 communication?
   a. 1 **c.** 3
   b. 2 **d.** 4
7. GMLAN is the General Motors term for which type of module communication?
   a. UART **c.** High-speed CAN
   b. Class 2 **d.** Keyword 2000
8. CAN H and CAN L operate how?
   a. CAN H is at 2.5 volts when not transmitting.
   b. CAN L is at 2.5 volts when not transmitting.
   c. CAN H goes to 3.5 volts when transmitting.
   d. All of the above
9. Which terminal of the OBD-II data link connector is the signal ground for all vehicles?
   a. 1
   b. 3
   c. 4
   d. 5
10. Terminal 16 of the OBD-II data link connector is used for what?
   a. Chassis ground
   b. 12 V positive
   c. Module (signal ground)
   d. Manufacturer's discretion

chapter 50 BATTERIES

OBJECTIVES: After studying Chapter 50, the reader will be able to: • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "B" (Battery Diagnosis and Service). • Describe how a battery works. • List battery ratings. • Describe deep cycling. • Discuss how charge indicators work.

KEY TERMS: AGM 542 • Ampere hour 543 • Battery Council International (BCI) 543 • CA 543 • CCA 543 • Cells 539 • Deep cycling 543 • Electrolyte 540 • Element 539 • Flooded cell batteries 542 • Gassing 539 • Gel battery 542 • Grid 538 • Low-water-loss batteries 538 • Maintenance-free battery 538 • MCA 543 • Partitions 539 • Porous lead 539 • Recombinant battery 542 • Reserve capacity 543 • Sediment chamber 538 • SLA 542 • SLI 539 • Specific gravity 540 • Sponge lead 539 • SVR 542 • VRLA 542

INTRODUCTION

PURPOSE AND FUNCTION

Everything electrical in a vehicle is supplied current from the battery. The battery is one of the most important parts of a vehicle because it is the heart or foundation of the electrical system. The primary purpose of an automotive battery is to provide a source of electrical power for starting and for electrical demands that exceed alternator output.

WHY BATTERIES ARE IMPORTANT

The battery also acts as a stabilizer to the voltage for the entire electrical system. The battery is a voltage stabilizer because it acts as a reservoir where large amounts of current (amperes) can be removed quickly during starting and replaced gradually by the alternator during charging.

- The battery *must* be in good (serviceable) condition before the charging system and the cranking system can be tested. For example, if a battery is discharged, the cranking circuit (starter motor) could test as being defective because the battery voltage might drop below specifications.
- The charging circuit could also test as being defective because of a weak or discharged battery. It is important to test the vehicle battery before further testing of the cranking or charging system.

BATTERY CONSTRUCTION

CASE

Most automotive battery cases (container or covers) are constructed of polypropylene, a thin (approximately 0.08 in., or 0.02 mm, thick), strong, and lightweight plastic. In contrast, containers for industrial batteries and some truck batteries are constructed of a hard, thick rubber material.

Inside the case are six cells (for a 12 volt battery). ● **SEE FIGURE 50–1.** Each cell has positive and negative plates. Built into the bottom of many batteries are ribs that support the lead-alloy plates and provide a space for sediment to settle, called the **sediment chamber.** This space prevents spent active material from causing a short circuit between the plates at the bottom of the battery.

A **maintenance-free battery** uses little water during normal service because of the alloy material used to construct the battery plate grids. Maintenance-free batteries are also called **low-water-loss batteries.**

GRIDS

Each positive and negative plate in a battery is constructed on a framework, or **grid,** made primarily of lead. Lead is a

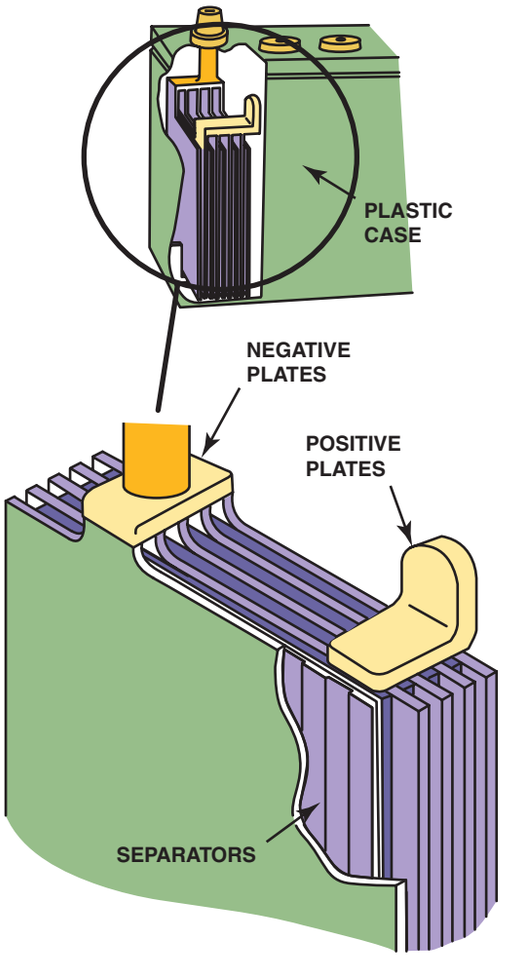


FIGURE 50–1 Batteries are constructed of plates grouped into cells and installed in a plastic case.

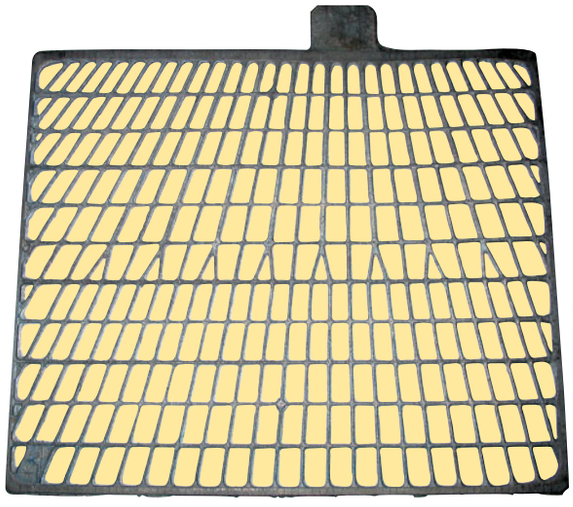


FIGURE 50–2 A grid from a battery used in both positive and negative plates.

soft material and must be strengthened for use in an automotive battery grid. Adding antimony or calcium to the pure lead adds strength to the lead grids. ● **SEE FIGURE 50–2.**

Battery grids hold the active material and provide the electrical pathways for the current created in the plate.

Maintenance-free batteries use calcium instead of antimony, because 0.2% calcium has the same strength as 6% antimony. A typical lead-calcium grid uses only 0.09% to 0.12% calcium. Using low amounts of calcium instead of higher amounts of antimony reduces **gassing.** Gassing is the release of hydrogen and oxygen from the battery that occurs during charging and results in water usage.

? **FREQUENTLY ASKED QUESTION**

What Is an SLI Battery?

Sometimes the term *SLI* is used to describe a type of battery. **SLI** means starting, lighting, and ignition, and describes the use of a typical automotive battery. Other types of batteries used in industry are usually batteries designed to be deep cycled and are usually not as suitable for automotive needs.

Low-maintenance batteries use a low percentage of antimony (about 2% to 3%), or use antimony only in the positive grids and calcium for the negative grids. *The percentages that make up the alloy of the plate grids constitute the major difference between standard and maintenance-free batteries.* The chemical reactions that occur inside each battery are identical regardless of the type of material used to construct the grid plates.

POSITIVE PLATES The positive plates have *lead dioxide (peroxides),* in paste form placed onto the grid framework. This process is called *pasting.* This active material can react with the sulfuric acid of the battery and is dark brown in color.

NEGATIVE PLATES The negative plates are pasted to the grid with a pure **porous lead,** called **sponge lead,** and are gray in color.

SEPARATORS The positive and the negative plates must be installed alternately next to each other without touching. Nonconducting *separators* are used, which allow room for the reaction of the acid with both plate materials, yet insulate the plates to prevent shorts. These separators are porous (with many small holes) and have ribs facing the positive plate. Separators can be made from resin-coated paper, porous rubber, fiberglass, or expanded plastic. Many batteries use envelope-type separators that encase the entire plate and help prevent any material that may shed from the plates from causing a short circuit between plates at the bottom of the battery.

CELLS **Cells** are constructed of positive and negative plates with insulating separators between each plate. Most batteries use one more negative plate than positive plate in each cell; however, many newer batteries use the same number of positive and negative plates. A cell is also called an **element.** Each cell is actually a 2.1 volt battery, regardless of the number of positive or negative plates used. The greater the number of plates used in each cell, the greater the amount of *current* that can be produced. Typical batteries contain four positive plates and five negative plates per cell. A 12 volt battery contains six cells connected in series, which produce 12.6 volts ($6 \times 2.1 = 12.6$) and contain 54 plates (9 plates per cell $\times$ 6 cells). If the same 12 volt battery had five positive plates and six negative plates, for a total of 11 plates per cell ($5 + 6$), or 66 plates (11 plates $\times$ 6 cells), then it would have the same voltage, but the amount of current that the battery could produce would be increased. ● **SEE FIGURE 50–3.**

The amperage capacity of a battery is determined by the amount of active plate material in the battery and the area of the plate material exposed to the electrolyte in the battery.

PARTITIONS Each cell is separated from the other cells by **partitions,** which are made of the same material as that used for the outside case of the battery. Electrical connections between cells are provided by lead connectors that loop over the top of the partition and connect the plates of the cells together. Many batteries connect the

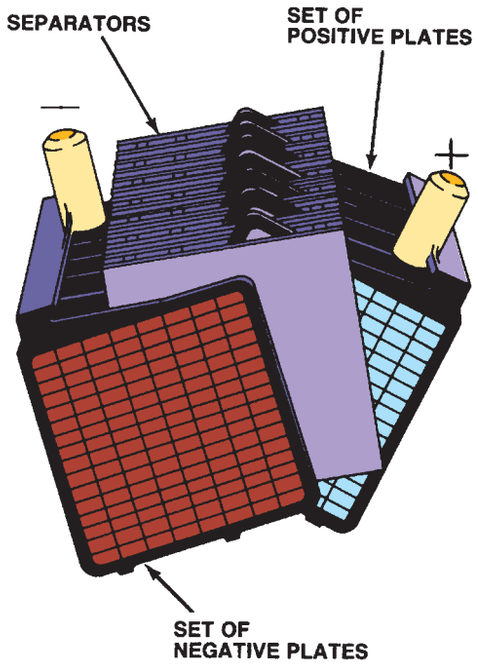


FIGURE 50–3 Two groups of plates are combined to form a battery element.

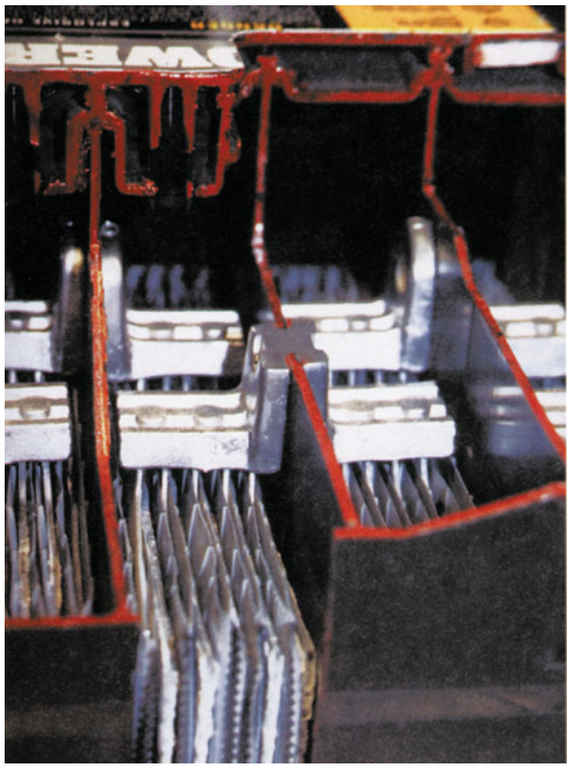


FIGURE 50–4 A cutaway battery showing the connection of the cells to each other through the partition.

cells directly through the partition connectors, which provide the shortest path for the current and the lowest resistance. ● **SEE FIGURE 50–4.**

ELECTROLYTE

Electrolyte is the term used to describe the acid solution in a battery. The electrolyte used in automotive batteries is a solution (liquid combination) of 36% sulfuric acid and 64% water. This electrolyte is used for both lead-antimony and lead-calcium (maintenance-free) batteries. The chemical symbol for this sulfuric acid solution is H_2SO_4.

H_2 = Symbol for hydrogen (the subscript 2 means that there are two atoms of hydrogen)

S = Symbol for sulfur

O_4 = Symbol for oxygen (the subscript 4 indicates that there are four atoms of oxygen)

Electrolyte is sold premixed in the proper proportion and is factory installed or added to the battery when the battery is sold. Additional electrolyte must *never* be added to any battery after the original electrolyte fill. It is normal for some water (H_2O) in the form of hydrogen and oxygen gases to escape during charging as a result of the chemical reactions. The escape of gases from a battery during charging or discharging is called gassing. Only pure distilled water should be added to a battery. If distilled water is not available, clean drinking water can be used.

HOW A BATTERY WORKS

PRINCIPLE INVOLVED

The principle of how a battery works is based on a scientific principle discovered years ago that states:

- When two dissimilar metals are placed in an acid, electrons flow between the metals if a circuit is connected between them.
- This can be demonstrated by pushing a steel nail and a piece of solid copper wire into a lemon. Connect a voltmeter to the ends of the copper wire and nail, and voltage will be displayed.

A fully charged lead-acid battery has a positive plate of lead dioxide (peroxide) and a negative plate of lead surrounded by a sulfuric acid solution (electrolyte). The difference in potential (voltage) between lead peroxide and lead in acid is approximately 2.1 volts.

DURING DISCHARGING

The positive plate lead dioxide (PbO_2) combines with the SO_4, forming $PbSO_4$ from the electrolyte and releases its O_2 into the electrolyte, forming H_2O. The negative plate also combines with the SO_4 from the electrolyte and becomes lead sulfate ($PbSO_4$). ● **SEE FIGURE 50–5.**

FULLY DISCHARGED STATE

When the battery is fully discharged, both the positive and the negative plates are $PbSO_4$ (lead sulfate) and the electrolyte has become water (H_2O). As the battery is being discharged, the plates and electrolyte approach the completely discharged state. There is also the danger of freezing when a battery is discharged, because the electrolyte is mostly water.

CAUTION: Never charge or jump start a frozen battery because the hydrogen gas can get trapped in the ice and ignite if a spark is caused during the charging process. The result can be an explosion.

DURING CHARGING

During charging, the sulfate from the acid leaves both the positive and the negative plates and returns to the electrolyte, where it becomes normal-strength sulfuric acid solution. The positive plate returns to lead dioxide (PbO_2), the negative plate is again pure lead (Pb), and the electrolyte becomes H_2SO_4. ● **SEE FIGURE 50–6.**

SPECIFIC GRAVITY

DEFINITION

The amount of sulfate in the electrolyte is determined by the electrolyte's **specific gravity,** which is the ratio of the weight of a given volume of a liquid to the weight of an equal volume of water. In other words, the more dense the liquid is, the higher its

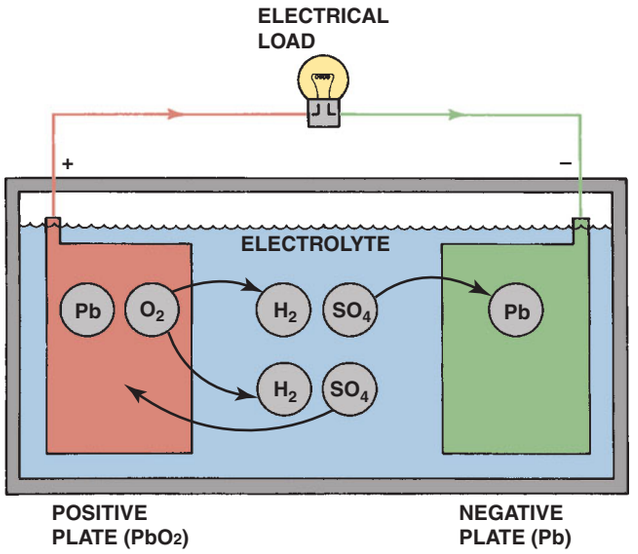


FIGURE 50–5 Chemical reaction for a lead-acid battery that is fully charged being discharged by the attached electrical load.

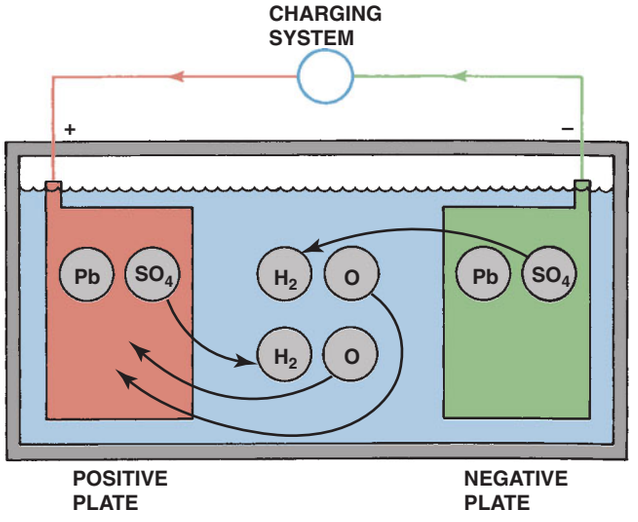


FIGURE 50–6 Chemical reaction for a lead-acid battery that is fully discharged being charged by the attached generator.

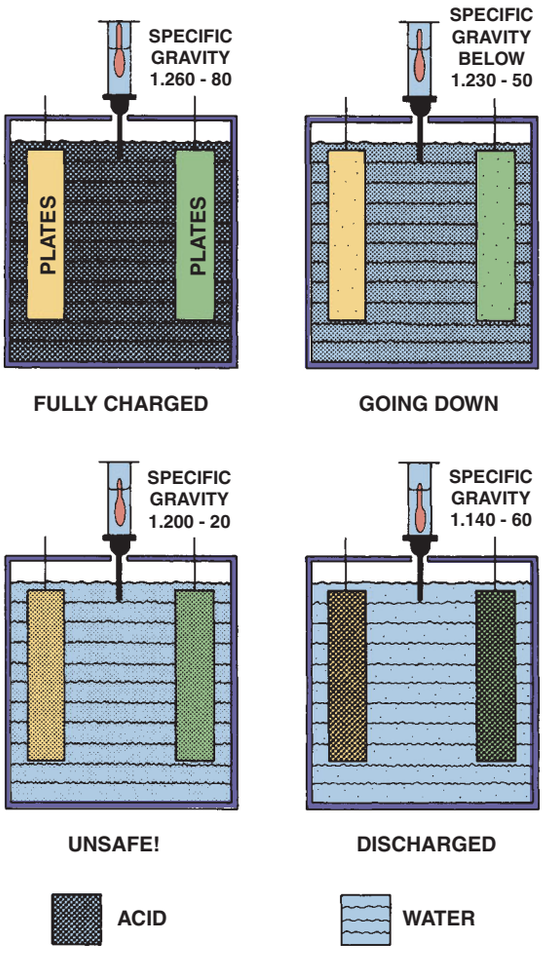


FIGURE 50–7 As the battery becomes discharged, the specific gravity of the battery acid decreases.

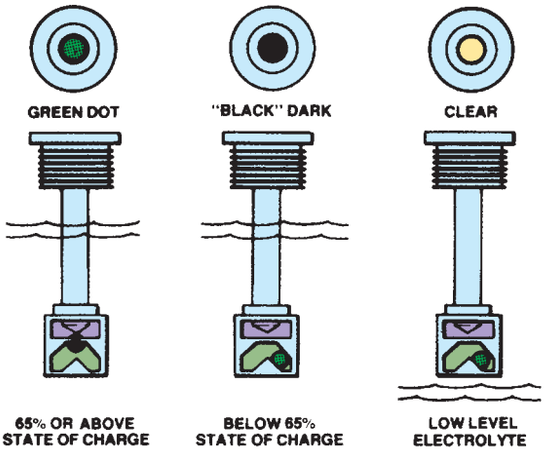


FIGURE 50–8 Typical battery charge indicator. If the specific gravity is low (battery discharged), the ball drops away from the reflective prism. When the battery is charged enough, the ball floats and reflects the color of the ball (usually green) back up through the sight glass and the sight glass is dark.

FREQUENTLY ASKED QUESTION

Is There an Easy Way to Remember How a Battery Works?

Yes. Think of the sulfuric acid solution in the electrolyte being deposited, then removed from the plates.

- **During discharge.** The acid (SO_4) is leaving the electrolyte and getting onto both plates.
- **During charging.** The acid (SO_4) is being forced from both plates and enters the electrolyte.

specific gravity. Pure water is the basis for this measurement and is given a specific gravity of 1.000 at 80°F (27°C). Pure sulfuric acid has a specific gravity of 1.835; the *correct* concentration of water and sulfuric acid (called electrolyte—64% water, 36% acid) is 1.260 to 1.280 at 80°F. The higher the battery's specific gravity, the more fully it is charged. ● **SEE FIGURE 50–7.**

CHARGE INDICATORS Some batteries are equipped with a built-in state-of-charge indicator, commonly called *green eyes.* This indicator is simply a small, ball-type hydrometer that is installed in one cell. This hydrometer uses a plastic ball that floats if the electrolyte density is sufficient (which it is when the battery is about 65% charged). When the ball floats, it appears in the hydrometer's sight glass, changing its color. ● **SEE FIGURE 50–8.**

Because the hydrometer is only testing one cell (out of six on a 12 volt battery), and because the hydrometer ball can easily stick

SPECIFIC GRAVITY	STATE OF CHARGE	BATTERY VOLTAGE (V)
1.265	Fully charged	12.6 or higher
1.225	75% charged	12.4
1.190	50% charged	12.2
1.155	25% charged	12.0
Lower than 1.120	Discharged	11.9 or lower

CHART 50–1

A comparison showing the relationship among specific gravity, battery voltage, and state of charge.

in one position, do not trust that this is accurate information about a state of charge (SOC) of the battery.

Values of specific gravity, state of charge, and battery voltage at 80°F (27°C) are given in ● **CHART 50–1.**

VALVE REGULATED LEAD-ACID BATTERIES

TERMINOLOGY There are two basic types of **valve regulated lead-acid (VRLA),** also called **sealed valve-regulated (SVR)** or **sealed lead-acid (SLA),** batteries. These batteries use a low-pressure venting system that releases excess gas and automatically reseals if a buildup of gas is created due to overcharging. The two types include the following:

- **Absorbed glass mat.** The acid used in an **absorbed glass mat (AGM)** battery is totally absorbed into the separator, making the battery leakproof and spillproof. The battery is assembled by compressing the cell about 20%, then inserting it into the container. The compressed cell helps reduce damage caused by vibration and helps keep the acid tightly against the plates. The sealed maintenance-free design uses a pressure release valve in each cell. Unlike conventional batteries that use a liquid electrolyte, called **flooded cell batteries,** most of the hydrogen and oxygen given off during charging remains inside the battery. The separator or mat is only 90% to 95% saturated with electrolyte, thereby allowing a portion of the mat to be filled with gas. The gas spaces provide channels to allow the hydrogen and oxygen gases to recombine rapidly and safely. Because the acid is totally absorbed into the glass mat separator, an AGM battery can be mounted in any direction. AGM batteries also have a longer service life, often lasting 7 to 10 years. Absorbed glass mat batteries are used as standard equipment in some vehicles such as the Chevrolet Corvette and in most Toyota hybrid electric vehicles. ● **SEE FIGURE 50–9.**
- **Gelled electrolyte batteries.** In a gelled electrolyte battery, silica is added to the electrolyte, which turns the electrolyte into a substance similar to gelatin. This type of battery is also called a **gel battery.**

Both types of valve-regulated, lead-acid batteries are also called **recombinant battery** design. A recombinant-type battery means that the oxygen gas generated at the positive plate travels through the dense electrolyte to the negative plate. When the oxygen reaches the negative plate, it reacts with the lead, which consumes the oxygen gas and prevents the formation of hydrogen gas. It is because of this oxygen recombination that VRLA batteries do not use water.



FIGURE 50–9 An absorbed glass mat battery is totally sealed and is more vibration resistant than conventional lead-acid batteries.

CAUSES AND TYPES OF BATTERY FAILURE

NORMAL LIFE Most automotive batteries have a useful service life of three to seven years; however, proper care can help increase the life of a battery, but abuse can shorten it. The major cause of premature battery failure is overcharging.

CHARGING VOLTAGE The automotive charging circuit, consisting of an alternator and connecting wires, must be operating correctly to prevent damage to the battery.

- Charging voltages higher than 15.5 volts can damage a battery by warping the plates as a result of the heat of overcharging.
- AGM batteries can be damaged if charged at a voltage higher than 14.5 volts.

Overcharging also causes the active plate material to disintegrate and fall out of the supporting grid framework. Vibration or bumping can also cause internal damage similar to that caused by overcharging. It is important, therefore, to ensure that all automotive batteries are securely clamped down in the vehicle. The shorting of cell plates can occur without notice. If one of the six cells of a 12 volt battery is shorted, the resulting voltage of the battery is only 10 volts (12 − 2 = 10). With only 10 volts available, the starter *usually* will not be able to start the engine.

BATTERY HOLD-DOWNS All batteries must be attached securely to the vehicle to prevent battery damage. Normal vehicle vibrations can cause the active materials inside the battery to shed. Battery hold-down clamps or brackets help reduce vibration, which can greatly reduce the capacity and life of any battery. ● **SEE FIGURE 50–10.**

BATTERY RATINGS

Batteries are rated according to the amount of current they can produce under specific conditions.

COLD-CRANKING AMPERES Every automotive battery must be able to supply electrical power to crank the engine in cold weather and still provide battery voltage high enough to operate the ignition



FIGURE 50–10 A typical battery hold-down bracket. All batteries should use a bracket to prevent battery damage due to vibration and shock.



FIGURE 50–11 This battery has a cranking amperes (CA) rating of 1,000. This means that this battery is capable of cranking an engine for 30 seconds at a temperature of 32°F (0°C) at a minimum of 1.2 volts per cell (7.2 volts for a 12 volt battery).

FREQUENTLY ASKED QUESTION

What Determines Battery Capacity?

The capacity of any battery is determined by the amount of active plate material in the battery. A battery with a large number of thin plates can produce high current for a short period. If a few thick plates are used, the battery can produce low current for a long period. A trolling motor battery used for fishing must supply a low current for a long period of time. An automotive battery is required to produce a high current for a short period for cranking. Therefore, every battery is designed for a specific application.

FREQUENTLY ASKED QUESTION

What Is Deep Cycling?

Deep cycling is almost fully discharging a battery and then completely recharging it. Golf cart batteries are an example of lead-acid batteries that must be designed to be deep cycled. A golf cart must be able to cover two 18-hole rounds of golf and then be fully recharged overnight. Charging is hard on batteries because the internal heat generated can cause plate warpage, so these specially designed batteries use thicker plate grids that resist warpage. Normal automotive batteries are not designed for repeated deep cycling.

system for starting. The cold-cranking ampere rating of a battery is the number of amperes that can be supplied by a battery at 0°F (−18°C) for 30 seconds while the battery still maintains a voltage of 1.2 volts per cell or higher. This means that the battery voltage would be 7.2 volts for a 12 volt battery and 3.6 volts for a 6 volt battery. The cold-cranking performance rating is called **cold-cranking amperes (CCA).** Try to purchase a battery with the highest CCA for the money. See the vehicle manufacturer's specifications for recommended battery capacity.

CRANKING AMPERES The designation **CA** refers to the number of amperes that can be supplied by a battery at 32°F (0°C). This rating results in a higher number than the more stringent CCA rating. ● **SEE FIGURE 50–11.**

MARINE CRANKING AMPERES **Marine cranking amperes (MCA)** is similar to cranking amperes and is tested at 32°F (0°C).

RESERVE CAPACITY The **reserve capacity** rating for batteries is *the number of minutes* for which the battery can produce 25 amperes and still have a battery voltage of 1.75 volts per cell (10.5 volts for a 12 volt battery). This rating is actually a measurement of the time for which a vehicle can be driven in the event of a charging system failure.

AMPERE HOUR **Ampere hour** is an older battery rating system that measures how many amperes of current the battery can produce over a period of time. For example, a battery that has a 50 amp-hour (A-H) rating can deliver 50 amperes for one hour or 1 ampere for 50 hours or any combination that equals 50 amp-hours.

BATTERY SIZES

BCI GROUP SIZES Battery sizes are standardized by the **Battery Council International (BCI).** When selecting a replacement battery, check the specified group number in service information, battery application charts at parts stores, or the owner's manual.

TYPICAL GROUP SIZE APPLICATIONS

- **24/24F (top terminals).** Fits many Honda, Acura, Infinity, Lexus, Nissan, and Toyota vehicles.
- **34/78 (dual terminals, both side and top posts).** Fits many General Motors pickups and SUVs, as well as midsize and larger GM sedans and large Chrysler/Dodge vehicles.
- **35 (top terminals).** Fits many Japanese brand vehicles.
- **65 (top terminals).** Fits most large Ford/Mercury passenger cars, trucks, and SUVs.
- **75 (side terminals).** Fits some General Motors small and midsize cars and some Chrysler/Dodge vehicles.
- **78 (side terminals).** Fits many General Motors pickups and SUVs, as well as midsize and larger GM sedans.

Exact dimensions can be found on the Internet by searching for BCI battery sizes.

REVIEW QUESTIONS

1. Why can discharged batteries freeze?
2. What are the battery-rating methods?
3. Why can a battery explode if it is exposed to an open flame or spark?

CHAPTER QUIZ

1. When a battery becomes completely discharged, both positive and negative plates become _____ and the electrolyte becomes _____.
   a. H_2SO_4 / Pb
   b. $PbSO_4$ / H_2O
   c. PbO_2 / H_2SO_4
   d. $PbSO_4$ / H_2SO_4
2. A fully charged 12 volt battery should indicate _____.
   a. 12.6 volts or higher
   b. A specific gravity of 1.265 or higher
   c. 12 volts
   d. Both a and b
3. Deep cycling means _____.
   a. Overcharging the battery
   b. Overfilling or underfilling the battery with water
   c. The battery is fully discharged and then recharged
   d. The battery is overfilled with acid (H_2SO_4)
4. What makes a battery "low maintenance" or "maintenance free"?
   a. Material is used to construct the grids.
   b. The plates are constructed of different metals.
   c. The electrolyte is hydrochloric acid solution.
   d. The battery plates are smaller, making more room for additional electrolytes.
5. The positive battery plate is _____.
   a. Lead dioxide
   b. Brown in color
   c. Sometimes called lead peroxide
   d. All of the above
6. Which battery rating is tested at 0°F (−18°C)?
   a. Cold-cranking amperes (CCA)
   b. Cranking amperes (CA)
   c. Reserve capacity
   d. Battery voltage test
7. Which battery rating is expressed in minutes?
   a. Cold-cranking amperes (CCA)
   b. Cranking amperes (CA)
   c. Reserve capacity
   d. Battery voltage test
8. What battery rating is tested at 32°F (0°C)?
   a. Cold-cranking amperes (CCA)
   b. Cranking amperes (CA)
   c. Reserve capacity
   d. Battery voltage test
9. What gases are released from a battery when it is being charged?
   a. Oxygen
   b. Hydrogen
   c. Nitrogen and oxygen
   d. Hydrogen and oxygen
10. A charge indicator (eye) operates by showing green or red when the battery is charged and dark if the battery is discharged. This charge indicator detects _____.
    a. Battery voltage
    b. Specific gravity
    c. Electrolyte water pH
    d. Internal resistance of the cells

chapter 51

BATTERY TESTING AND SERVICE

OBJECTIVES: **After studying Chapter 51, the reader will be able to:** • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "B" (Battery Diagnosis and Service). • List the precautions necessary when working with batteries. • Explain how to safely charge a battery. • Discuss how to perform a battery drain test. • Describe how to perform a battery load test. • Explain how to conduct a conductance test. • Discuss how to test batteries for open-circuit voltage and specific gravity.

KEY TERMS: Battery electrical drain test 552 • Dynamic voltage 546 • Hydrometer 547 • IOD 552 • Load test 547 • Open circuit voltage 546 • Parasitic load test 552 • Three-minute charge test 548



FIGURE 51–1 A visual inspection on this battery shows the electrolyte level was below the plates in all cells.



FIGURE 51–2 Corrosion on a battery cable could be an indication that the battery itself is either being overcharged or is sulfated, creating a lot of gassing of the electrolyte.

BATTERY SERVICE SAFETY CONSIDERATIONS

HAZARDS Batteries contain acid and release explosive gases (hydrogen and oxygen) during normal charging and discharging cycles.

SAFETY PROCEDURES To help prevent physical injury or damage to the vehicle, always adhere to the following safety procedures.

1. When working on any electrical component on a vehicle, disconnect the negative battery cable from the battery. When the negative cable is disconnected, all electrical circuits in the vehicle will be open, which will prevent accidental electrical contact between an electrical component and ground. Any electrical spark has the potential to cause explosion and personal injury.
2. Wear eye protection (goggles preferred) when working around any battery.
3. Wear protective clothing to avoid skin contact with battery acid.
4. Always adhere to all safety precautions as stated in the service procedures for the equipment used for battery service and testing.
5. Never smoke or use an open flame around any battery.

SYMPTOMS OF A WEAK OR DEFECTIVE BATTERY

The following warning signs indicate that a battery is near the end of its useful life.

- **Uses water in one or more cells.** This indicates that the plates are sulfated and that during the charging process, the water in the electrolyte is being turned into separate hydrogen and oxygen gases. ● **SEE FIGURE 51–1.**
- **Excessive corrosion on battery cables or connections.** Corrosion is more likely to occur if the battery is sulfated, creating hot spots on the plates. When the battery is being charged, the acid fumes are forced out of the vent holes and onto the battery cables, connections, and even on the battery tray underneath the battery. ● **SEE FIGURE 51–2.**
- **Slower than normal engine cranking.** When the capacity of the battery is reduced due to damage or age, it is less likely to be able to supply the necessary current for starting the engine, especially during cold weather.

BATTERY MAINTENANCE

NEED FOR MAINTENANCE Most new-style batteries are of a maintenance-free design that uses lead-calcium instead of lead-antimony plate grid construction. Because lead-calcium batteries do not release as much gas as the older-style, lead-antimony batteries, there is less consumption of water during normal service. Also, with less gassing, less corrosion is observed on the battery terminals, wiring, and support trays. If the electrolyte level can be checked, and if it is low, add only distilled water. Distilled water is recommended by all battery manufacturers, but if distilled water is not available, clean ordinary drinking water, low in mineral content, can be used.

Battery maintenance includes making certain that the battery case is clean and checking that the battery cables and hold-down fasteners are clean and tight.

BATTERY TERMINAL CLEANING Many battery-related faults are caused by poor electrical connections at the battery. Battery cable connections should be checked and cleaned to prevent voltage drop at the connections. One common reason for an engine to not start is loose or corroded battery cable connections. Perform an inspection and check for the following conditions.

- Loose or corroded connections at the battery terminals (should not be able to be moved by hand)
- Loose or corroded connections at the ground connector on the engine block
- Wiring that has been modified to add auxiliary power for a sound system, or other electrical accessory

If the connections are loose or corroded, use 1 tablespoon of baking soda in 1 quart (liter) of water and brush this mixture onto the battery and housing to neutralize the acid. Mechanically clean the connections and wash the area with water. ● **SEE FIGURE 51–3.**

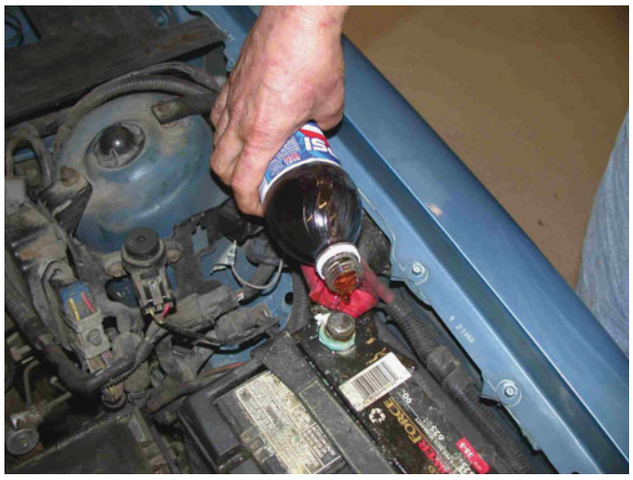


FIGURE 51–3 Besides baking soda and water, a sugar-free diet soft drink can also be used to neutralize the battery acid.

TECH TIP

Dynamic versus Open Circuit Voltage

Open circuit voltage is the voltage (usually of a battery) that exists *without* a load being applied. **Dynamic voltage** is the voltage of the power source (battery) with the circuit in operation. A vehicle battery, for example, may indicate that it has 12.6 volts or more, but that voltage will drop when the battery is put under a load such as cranking the engine. If the battery voltage drops too much, the starter motor will rotate more slowly and the engine may not start.

If the dynamic voltage is lower than specified, the battery may be weak or defective or the circuit may be defective.

BATTERY HOLD-DOWN The battery should also be secured with a hold-down bracket to prevent vibration from damaging the plates inside the battery. The hold-down bracket should be snug enough to prevent battery movement, yet not so tight as to cause the case to crack. Factory-original hold-down brackets are often available through local automobile dealers, and universal hold-down units are available through local automotive parts stores.

BATTERY VOLTAGE TEST

STATE OF CHARGE Testing the battery voltage with a voltmeter is a simple method for determining the state of charge of any battery. ● **SEE FIGURE 51–4.**

The voltage of a battery does not necessarily indicate whether the battery can perform satisfactorily, but it does indicate to the technician more about the battery's condition than a simple visual inspection. A battery that "looks good" may not be good. This test is commonly called an *open circuit battery voltage test* because it is conducted with an open circuit, no current flowing, and no load applied to the battery.

1. If the battery has just been charged or the vehicle has recently been driven, it is necessary to remove the surface charge from the battery before testing. A surface charge is a charge of higher-than-normal voltage that is just on the surface of the battery plates. The surface charge is quickly removed when the battery is loaded and therefore does not accurately represent the true state of charge of the battery.
2. To remove the surface charge, turn the headlights on high beam (brights) for one minute, then turn the headlights off and wait two minutes.



(a)



(b)

FIGURE 51–4 (a) A voltage reading of 12.28 volts indicates that the battery is not fully charged and should be charged before testing. (b) A battery that measures 12.6 volts or higher after the surface charge has been removed is 100% charged.

BATTERY VOLTAGE (V)	STATE OF CHARGE
12.6 or higher	100% charged
12.4	75% charged
12.2	50% charged
12.0	25% charged
11.9 or lower	Discharged

CHART 51–1

The estimated state of charge of a 12 volt battery after the surface charge has been removed.

SPECIFIC GRAVITY	BATTERY VOLTAGE (V)	STATE OF CHARGE
1.265	12.6 or higher	100% charged
1.225	12.4	75% charged
1.190	12.2	50% charged
1.155	12.0	25% charged
Lower than 1.120	11.9 or lower	Discharged

CHART 51–2

Measuring the specific gravity can detect a defective battery. A battery should be at least 75% charged before being load tested.

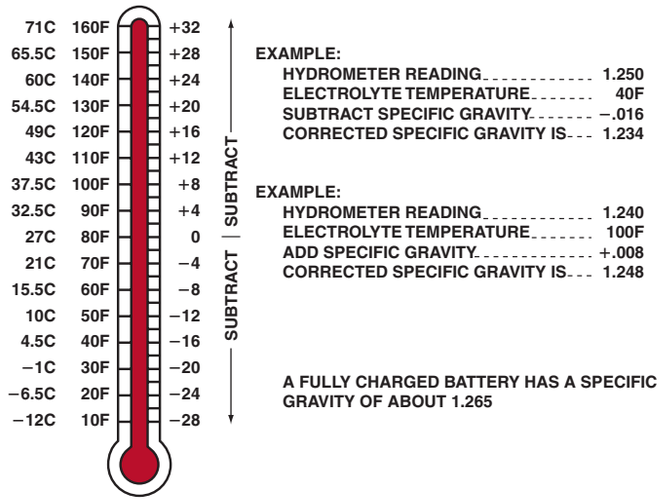


FIGURE 51–5 When testing a battery using a hydrometer, the reading must be corrected if the temperature is above or below 80°F (27°C).



FIGURE 51–6 This battery has cold-cranking amperes (CCA) of 550 A, cranking amperes (CA) of 680 A, and load test amperes of 270 A listed on the top label. Not all batteries have this complete information.

3. With the engine and all electrical accessories off, and the doors shut (to turn off the interior lights), connect a voltmeter to the battery posts. Connect the red positive lead to the positive post and the black negative lead to the negative post.

   NOTE: If the meter reads negative (−), the battery has been reverse charged (has reversed polarity) and should be replaced, or the meter has been connected incorrectly.

4. Read the voltmeter and compare the results with the state of charge. The voltages shown are for a battery at or near room temperature (70°F to 80°F, or 21°C to 27°C). ● **SEE CHART 51–1**.

HYDROMETER TESTING

If the battery has removable filler caps, the specific gravity of the electrolyte can also be checked. A **hydrometer** is a tester that measures the specific gravity. ● **SEE FIGURE 51–5.**

This test can also be performed on most maintenance-free batteries because their filler caps are removable, except for those produced by Delco (Delphi) Battery. The specific gravity test indicates the state of battery charge and can indicate a defective battery if the specific gravity of one or more cells varies by more than 0.050 from the value of the highest-reading cell. ● **SEE CHART 51–2.**

BATTERY LOAD TESTING

TERMINOLOGY One test to determine the condition of any battery is the **load test.** Most automotive starting and charging testers use a carbon pile to create an electrical load on the battery. The amount of the load is determined by the original CCA rating of the battery, which should be at least 75% charged before performing a load test. The capacity is measured in cold-cranking amperes, which is the number of amperes that a battery can supply at 0°F (−18°C) for 30 seconds.

TEST PROCEDURE To perform a battery load test, take the following steps.

STEP 1 **Determine the CCA rating of the battery.** The proper electrical load used to test a battery is half of the CCA rating or three times the ampere-hour rating, with a minimum 150 ampere load. ● **SEE FIGURE 51–6.**

STEP 2 **Connect the load tester to the battery.** Follow the instructions for the tester being used.

STEP 3 **Apply the load for a full 15 seconds.** Observe the voltmeter during the load testing and check the voltage at the end of the 15 sec. period while the battery is still under load. A good battery should indicate above 9.6 V.



FIGURE 51–7 An alternator regulator battery starter tester (ARBST) automatically loads the battery with a fixed load for 15 sec. to remove the surface charge, then removes the load for 30 sec. to allow the battery to recover, and then reapplies the load for another 15 sec. The results of the test are then displayed.

FREQUENTLY ASKED QUESTION

What Is the Three-Minute Charge Test?

A **three-minute charge test** is used to check if a battery is sulfated, and is performed as follows:

- Connect a battery charger and a voltmeter to the battery terminals.
- Charge the battery at a rate of 40 amperes for three minutes.
- At the end of three minutes, read the voltmeter.

Results: If the voltage is above 15.5 volts, replace the battery. If the voltage is below 15.5 volts, the battery is not sulfated and should be charged and retested.

This is *not* a valid test of many maintenance-free batteries, such as the Delphi Freedom. Due to the high internal resistance, a discharged Delphi Freedom battery may not start to accept a charge for several hours. Always use another alternative battery test before discarding a battery based on the results of the three-minute charge test.

STEP 4 **Repeat the test.** Many battery manufacturers recommend performing the load test twice, using the first load period to remove the surface charge on the battery and the second test to provide a truer indication of the condition of the battery. Wait 30 seconds between tests to allow time for the battery to recover. ● **SEE FIGURE 51–7.**

Results: If the battery fails the load test, recharge the battery and retest. If the load test is failed again, replacement of the battery is required.

ELECTRONIC CONDUCTANCE TESTING

TERMINOLOGY General Motors Corporation, Chrysler Corporation, and Ford specify that an electronic conductance tester be used to test batteries in vehicles still under factory warranty. Conductance is a measure of how well a battery can create current. This tester sends a small signal through the battery and then measures a part of the AC response. As a battery ages, the plates can become sulfated and shed active materials from the grids, reducing the battery capacity. Conductance testers can be used to test flooded or absorbed glass (AGM) type batteries. The unit can determine the following information about a battery.

- CCA
- State of charge
- Voltage of the battery
- Defects such as shorts and opens

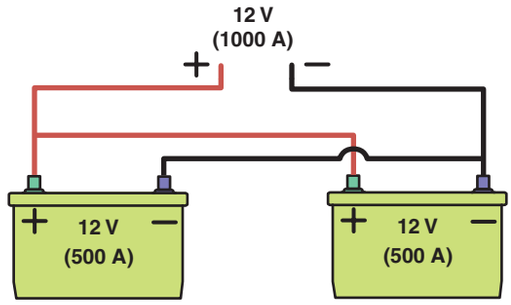


FIGURE 51–8 Most light-duty vehicles equipped with two batteries are connected in parallel as shown. Two 500 A, 12 volt batteries are capable of supplying 1,000 A at 12 volts, which is needed to start many diesel engines.

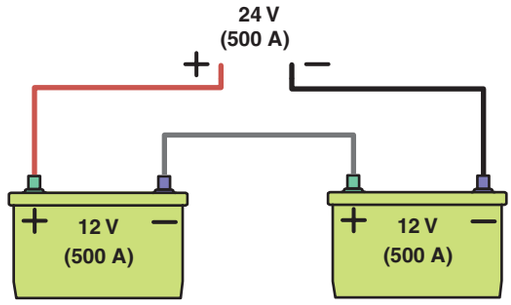


FIGURE 51–9 Many heavy-duty trucks and buses use two 12 volt batteries connected in series to provide 24 volts.

FREQUENTLY ASKED QUESTION

How Should You Test a Vehicle Equipped with Two Batteries?

Many vehicles equipped with a diesel engine use two batteries. These batteries are usually electrically connected in parallel to provide additional current (amperes) at the same voltage. ● **SEE FIGURE 51–8.**

Some heavy-duty trucks and buses connect two batteries in series to provide about the same current as one battery, but with twice the voltage, as shown in ● **FIGURE 51–9.**

To successfully test the batteries, they should be disconnected and tested separately. If just one battery is found to be defective, most experts recommend that both be replaced to help prevent future problems. Because the two batteries are electrically connected, a fault in one battery can cause the good battery to discharge into the defective battery, thereby affecting both even if just one battery is at fault.

However, a conductance tester is not designed to accurately determine the state of charge or CCA rating of a new battery. Unlike a battery load test, a conductance tester can be used on a battery that is discharged. This type of tester should only be used to test batteries that have been in service. ● **SEE FIGURE 51–10.**

TEST PROCEDURE

STEP 1 Connect the unit to the positive and negative terminals of the battery. If testing a side post battery, always use the lead adapters and *never* use steel bolts as these can cause an incorrect reading.

NOTE: Test results can be incorrectly reported on the display if proper, clean connections to the battery are not made. Also be sure that all accessories and the ignition switch are in the off position.

STEP 2 Enter the CCA rating (if known) and push the arrow keys.

STEP 3 The tester determines and displays one of the following:

- **Good battery.** The battery can return to service.
- **Charge and retest.** Fully recharge the battery and return it to service.
- **Replace the battery.** The battery is not serviceable and should be replaced.
- **Bad cell—replace.** The battery is not serviceable and should be replaced.

Some conductance testers can check the charging and cranking circuits, too.



FIGURE 51–10 A conductance tester is very easy to use and has proved to accurately determine battery condition if the connections are properly made. Follow the instructions on the display exactly for best results.

BATTERY CHARGING

CHARGING PROCEDURE

If the state of charge of a battery is low, it must be recharged. It is best to slow charge any battery to prevent possible overheating damage to the battery. Perform the following steps.

STEP 1 **Determine the charge rate.** The charge rate is based on the current state of charge (SOC) and charging rate. ● **SEE CHART 51–3** for the recommended charging rate.

STEP 2 **Connect a battery charger to the battery.** Be sure the charger is not plugged in when connecting a charger to a

SAFETY TIP

Never Charge or Jump Start a Frozen Battery

A discharged battery can freeze because the electrolyte becomes mostly water. Never attempt to charge or jump start a vehicle that has a frozen battery. When the battery freezes, it often bulges at the sides because water expands about 9% when it freezes, forming ice crystals that occupy more space than liquid water. The crystals can trap bubbles of hydrogen and oxygen that are created during the chemical processes in a battery. When attempting to charge or jump start the frozen battery, these pockets of gases can explode. Because the electrolyte expands, the freezing action usually destroys the plates and can loosen the active material from the grids. It is rare for a frozen battery to be restored to useful service.

OPEN CIRCUIT VOLTAGE	BATTERY SPECIFIC GRAVITY*	STATE OF CHARGE	CHARGING TIME TO FULL CHARGE AT 80°F**					
			at 60 amps	at 50 amps	at 40 amps	at 30 amps	at 20 amps	at 10 amps
12.6	1.265	100%	FULL CHARGE					
12.4	1.225	75%	15 min.	20 min.	27 min.	35 min.	48 min.	90 min.
12.2	1.190	50%	35 min.	45 min.	55 min.	75 min.	95 min.	180 min.
12.0	1.155	25%	50 min.	65 min.	85 min.	115 min.	145 min.	260 min.
11.8	1.120	0%	65 min.	85 min.	110 min.	150 min.	195 min.	370 min.

CHART 51–3

Battery charging guideline showing the charging times that vary according to state of charge, temperature, and charging rate. It may take eight hours or more to charge a fully discharged battery.
*Correct for temperature
**If colder, it'll take longer



FIGURE 51–11 A typical industrial battery charger. Be sure that the ignition switch is in the off position before connecting any battery charger. Connect the cables of the charger to the battery before plugging the charger into the outlet. This helps prevent a voltage spike and spark that could occur if the charger happened to be accidentally left on. Always follow the battery charger manufacturer's instructions.

battery. Always follow the battery charger's instructions for proper use.

STEP 3 **Set the charging rate.** The initial charge rate should be about 35 A for 30 minutes to help start the charging process. Fast charging a battery increases the temperature of the battery and can cause warping of the plates inside the battery. Fast charging also increases the amount of gassing (release of hydrogen and oxygen), which can create a health and fire hazard. The battery temperature should not exceed 125°F (hot to the touch).

- Fast charge: 15 A maximum
- Slow charge: 5 A maximum

● **SEE FIGURE 51–11.**

CHARGING AGM BATTERIES Charging an absorbed glass mat (AGM) battery requires a different charger than is used to recharge a flooded-type battery. The differences include:

- The AGM can be charged with high current, up to 75% of the ampere-hour rating due to lower internal resistance.
- The charging voltage has to be kept at or below 14.4 volts to prevent damage.

Because most conventional battery chargers use a charging voltage of 16 volts or higher, a charger specifically designed to charge AGM batteries must be used.

Absorbed glass mat batteries are often used as auxiliary batteries in hybrid electric vehicles when the battery is located inside the vehicle. ● **SEE CHART 51–4** for a summary of the locations of the 12 volt auxiliary battery and high-voltage battery and safety switch/plug.

TECH TIP

Charge Batteries at 1% of Their CCA Rating

Many batteries are damaged due to being overcharged. To help prevent damage such as warped plates and excessive release of sulfur smell gases, charge batteries at a rate equal to 1% of the battery's CCA rating. For example, a battery with a 700 CCA rating should be charged at 7 amperes (700 × 0.01 = 7 amperes). No harm will occur to the battery at this charge rate even though it may take longer to achieve a full charge. This means that a battery may require eight or more hours to become fully charged depending on the battery capacity and state of charge (SOC).

TECH TIP

Always Use Adapters on Side Post Batteries

Side post batteries require that an adapter be used when charging the battery, if it is removed from the vehicle. Do not use steel bolts. If a bolt is threaded into the terminal, only the parts of the threads that contact the battery terminal will be conducting all of the charging current. An adapter or a bolt with a nut attached is needed to achieve full contact with the battery terminals. ● **SEE FIGURE 51–12.**

BATTERY CHARGE TIME

The time needed to charge a completely discharged battery can be estimated by using the reserve capacity rating of the battery in minutes divided by the charging rate.

Hours needed to charge the battery =
Reserve capacity ÷ Charge current

For example, if a 10 A charge rate is applied to a discharged battery that has a 90-minute reserve capacity, the time needed to charge the battery will be nine hours.

90 minutes ÷ 10 A = 9 hours

JUMP STARTING

To jump start another vehicle with a dead battery, connect good-quality copper jumper cables or a jump box to the good battery and the dead battery, as shown in ● **FIGURE 51–13.**

When using jumper cables or a battery jump box, the last connection made should always be on the engine block or an engine bracket on the dead vehicle as far from the battery as possible. ● **SEE FIGURE 51–14.**

It is normal for a spark to be created when the jumper cables finally complete the jumping circuit, and this spark could cause an explosion of the gases around the battery. Many newer vehicles have special ground and/or positive power connections built away from the battery just for the purpose of jump starting. Check the owner's manual or service information for the exact location.

MAKE, MODEL (YEARS)	AUXILIARY 12 V BATTERY LOCATION	HV BATTERY PACK LOCATION (VOLTAGE)	TYPE OF 12 V BATTERY
Cadillac Escalade (2008+) (two mode)	Under the hood; driver's side	Under second row seat (300 volts)	Flooded lead-acid
Chevrolet Malibu (2008+)	Under the hood; driver's side	Mounted behind rear seat under vehicle floor (36 volts)	Flooded lead-acid
Chevrolet Silverado (2004–2008) (PHT)	Under the hood; driver's side	Under second row seat (42 volts)	Flooded lead-acid
Chevrolet Tahoe (two mode)	Under the hood; driver's side	Under second row seat (300 volts)	Flooded lead-acid
Chrysler Aspen (2009)	Under driver's side door, under vehicle	Under rear seat; driver's side (288 volts)	Flooded lead-acid
Dodge Durango (2009)	Under driver's side door, under vehicle	Under rear seat; driver's side (288 volts)	Flooded lead-acid
Ford Escape (2005+)	Under the hood; driver's side	Cargo area in the rear under carpet (300 volts)	Flooded lead-acid
GMC Sierra (2004–2008) (PHT)	Under the hood; driver's side	Under second row seat (42 volts)	Flooded lead-acid
GMC Yukon (2008+) (two mode)	Under the hood; driver's side	Under second row seat (300 volts)	Flooded lead-acid
Honda Accord (2005–2007)	Under the hood; driver's side	Behind rear seat (144 volts)	Flooded lead-acid
Honda Civic (2003+)	Under the hood; driver's side	Behind rear seat (144 to 158 volts, 2006+)	Flooded lead-acid
Honda Insight (1999–2005)	Under the hood; center under windshield	144 volts; under hatch floor in the rear	Flooded lead-acid
Honda Insight (2010+)	Under the hood; driver's side	144 volts; under floor behind rear seat	Flooded lead-acid
Lexus GS450h (2007+)	In the trunk; driver's side, behind interior panel	Trunk behind rear seat (288 volts)	Absorbed glass mat (AGM)
Lexus LS 600h (2006+)	In the trunk; driver's side, behind interior panel	Trunk behind rear seat (288 volts)	Absorbed glass mat (AGM)
Lexus RX400h (2006–2009)	Under the hood; passenger side	Under the second row seat (288 volts)	Flooded lead-acid
Mercury Mariner (2005+)	Under the hood; driver's side	Cargo area in the rear under carpet (300 volts)	Flooded lead-acid
Nissan Altima (2007+)	In the trunk; driver's side	Behind rear seat (245 volts)	Absorbed glass mat (AGM)
Saturn AURA Hybrid (2007+)	Under the hood; driver's side	Behind the rear seat; under the vehicle floor (36 volts)	Flooded lead-acid
Saturn VUE Hybrid (2007+)	Under the hood; driver's side	Behind the rear seat; under the vehicle floor (36 volts)	Flooded lead-acid
Toyota Camry Hybrid (2007+)	In the trunk; passenger side	Behind the rear seat; under the vehicle floor (245 volts)	Absorbed glass mat (AGM)
Toyota Highlander Hybrid (2006–2009)	Under the hood; passenger side	Under the second row seat (288 volts)	Flooded lead-acid
Toyota Prius (2001–2003)	In the trunk; driver's side	Behind rear seat (274 volts)	Absorbed glass mat (AGM)
Toyota Prius (2004–2009)	In the trunk; driver's side	Behind rear seat (201 volts)	Absorbed glass mat (AGM)
Toyota Prius (2010+)	In the trunk; driver's side	Behind rear seat (201.6 volts)	Absorbed glass mat (AGM)

CHART 51–4

A summary chart showing where the 12 volt and high-voltage batteries and shut-off switch/plugs are located. Only the auxiliary 12 volt batteries can be serviced or charged.

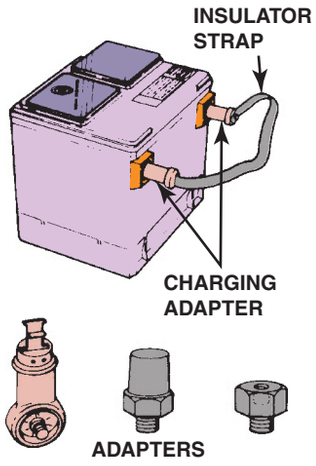


FIGURE 51–12 Adapters should be used on side terminal batteries whenever charging.



FIGURE 51–13 A typical battery jump box used to jump start vehicles. These hand-portable units have almost made jumper cables obsolete.

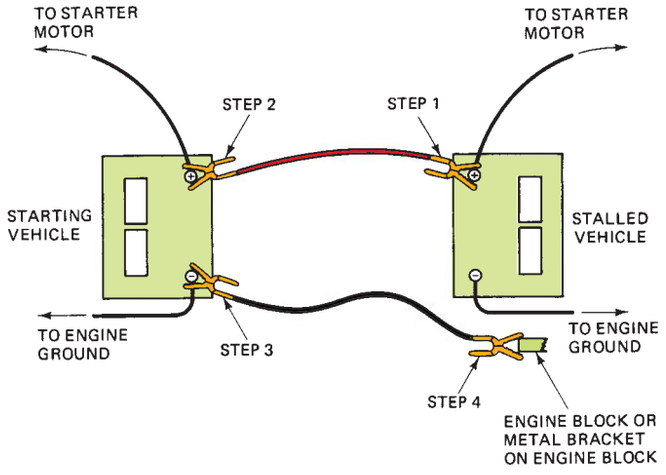


FIGURE 51–14 Jumper cable usage guide. Notice that the last connection should be the engine block of the disabled vehicle to help prevent the spark that normally occurs from igniting the gases from the battery.

FREQUENTLY ASKED QUESTION

Should Batteries Be Kept Off of Concrete Floors?

All batteries should be stored in a cool, dry place when not in use. Many technicians have been warned not to store or place a battery on concrete. According to battery experts, it is the temperature difference between the top and the bottom of the battery that causes a difference in the voltage potential between the top (warmer section) and the bottom (colder section). It is this difference in temperature that causes self-discharge to occur.

In fact, submarines cycle seawater around their batteries to keep all sections of the battery at the same temperature to help prevent self-discharge.

Therefore, always store or place batteries up off the floor and in a location where the entire battery can be kept at the same temperature, avoiding extreme heat and freezing temperatures. Concrete cannot drain the battery directly because the case of the battery is a very good electrical insulator.

TECH TIP

Look at the Battery Date Code

All major battery manufacturers stamp codes on the battery case that give the date of manufacture and other information. Most battery manufacturers use a number to indicate the year of manufacture and a letter to indicate the month of manufacture, except the letter I, because it can be confused with the number 1. For example:

A = January	G = July
B = February	H = August
C = March	J = September
D = April	K = October
E = May	L = November
F = June	M = December

The shipping date from the manufacturing plant is usually indicated by a *sticker* on the end of the battery. Almost every battery manufacturer uses just one letter and one number to indicate the month and year. ● **SEE FIGURE 51–15.**

BATTERY ELECTRICAL DRAIN TEST

TERMINOLOGY The **battery electrical drain test** determines if any component or circuit in a vehicle is causing a drain on the battery when everything is off. This test is also called the **ignition off draw (IOD)** or **parasitic load test.**

Many electronic components draw a continuous, slight amount of current from the battery when the ignition is off. These components include:

1. Electronically tuned radios for station memory and clock circuits
2. Computers and controllers, through slight diode leakage
3. The alternator, through slight diode leakage

These components may cause a voltmeter to read full battery voltage if it is connected between the negative battery terminal and the removed end of the negative battery cable. Because of



FIGURE 51–15 The code on the Delphi battery indicates that it was built in 2005 (5), in February (B), on the eleventh day (11), during third shift (C), and in the Canadian plant (Z).



FIGURE 51–16 This mini clamp-on digital multimeter is being used to measure the amount of battery electrical drain that is present. In this case, a reading of 20 mA (displayed on the meter as 00.02 A) is within the normal range of 20 to 30 mA. Be sure to clamp around all of the positive battery cable or all of the negative battery cable, whichever is easiest to get the clamp around.

this fact, voltmeters should not be used for battery drain testing. This test should be performed when one of the following conditions exists.

1. When a battery is being charged or replaced (a battery drain could have been the cause for charging or replacing the battery)
2. When the battery is suspected of being drained

PROCEDURE FOR BATTERY ELECTRICAL DRAIN TEST

- **Inductive DC ammeter.** The fastest and easiest method to measure battery electrical drain is to connect an inductive DC ammeter that is capable of measuring low current (10 mA). ● **SEE FIGURE 51–16** for an example of a clamp-on digital multimeter being used to measure battery drain.
- **DMM set to read milliamperes.** Following is the procedure for performing the battery electrical drain test using a DMM set to read DC amperes.

STEP 1 Make certain that all lights, accessories, and ignition are off.

STEP 2 Check all vehicle doors to be certain that the interior courtesy (dome) lights are off.

STEP 3 Disconnect the *negative* (−) battery cable and install a parasitic load tool, as shown in ● **FIGURE 51–17**.

STEP 4 Start the engine and drive the vehicle about 10 minutes, being sure to turn on all the lights and accessories including the radio.

STEP 5 Turn the engine and all accessories off including the underhood light.

STEP 6 Connect an ammeter across the parasitic load tool switch and wait 20 minutes for all computers and circuits to shut down.

STEP 7 Open the switch on the load tool and read the battery electrical drain on the meter display.

NOTE: Using a voltmeter or test light to measure battery drain is *not* recommended by most vehicle manufacturers. The high internal resistance of the voltmeter results in an irrelevant reading that does not provide the technician with adequate information about a problem.



FIGURE 51–17 After connecting the shut-off tool, start the engine and operate all accessories. Stop the engine and turn off everything. Connect the ammeter across the shut-off switch in parallel. Wait 20 minutes. This time allows all electronic circuits to "time out" or shut down. Open the switch—all current now will flow through the ammeter. A reading greater than specified (usually greater than 50 mA, or 0.05 A) indicates a problem that should be corrected.

SPECIFICATIONS

Results:

- Normal = 20 to 30 mA (0.02 to 0.03 A)
- Maximum allowable = 50 mA (0.05 A)

RESET ALL MEMORY FUNCTIONS

Be sure to reset the clock, "auto up" windows, and antitheft radio if equipped. ● **SEE FIGURE 51–18.**

BATTERY DRAIN AND RESERVE CAPACITY

It is normal for a battery to self-discharge even if there is not an electrical load such as computer memory to drain the battery. According to General Motors, this self-discharge is about 13 mA (0.013 A).

Some vehicle manufacturers specify a maximum allowable parasitic draw or battery drain be based on the reserve capacity of the battery. The calculation used is the reserve capacity of the battery divided by 4; this equals the maximum allowable battery drain.



FIGURE 51–18 The battery was replaced in this Acura and the radio displayed "code" when the replacement battery was installed. Thankfully, the owner had the five-digit code required to unlock the radio.

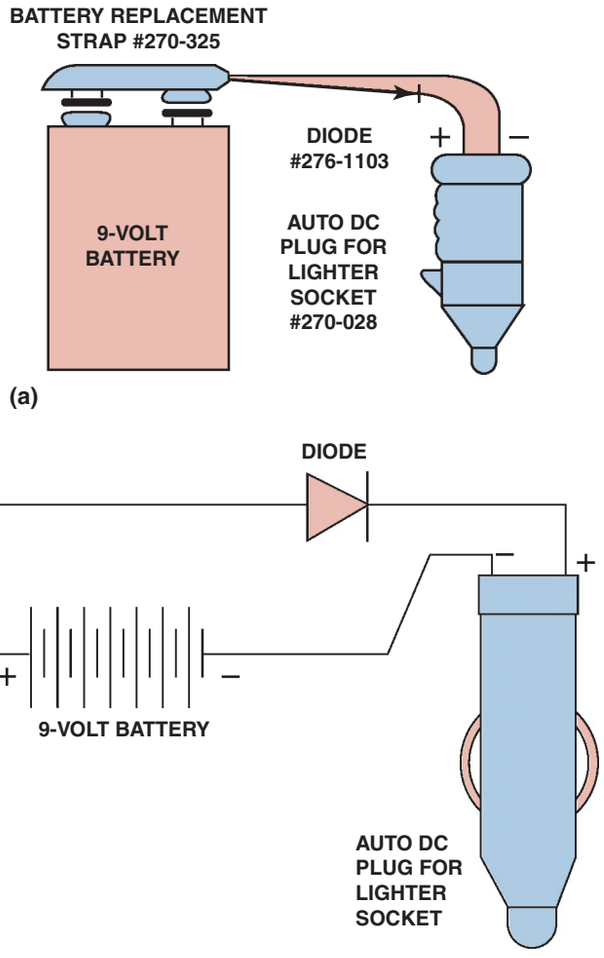


FIGURE 51–19 (a) Memory saver. The part numbers represent components from Radio Shack. (b) A schematic drawing of the same memory saver. Some experts recommend using a 12 volt lantern battery instead of a small 9 volt battery to help ensure that there will be enough voltage in the event that a door is opened while the vehicle battery is disconnected. Interior lights could quickly drain a small 9 volt battery.

REAL WORLD FIX

The Chevrolet Battery Story

A 2005 Chevrolet Impala was being diagnosed for a dead battery. Testing for a battery drain (parasitic draw) showed 2.25 A, which was clearly over the acceptable value of 0.050 or less. At the suggestion of the shop foreman, the technician used a Tech 2 scan tool to check if all of the computers and modules went to sleep after the ignition was turned off. The scan tool display indicated that the instrument panel (IP) showed that it remained awake after all of the others had gone into sleep mode. The IP cluster was unplugged and the vehicle was tested for an electrical drain again. This time, it was only 32 mA (0.032 A), well within the normal range. Replacing the IP cluster solved the excessive battery drain.

For example, a battery rated at 120 minutes reserve capacity should have a maximum battery drain of 30 mA.

120 minutes reserve capacity ÷ 4 = 30 mA

FINDING THE SOURCE OF THE DRAIN If there is a drain, check and temporarily disconnect the following components.

1. Underhood light
2. Glove compartment light
3. Trunk light

If after disconnecting these three components the battery drain draws more than 50 mA (0.05 A), disconnect one fuse at a time from the fuse box until the excessive drain drops to normal.

NOTE: Do not reinsert fuses after they have been removed as this action can cause modules to "wake up," leading to an inconclusive test.

If the excessive battery drain stops after one fuse is disconnected, the source of the drain is located in that particular circuit, as labeled on the fuse box. Continue to disconnect the *power-side* wire connectors from each component included in that particular circuit until the test light goes off. The source of the battery drain can then be traced to an individual component or part of one circuit.

TECH TIP

It Could Happen to You!

The owner of a Toyota replaced the battery. After doing so, the owner noted that the "airbag" amber warning lamp was lit and the radio was locked out. The owner had purchased the vehicle used and did not know the four-digit security code needed to unlock the radio. Determined to fix the problem, the owner tried three four-digit numbers, hoping that one of them would work. However, after three tries, the radio became permanently disabled.

Frustrated, the owner went to a dealer. It cost over $300 to fix the problem. A special tool was required to easily reset the airbag lamp. The radio had to be removed and sent out of state to an authorized radio service center and then reinstalled into the vehicle.

Therefore, before disconnecting the battery, check to be certain that the owner has the security code for a security-type radio. A "memory saver" may be needed to keep the radio powered up when the battery is being disconnected. ● **SEE FIGURE 51–19.**



FIGURE 51–20 Many newer vehicles have batteries that are sometimes difficult to find. Some are located under plastic panels under the hood, under the front fender, or even under the rear seat as shown here.

? FREQUENTLY ASKED QUESTION

Where Is the Battery?

Many vehicle manufacturers today place the battery under the backseat, under the front fender, or in the trunk. **SEE FIGURE 51–20.**

Often, the battery is not visible even if it is located under the hood. When testing or jump starting a vehicle, look for a battery access point.

WHAT TO DO IF A BATTERY DRAIN STILL EXISTS

If all the fuses have been disconnected and the drain still exists, the source of the drain has to be between the battery and the fuse box. The most common sources of drain under the hood include the following:

1. **The alternator.** Disconnect the alternator wires and retest. If the ammeter now reads a normal drain, the problem is a defective diode(s) in the alternator.
2. **The starter solenoid (relay) or wiring near its components.** These are also a common source of battery drain, due to high current flows and heat, which can damage the wire or insulation.

TECH TIP

Check the Battery Condition First

A discharged or defective battery has lower voltage potential than a good battery that is at least 75% charged. This lower battery voltage cannot properly power the starter motor. A weak battery could also prevent the charging voltage from reaching the voltage regulator cutoff point. This lower voltage could be interpreted as indicating a defective alternator and/or voltage regulator. If the vehicle continues to operate with low system voltage, the stator winding in the alternator can be overheated, causing alternator failure.

BATTERY SYMPTOM GUIDE

The following list will assist technicians in troubleshooting batteries.

Problem	Possible Causes and/or Solutions
1. Headlights are dimmer than normal.	1. Discharged battery or poor connections on the battery, engine, or body
2. Solenoid clicks.	2. Discharged battery or poor connections on the battery or an engine fault, such as coolant on top of the pistons, causing a hydrostatic lock
3. Engine is slow in cranking.	3. Discharged battery, high-resistance battery cables, or defective starter or solenoid
4. Battery will not accept a charge.	4. Possible loose battery cable connections (If the battery is a maintenance-free type, attempt to fast charge the battery for several hours. If the battery still will not accept a charge, replace the battery.)
5. Battery is using water.	5. Check charging system for too high a voltage (If the voltage is normal, the battery is showing signs of gradual failure. Load test and replace the battery, if necessary.)

REVIEW QUESTIONS

1. What are the results of a voltmeter test of a battery and its state of charge?
2. What are the steps for performing a battery load test?
3. How is a battery drain test performed?
4. Why should a battery not be fast charged?

CHAPTER QUIZ

1. Technician A says that distilled or clean drinking water should be added to a battery when the electrolyte level is low. Technician B says that fresh electrolyte (solution of acid and water) should be added. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. All batteries should be in a secure bracket that is bolted to the vehicle to prevent physical damage to the battery.
   a. True
   b. False

3. A battery date code sticker indicates D6. What does this mean?
   a. The date it was shipped from the factory was December 2006.
   b. The date it was shipped from the factory was April 2006.
   c. The battery expires in December 2002.
   d. It was built the second day of the week (Tuesday).
4. Many vehicle manufacturers recommend that a special electrical connector be installed between the battery and the battery cable when testing for _____.
   a. Battery drain (parasitic drain)
   b. Specific gravity
   c. Battery voltage
   d. Battery charge rate
5. When load testing a battery, which battery rating is often used to determine how much load to apply to the battery?
   a. CA
   b. RC
   c. MCA
   d. CCA
6. When measuring the specific gravity of the electrolyte, the maximum allowable difference between the highest and lowest hydrometer reading is _____.
   a. 0.010
   b. 0.020
   c. 0.050
   d. 0.50
7. A battery high-rate discharge (load capacity) test is being performed on a 12 volt battery. Technician A says that a good battery should have a voltage reading of higher than 9.6 volts while under load at the end of the 15 sec. test. Technician B says that the battery should be discharged (loaded) to twice its CCA rating. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. When charging a lead-acid (flooded-type) battery, _____.
   a. The initial charging rate should be about 35 amperes for 30 minutes
   b. The battery may not accept a charge for several hours, yet may still be a good (serviceable) battery
   c. The battery temperature should not exceed 125°F (hot to the touch)
   d. All of the above
9. Normal battery drain (parasitic drain) in a vehicle with many computer and electronic circuits is _____.
   a. 20 to 30 milliamperes
   b. 2 to 3 amperes
   c. 150 to 300 milliamperes
   d. None of the above
10. When jump starting, _____.
   a. The last connection should be the positive post of the dead battery
   b. The last connection should be the engine block of the dead vehicle
   c. The alternator must be disconnected on both vehicles
   d. Both a and c

chapter 52 CRANKING SYSTEM

OBJECTIVES: After studying Chapter 52, the reader will be able to: • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "C" (Starting System Diagnosis and Repair). • Describe how the cranking circuit works. • Discuss how a starter motor converts electrical power into mechanical power. • Describe the hold-in and pull-in windings of a starter solenoid.

KEY TERMS: Armature 560 • Brush-end housing 560 • Brushes 561 • CEMF 559 • Commutator-end housing 560 • Commutator segments 561 • Compression spring 563 • Drive-end housing 560 • Field coils 560 • Field housing 560 • Field poles 560 • Ground brushes 561 • Hold-in winding 564 • Insulated brushes 561 • Mesh spring 563 • Neutral safety switch 557 • Overrunning clutch 563 • PM starter 560 • Pole shoes 560 • Pull-in winding 564 • RVS 558 • Starter drive 562 • Starter solenoid 564 • Through bolts 560

CRANKING CIRCUIT

PARTS INVOLVED For any engine to start, it must first be rotated using an external power source. It is the purpose and function of the cranking circuit to create the necessary power and transfer it from the battery to the starter motor, which rotates the engine.

The cranking circuit includes those mechanical and electrical components required to crank the engine for starting. The cranking force in the early 1900s was the driver's arm, because the driver had to physically crank the engine until it started. Modern cranking circuits include the following:

1. **Starter motor.** The starter is normally a 0.5 to 2.6 horsepower (0.4 to 2 kilowatts) electric motor that can develop nearly 8 horsepower (6 kilowatts) for a very short time when first cranking a cold engine. ● **SEE FIGURE 52–1.**
2. **Battery.** The battery must be of the correct capacity and be at least 75% charged to provide the necessary current and voltage for correct starter operation.

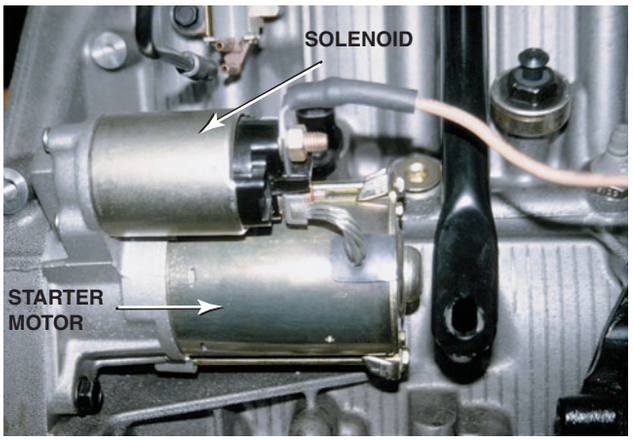


FIGURE 52–1 A typical solenoid-operated starter.

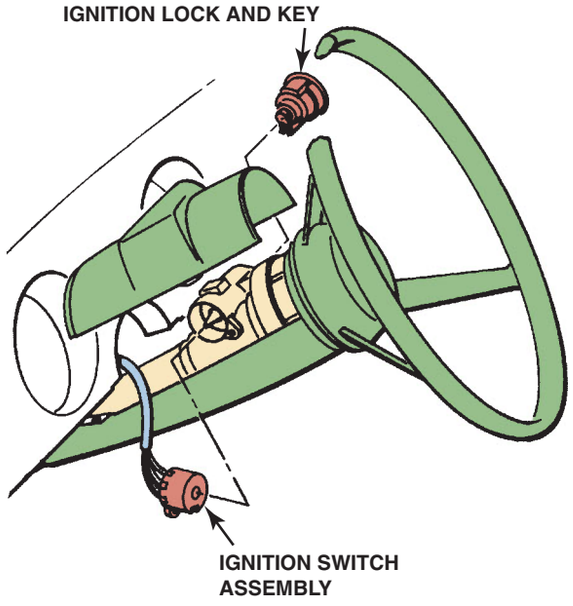


FIGURE 52–2 Some column-mounted ignition switches act directly on the electrical ignition switch itself, whereas others use a link from the lock cylinder to the ignition switch.

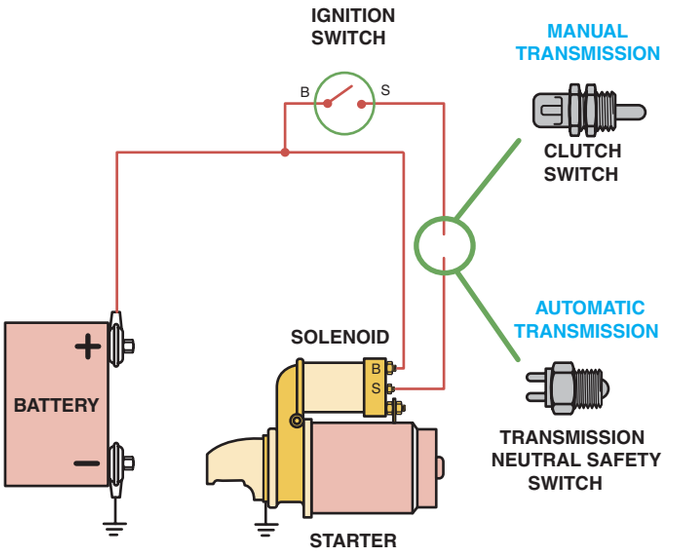


FIGURE 52–3 To prevent the engine from cranking, an electrical switch is usually installed to open the circuit between the ignition switch and the starter solenoid.

3. **Starter solenoid or relay.** The high current required by the starter must be able to be turned on and off. A large switch would be required if the current were controlled by the driver directly. Instead, a small current switch (ignition switch) operates a solenoid or relay that controls the high current to the starter.
4. **Starter drive.** The starter drive uses a small pinion gear that contacts the engine flywheel gear teeth and transmits starter motor power to rotate the engine.
5. **Ignition switch.** The ignition switch and safety control switches control the starter motor operation. ● **SEE FIGURE 52–2.**

CONTROL CIRCUIT PARTS AND OPERATION The engine is cranked by an electric motor that is controlled by a key-operated ignition switch. The ignition switch will not operate the starter unless the automatic transmission is in neutral or park, or the clutch pedal is depressed on manual transmission/transaxle vehicles. This is to prevent an accident that might result from the vehicle moving forward or rearward when the engine is started. The types of controls that are used to be sure that the vehicle will not move when being cranked include the following:

- Many automobile manufacturers use an electric switch called a **neutral safety switch,** which opens the circuit between the ignition switch and the starter to prevent starter motor operation, unless the gear selector is in neutral or park. The safety switch can be attached either to the steering column inside the vehicle near the floor or on the side of the transmission.
- Many manufacturers use a mechanical blocking device in the steering column to prevent the driver from turning the key switch to the start position unless the gear selector is in neutral or park.
- Many manual transmission vehicles also use a safety switch to permit cranking only if the clutch is depressed. This switch is commonly called the *clutch safety switch.* ● **SEE FIGURE 52–3**.

COMPUTER-CONTROLLED STARTING

OPERATION Some key-operated ignition systems and most push-button-to-start systems use the computer to crank the engine. The ignition switch start position on the push-to-start button is used as an input signal to the powertrain control module (PCM). Before the PCM cranks the engine, the following conditions must be met.

- The brake pedal is depressed.
- The gear selector is in park or neutral.
- The correct key fob (code) is present in the vehicle.

A typical push-button start system includes the following sequence.

- The ignition key can be turned to the start position, released, and the PCM cranks the engine until it senses that the engine has started.



FIGURE 52–4 Instead of using an ignition key to start the engine, some vehicles are using a start button which is also used to stop the engine, as shown on this Jaguar.



FIGURE 52–5 The top button on this key fob is the remote start button.

- The PCM can detect that the engine has started by looking at the engine speed signal.
- Normal cranking speed can vary between 100 and 250 RPM. If the engine speed exceeds 400 RPM, the PCM determines that the engine started and opens the circuit to the "S" (start) terminal of the starter solenoid that stops the starter motor.

Computer-controlled starting is almost always part of the system if a push-button start is used. ● **SEE FIGURE 52–4.**

REMOTE STARTING Remote starting, sometimes called **remote vehicle start (RVS),** is a system that allows the driver to start the engine of the vehicle from inside the house or a building at a distance of about 200 ft (65 m). The doors remain locked to reduce the possibility of theft. This feature allows the heating or air-conditioning system to start before the driver arrives. ● **SEE FIGURE 52–5.**

NOTE: Most remote start systems will turn off the engine after 10 minutes of run time unless reset by using the remote.

STARTER MOTOR OPERATION

PRINCIPLES A starter motor uses electromagnetic principles to convert electrical energy from the battery (up to 300 amperes) to mechanical power (up to 8 horsepower [6 kilowatts]) to crank the engine. Current for the starter motor or power circuit is controlled by a solenoid or relay, which is itself controlled by the driver-operated ignition switch.

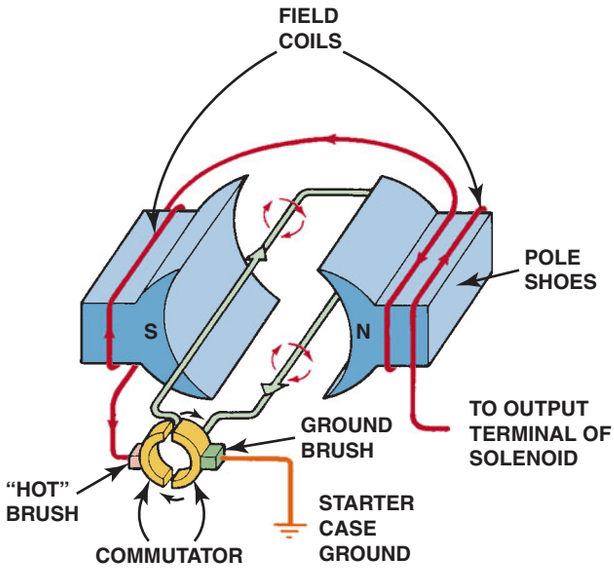


FIGURE 52–6 This series-wound electric motor shows the basic operation with only two brushes: one hot brush and one ground brush. The current flows through both field coils, then through the hot brush and the loop winding of the armature, before reaching ground through the ground brush.

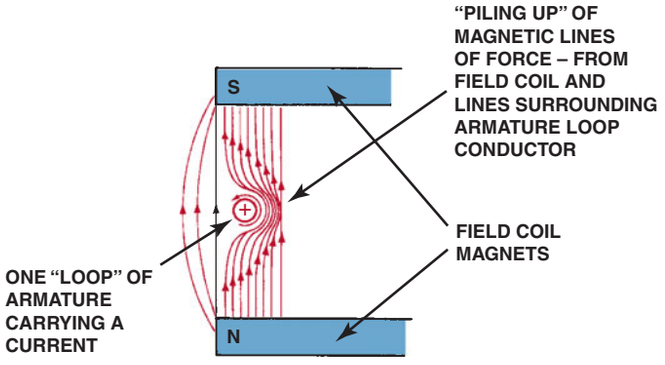


FIGURE 52–7 The interaction of the magnetic fields of the armature loops and field coils creates a stronger magnetic field on the right side of the conductor, causing the armature loop to move toward the left.

The current travels through the brushes and into the armature windings, where other magnetic fields are created around each copper wire loop in the armature. The two strong magnetic fields created inside the starter housing create the force that rotates the armature.

Inside the starter housing is a strong magnetic field created by the field coil magnets. The armature, a conductor, is installed inside this strong magnetic field, with little clearance between the armature and the field coils.

The two magnetic fields act together, and their lines of force "bunch up" or are strong on one side of the armature loop wire and become weak on the other side of the conductor. This causes the conductor (armature) to move from the area of strong magnetic field strength toward the area of weak magnetic field strength. ● **SEE FIGURES 52–6 AND 52–7.**

The difference in magnetic field strength causes the armature to rotate. This rotation force (torque) is increased as the current flowing through the starter motor increases. The torque of a starter is

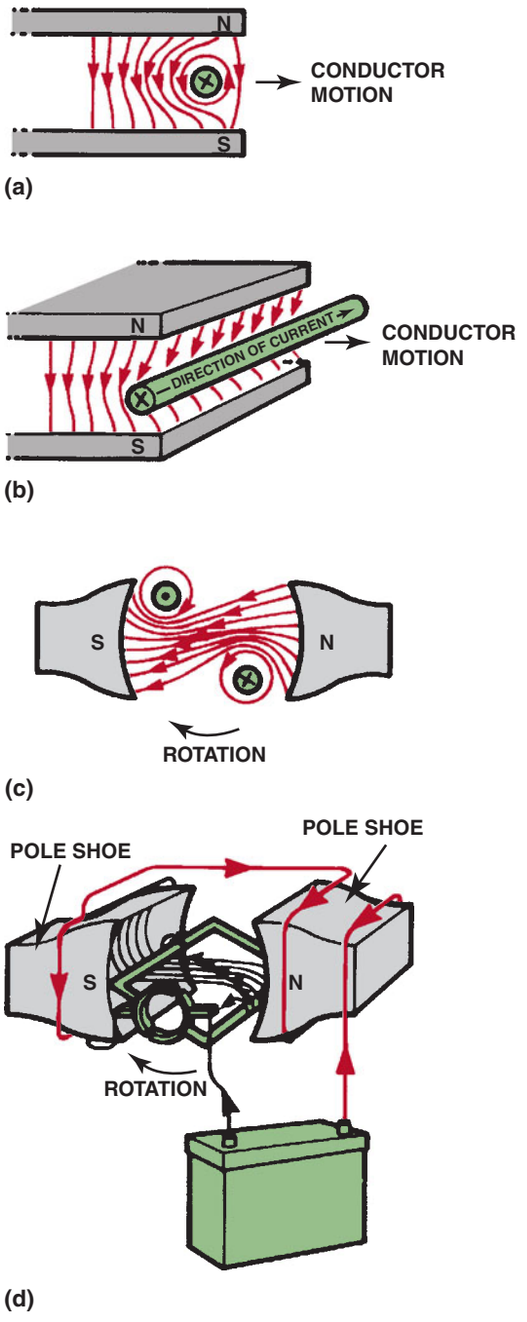


FIGURE 52–8 The armature loops rotate due to the difference in the strength of the magnetic field. The loops move from a strong magnetic field strength toward a weaker magnetic field strength.

determined by the strength of the magnetic fields inside the starter. Magnetic field strength is measured in ampere-turns. If the current or the number of turns of wire is increased, the magnetic field strength is increased.

The magnetic field of the starter motor is provided by two or more pole shoes and field windings. The pole shoes are made of iron and are attached to the frame with large screws. ● **SEE FIGURE 52–8**.

● **FIGURE 52–9** shows the paths of magnetic flux lines within a four-pole motor.

The field windings are usually made of a heavy copper ribbon to increase their current-carrying capacity and electromagnetic field strength. ● **SEE FIGURE 52–10**.

Automotive starter motors usually have four pole shoes and two to four field windings to provide a strong magnetic field within

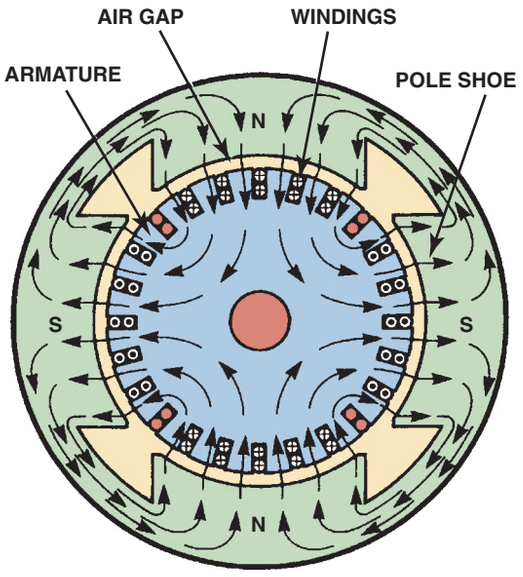


FIGURE 52–9 Magnetic lines of force in a four-pole motor.

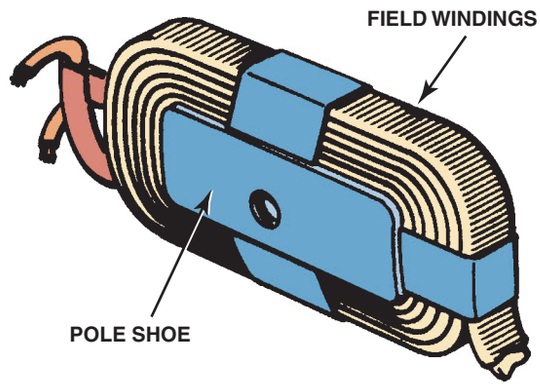


FIGURE 52–10 A pole shoe and field winding.

the motor. Pole shoes that do not have field windings are magnetized by flux lines from the wound poles.

SERIES MOTORS A series motor develops its maximum torque at the initial start (0 RPM) and develops less torque as the speed increases.

- A series motor is commonly used for an automotive starter motor because of its high starting power characteristics.
- A series starter motor develops less torque at high RPM, because a current is produced in the starter itself that acts against the current from the battery. Because this current works against battery voltage, it is called counterelectromotive force, or **CEMF.** This CEMF is produced by electromagnetic induction in the armature conductors, which are cutting across the magnetic lines of force formed by the field coils. This induced voltage operates against the applied voltage supplied by the battery, which reduces the strength of the magnetic field in the starter.
- Because the power (torque) of the starter depends on the strength of the magnetic fields, the torque of the starter decreases as the starter speed increases. A series-wound starter also draws less current at higher speeds and will keep increasing in speed under light loads. This could lead to the destruction of the starter motor unless controlled or prevented. ● **SEE FIGURE 52–11**.

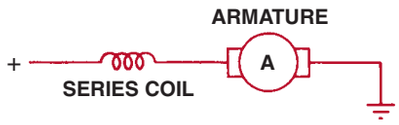


FIGURE 52–11 This wiring diagram illustrates the construction of a series-wound electric motor. Notice that all current flows through the field coils, then through the armature (in series) before reaching ground.

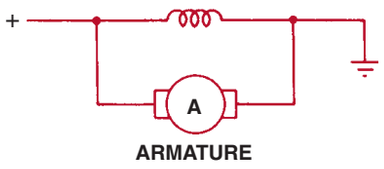


FIGURE 52–12 This wiring diagram illustrates the construction of a shunt-type electric motor, and shows the field coils in parallel (or shunt) across the armature.

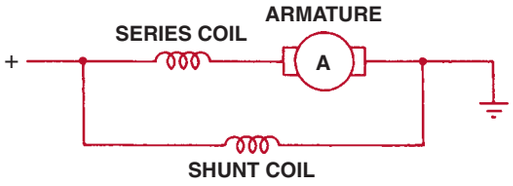


FIGURE 52–13 A compound motor is a combination of series and shunt types, using part of the field coils connected electrically in series with the armature and some in parallel (shunt).

SHUNT MOTORS

Shunt-type electric motors have the field coils in parallel (or shunt) across the armature.

A shunt-type motor has the following features.

- A shunt motor does not decrease in torque at higher motor RPM, because the CEMF produced in the armature does not decrease the field coil strength.
- A shunt motor, however, does not produce as high a starting torque as that of a series-wound motor, and is not used for starters. Some small electric motors, such as used for windshield wiper motors, use a shunt motor but most use permanent magnets rather than electromagnets.

● **SEE FIGURE 52–12**.

PERMANENT MAGNET MOTORS

A **permanent magnet (PM) starter** uses permanent magnets that maintain constant field strength, the same as a shunt-type motor, so they have similar operating characteristics. To compensate for the lack of torque, all PM starters use gear reduction to multiply starter motor torque. The permanent magnets used are an alloy of neodymium, iron, and boron, and are almost 10 times more powerful than previously used permanent magnets.

COMPOUND MOTORS

A compound-wound, or compound, motor has the operating characteristics of a series motor *and* a shunt-type motor, because some of the field coils are connected to the armature in series and some (usually only one) are connected directly to the battery in parallel (shunt) with the armature.

Compound-wound starter motors are commonly used in Ford, Chrysler, and some GM starters. The shunt-wound field coil is called a shunt coil and is used to limit the maximum speed of the starter. Because the shunt coil is energized as soon as the battery current is sent to the starter, it is used to engage the starter drive on older Ford positive engagement–type starters. ● **SEE FIGURE 52–13**.

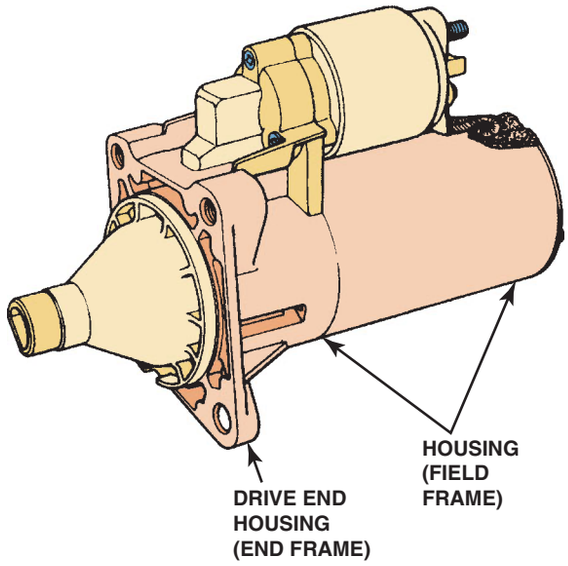


FIGURE 52–14 A typical starter motor showing the drive-end housing.

HOW THE STARTER MOTOR WORKS

PARTS INVOLVED

A starter consists of the main structural support of a starter called the main **field housing,** one end of which is called a **commutator-end** (or **brush-end) housing** and the other end a **drive-end housing.** The drive-end housing contains the drive pinion gear, which meshes with the engine flywheel gear teeth to start the engine. The commutator-end plate supports the end containing the starter brushes. **Through bolts** hold the three components together. ● **SEE FIGURE 52–14**.

- **Field coils.** The steel housing of the starter motor contains permanent magnets or four electromagnets that are connected directly to the positive post of the battery to provide a strong magnetic field inside the starter. The four electromagnets use heavy copper or aluminum wire wrapped around a soft-iron core, which is contoured to fit against the rounded internal surface of the starter frame. The soft-iron cores are called **pole shoes.** Two of the four pole shoes are wrapped with copper wire in one direction to create a north pole magnet, and the other two pole shoes are wrapped in the opposite direction to create a south pole magnet. These magnets, when energized, create strong magnetic fields inside the starter housing and, therefore, are called **field coils.** The soft-iron cores (pole shoes) are often called **field poles.** ● **SEE FIGURE 52–15**.
- **Armature.** Inside the field coils is an **armature** that is supported with either bushings or ball bearings at both ends, which permit it to rotate. The armature is constructed of thin, circular disks of steel laminated together and wound lengthwise with heavy-gauge insulated copper wire. The laminated iron core supports the copper loops of wire and helps concentrate the magnetic field produced by the coils. ● **SEE FIGURE 52–16**.

Insulation between the laminations helps to increase the magnetic efficiency in the core. For reduced resistance, the armature conductors are made of a thick copper wire. The two ends of each conductor are attached to two adjacent commutator bars.

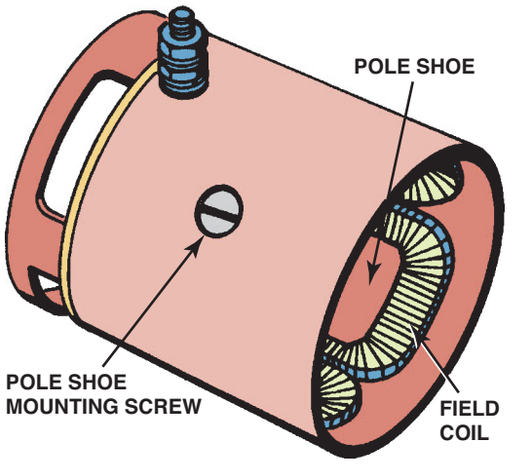


FIGURE 52–15 Pole shoes and field windings installed in the housing.

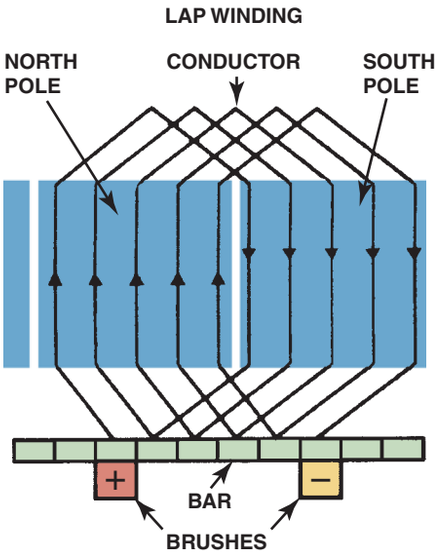


FIGURE 52–17 An armature showing how its copper wire loops are connected to the commutator.

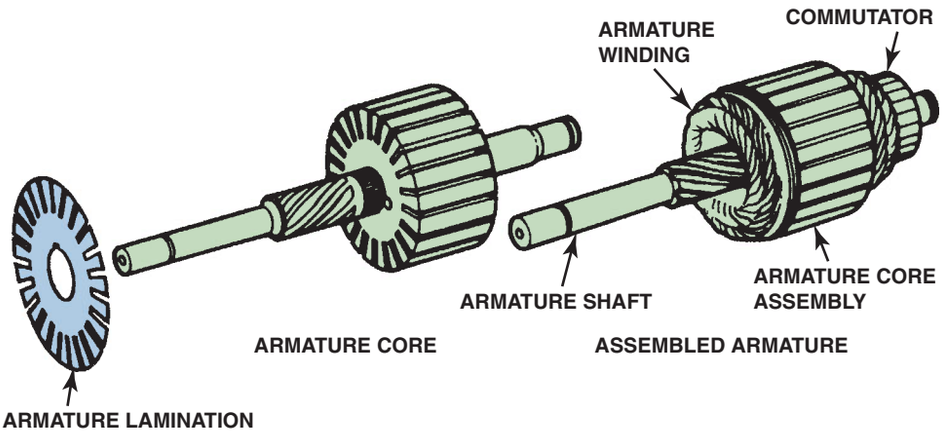


FIGURE 52–16 A typical starter motor armature. The armature core is made from thin sheet metal sections assembled on the armature shaft, which is used to increase the magnetic field strength.

The commutator is made of copper bars insulated from each other by mica or some other insulating material. ● **SEE FIGURE 52–17**.

The armature core, windings, and commutator are assembled on a long armature shaft. This shaft also carries the pinion gear that meshes with the engine flywheel ring gear.

STARTER BRUSHES

To supply the proper current to the armature, a four-pole motor must have four brushes riding on the commutator. Most automotive starters have two grounded and two insulated brushes, which are held against the commutator by spring force.

The ends of the copper armature windings are soldered to **commutator segments.** The electrical current that passes through the field coils is then connected to the commutator of the armature by brushes that can move over the segments of the rotating armature. These **brushes** are made of a combination of copper and carbon.

- The copper is a good conductor material.
- The carbon added to the starter brushes helps provide the graphite-type lubrication needed to reduce wear of the brushes and the commutator segments.

The starter uses four brushes—two brushes to transfer the current from the field coils to the armature, and two brushes to provide the ground return path for the current that flows through the armature.

The two sets of brushes include:

1. Two **insulated brushes,** which are in holders and are insulated from the housing.
2. Two **ground brushes,** which use bare, stranded copper wire connections to the brushes. The ground brush holders are not insulated and attach directly to the field housing or brush-end housing. ● **SEE FIGURE 52–18**.

PERMANENT MAGNET FIELDS

Permanent magnets are used in place of the electromagnetic field coils and pole shoes in many starters today. This eliminates the motor field circuit, which in turn eliminates the potential for field coil faults and other electrical problems. The motor has only an armature circuit.

GEAR-REDUCTION STARTERS

PURPOSE AND FUNCTION

Gear-reduction starters are used by many automotive manufacturers. The purpose of the gear reduction (typically 2:1 to 4:1) is to increase starter motor speed and provide the torque multiplication necessary to crank an engine.

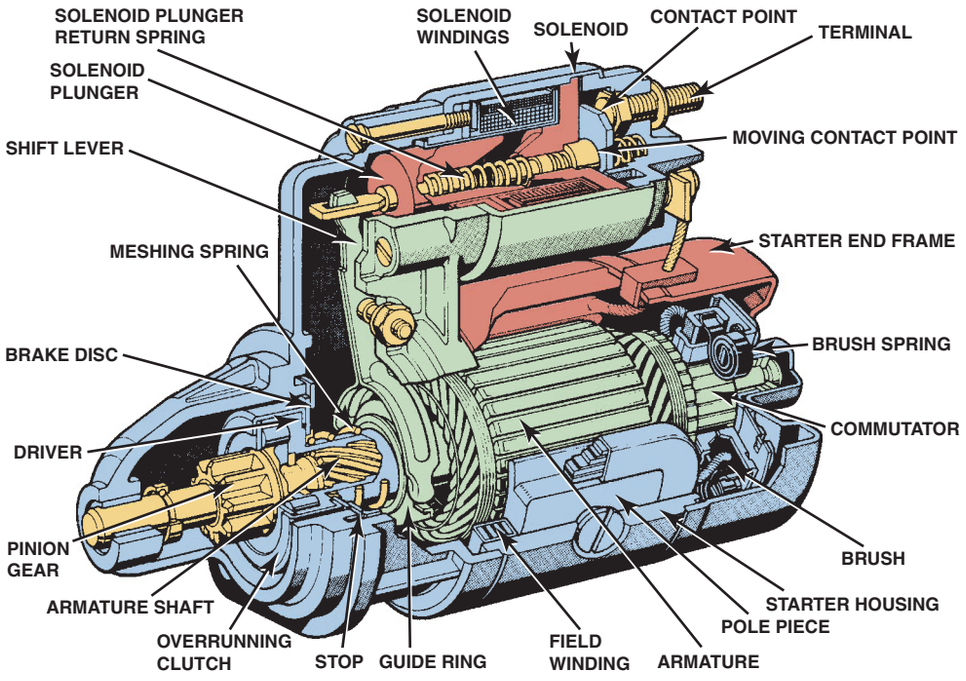


FIGURE 52–18 A cutaway of a typical starter motor showing the commutator, brushes, and brush spring.



FIGURE 52–19 This starter permanent magnet field housing was ruined when someone used a hammer on the field housing in an attempt to "fix" a starter that would not work. A total replacement is the only solution in this case.

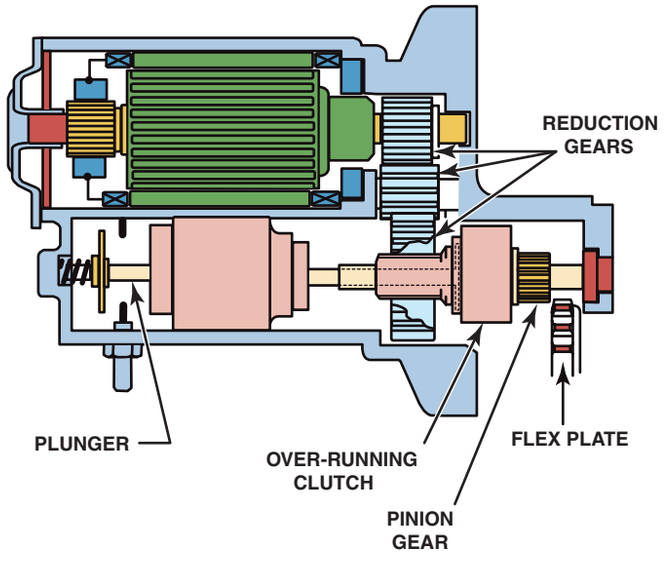


FIGURE 52–20 A typical gear-reduction starter.

TECH TIP

Don't Hit That Starter!

In the past, it was common to see service technicians hitting a starter in their effort to diagnose a no-crank condition. Often the shock of the blow to the starter aligned or moved the brushes, armature, and bushings. Many times, the starter functioned after being hit, even if only for a short time.

However, most starters today use permanent magnet fields, and the magnets can be easily broken if hit. A magnet that is broken becomes two weaker magnets. Some early PM starters used magnets that were glued or bonded to the field housing. If struck with a heavy tool, the magnets could be broken with parts of the magnet falling onto the armature and into the bearing pockets, making the starter impossible to repair or rebuild. ● **SEE FIGURE 52–19.**

As a series-wound motor increases in rotational speed, the starter produces less power, and less current is drawn from the battery because the armature generates greater CEMF as the starter speed increases. However, a starter motor's maximum torque occurs at 0 RPM and torque decreases with increasing RPM. A smaller starter using a gear-reduction design can produce the necessary cranking power with reduced starter amperage requirements. Lower current requirements mean that smaller battery cables can be used. Many permanent magnet starters use a planetary gear set (a type of gear reduction) to provide the necessary torque for starting. ● **SEE FIGURE 52–20.**

STARTER DRIVES

PURPOSE AND FUNCTION A **starter drive** includes small pinion gears that mesh with and rotate the larger gear on the engine flywheel or flex plate for starting. The pinion gear must engage with

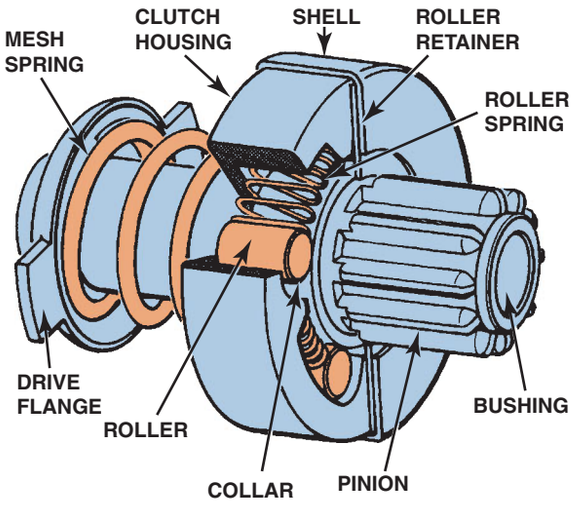


FIGURE 52–21 A cutaway of a typical starter drive showing all of the internal parts.

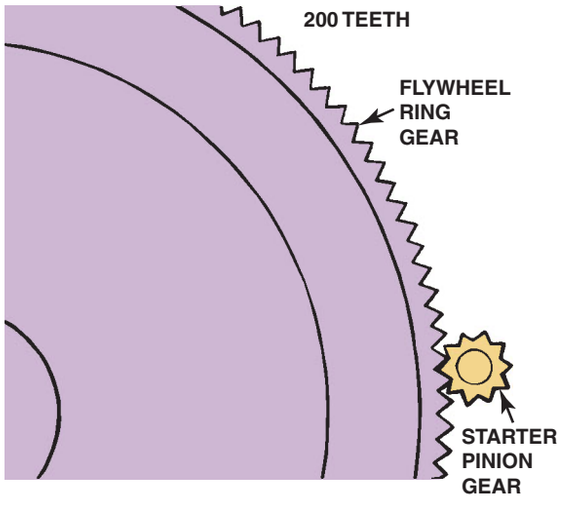


FIGURE 52–22 The ring gear to pinion gear ratio is usually 15:1 to 20:1.

the engine gear slightly *before* the starter motor rotates, to prevent serious damage to either the starter gear or the engine, but must be disengaged after the engine starts. The ends of the starter pinion gear are tapered to help the teeth mesh more easily without damaging the flywheel ring gear teeth. ● **SEE FIGURE 52–21**.

STARTER DRIVE GEAR RATIO The ratio of the number of teeth on the engine ring gear to the number on the starter pinion is between 15:1 and 20:1. A typical small starter pinion gear has 9 teeth that turn an engine ring gear with 166 teeth. This provides an 18:1 gear reduction; thus, the starter motor is rotating approximately 18 times faster than the engine. Normal cranking speed for the engine is 200 RPM (varies from 70 to 250 RPM). This means that the starter motor speed is 18 times faster, or 3600 starter RPM (200 × 18 = 3600). If the engine starts and is accelerated to 2000 RPM (normal cold engine speed), the starter will be destroyed by the high speed (36,000 RPM) if the starter was not disengaged from the engine. ● **SEE FIGURE 52–22**.

STARTER DRIVE OPERATION All starter drive mechanisms use a type of one-way clutch that allows the starter to rotate the engine, but then turns freely if the engine speed is greater than the starter motor speed. This clutch, called an **overrunning clutch,** protects the starter motor from damage if the ignition switch is held in the start position after the engine starts. The overrunning clutch, which is built in as a part of the starter drive unit, uses steel balls or rollers installed in tapered notches. ● **SEE FIGURE 52–23**.

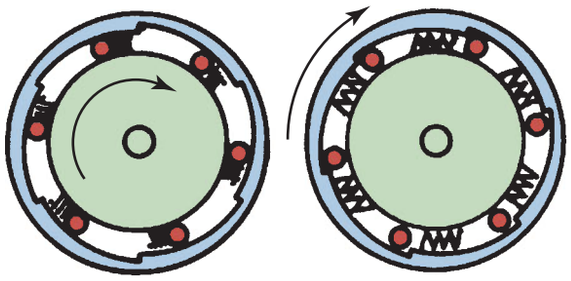


FIGURE 52–23 Operation of the overrunning clutch. (a) Starter motor is driving the starter pinion and cranking the engine. The rollers are wedged against spring force into their slots. (b) The engine has started and is rotating faster than the starter armature. Spring force pushes the rollers so they can rotate freely.

? FREQUENTLY ASKED QUESTION

What Is a Bendix?

Older-model starters often used a Bendix drive mechanism, which used inertia to engage the starter pinion with the engine flywheel gear. Inertia is the tendency of a stationary object to remain stationary, because of its weight, unless forced to move. On these older-model starters, the small starter pinion gear was attached to a shaft with threads, and the weight of this gear caused it to be spun along the threaded shaft and mesh with the flywheel whenever the starter motor spun. If the engine speed was greater than the starter speed, the pinion gear was forced back along the threaded shaft and out of mesh with the flywheel gear. The Bendix drive mechanism has generally not been used since the early 1960s, but some technicians use this term when describing a starter drive.

This taper forces the balls or rollers tightly into the notch, when rotating in the direction necessary to start the engine. When the engine rotates faster than the starter pinion, the balls or rollers are forced out of the narrow tapered notch, allowing the pinion gear to turn freely (overrun).

The spring between the drive tang or pulley and the overrunning clutch and pinion is called a **mesh spring.** It helps to cushion and control the engagement of the starter drive pinion with the engine flywheel gear. This spring is also called a **compression spring,** because the starter solenoid or starter yoke compresses the spring and the spring tension causes the starter pinion to engage the engine flywheel.

FAILURE MODE A starter drive is generally a dependable unit and does not require replacement unless defective or worn. The major wear occurs in the overrunning clutch section of the starter drive unit. The steel balls or rollers wear and often do not wedge tightly into the tapered notches as is necessary for engine cranking. A worn starter drive can cause the starter motor to operate and then stop cranking the engine and creating a "whining" noise. The whine indicates that the starter motor is operating and that the starter drive is not rotating the engine flywheel. The entire starter drive is replaced

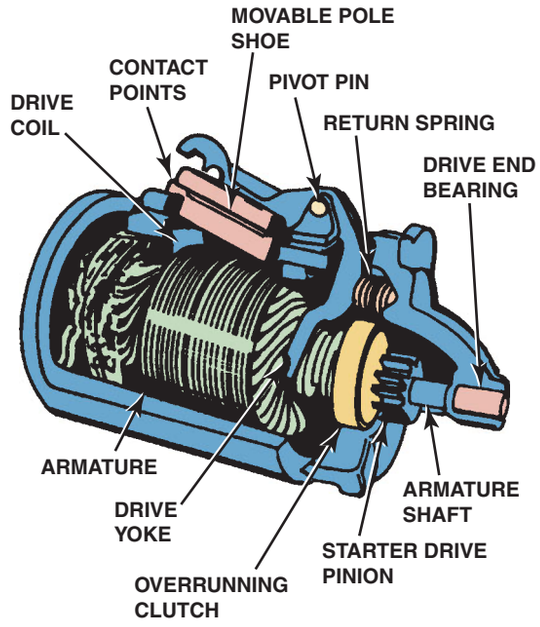


FIGURE 52–24 A Ford movable pole shoe starter.

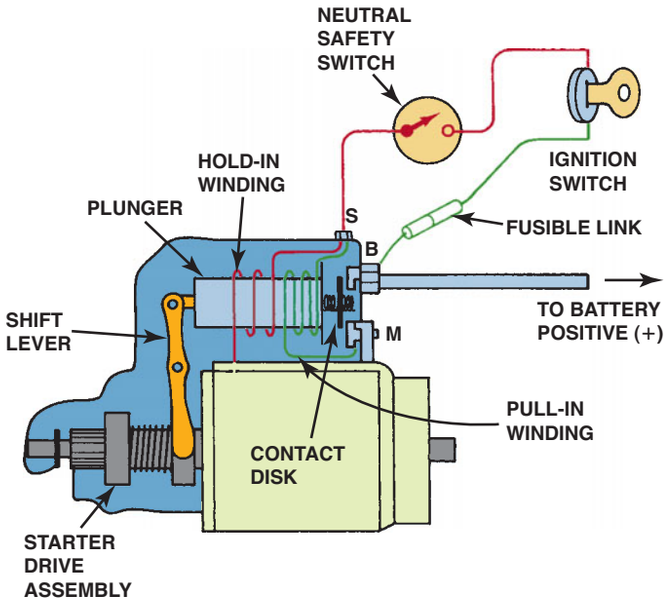


FIGURE 52–25 Wiring diagram of a typical starter solenoid. Notice that both the pull-in winding and the hold-in winding are energized when the ignition switch is first turned to the "start" position. As soon as the solenoid contact disk makes electrical contact with both the B and M terminals, the battery current is conducted to the starter motor and electrically neutralizes the pull-in winding.

as a unit. The overrunning clutch section of the starter drive cannot be serviced or repaired separately because the drive is a sealed unit. Starter drives are most likely to fail intermittently at first and then more frequently, until replacement becomes necessary to start the engine. Intermittent starter drive failure (starter whine) is often most noticeable during cold weather.

POSITIVE ENGAGEMENT STARTERS

OPERATION Positive engagement starters (direct drive) were used on Ford engines from 1973 to 1990. These starters use the shunt coil winding and a movable pole shoe to engage the starter drive. The high starting current is controlled by an ignition switch–operated starter solenoid, usually mounted near the positive post of the battery. When this control circuit is closed, current flows through a hollow coil (called a drive coil) that attracts a movable pole shoe.

As soon as the starter drive has engaged the engine flywheel, a tang on the movable pole shoe "opens" a set of contact points. The contact points provide the ground return path for the drive coil operation. After these grounding contacts are opened, all of the starter current can flow through the remaining three field coils and through the brushes to the armature, causing the starter to operate.

The movable pole shoe is held down (which keeps the starter drive engaged) by a smaller coil on the inside of the main drive coil. This coil, called the *holding coil*, is strong enough to hold the starter drive engaged while permitting the flow of the maximum possible current to operate the starter. ● **SEE FIGURE 52–24**.

ADVANTAGES The movable metal pole shoe is attached to and engages the starter drive with a lever (called the plunger lever). As a result, this type of starter does not use a solenoid to engage the starter drive.

DISADVANTAGES If the grounding contact points are severely pitted, the starter may not operate the starter drive or the starter motor because of the resulting poor ground for the drive coil. If the contact points are bent or damaged enough to prevent them from opening, the starter will "clunk" the starter drive into engagement but will not allow the starter motor to operate.

SOLENOID-OPERATED STARTERS

SOLENOID OPERATION A **starter solenoid** is an electromagnetic switch containing two separate, but connected, electromagnetic windings. This switch is used to engage the starter drive and control the current from the battery to the starter motor.

SOLENOID WINDINGS The two internal windings contain approximately the same number of turns but are made from different-gauge wire. Both windings together produce a strong magnetic field that pulls a metal plunger into the solenoid. The plunger is attached to the starter drive through a shift fork lever. When the ignition switch is turned to the start position, the motion of the plunger into the solenoid causes the starter drive to move into mesh with the flywheel ring gear.

1. The heavier-gauge winding (called the **pull-in winding**) is needed to draw the plunger into the solenoid and is grounded through the starter motor.
2. The lighter-gauge winding (called the **hold-in winding**), which is grounded through the starter frame, produces enough magnetic force to keep the plunger in position. The main purpose of using two separate windings is to permit as much current as possible to operate the starter and yet provide the strong magnetic field required to move the starter drive into engagement. ● **SEE FIGURE 52–25**.

OPERATION

1. The solenoid operates as soon as the ignition or computer-controlled relay energizes the "S" (start) terminals. At that

FREQUENTLY ASKED QUESTION

How Are Starters Made So Small?

Starters and most components in a vehicle are being made as small and as light in weight as possible to help increase vehicle performance and fuel economy. A starter can be constructed smaller due to the use of gear reduction and permanent magnets to achieve the same cranking torque as a straight drive starter, but using much smaller components. ● **SEE FIGURE 52–26** for an example of an automotive starter armature that is palm size.



FIGURE 52–26 A palm-size starter armature.

instant, the plunger is drawn into the solenoid enough to engage the starter drive.

2. The plunger makes contact with a metal disk that connects the battery terminal post of the solenoid to the motor terminal. This permits full battery current to flow through the solenoid to operate the starter motor.
3. The contact disk also electrically disconnects the pull-in winding. The solenoid *has* to work to supply current to the starter. Therefore, if the starter motor operates at all, the solenoid is working, even though it may have high external resistance that could cause slow starter motor operation.

REVIEW QUESTIONS

1. What is the difference between the control circuit and the power (motor) circuit sections of a typical cranking circuit?
2. What are the parts of a typical starter?
3. Why does a gear-reduction unit reduce the amount of current required by the starter motor?
4. What are the symptoms of a defective starter drive?

CHAPTER QUIZ

1. Starter motors operate on the principle that _____.
   a. The field coils rotate in the opposite direction from the armature
   b. Opposite magnetic poles repel
   c. Like magnetic poles repel
   d. The armature rotates from a strong magnetic field toward a weaker magnetic field
2. Series-wound electric motors _____.
   a. Produce electrical power
   b. Produce maximum power at 0 RPM
   c. Produce maximum power at high RPM
   d. Use a shunt coil
3. Technician A says that a defective solenoid can cause a starter whine. Technician B says that a defective starter drive can cause a starter whining noise. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. The neutral safety switch is located _____.
   a. Between the starter solenoid and the starter motor
   b. Inside the ignition switch itself
   c. Between the ignition switch and the starter solenoid
   d. In the battery cable between the battery and the starter solenoid
5. The brushes are used to transfer electrical power between _____.
   a. Field coils and the armature
   b. The commutator segments
   c. The solenoid and the field coils
   d. The armature and the solenoid
6. The faster a starter motor rotates, _____.
   a. The more current it draws from the battery
   b. The less CEMF is generated
   c. The less current it draws from the battery
   d. The greater the amount of torque produced
7. Normal cranking speed of the engine is about _____.
   a. 2000 RPM **c.** 1000 RPM
   b. 1500 RPM **d.** 200 RPM
8. A starter motor rotates about _____ times faster than the engine.
   a. 18 **c.** 5
   b. 10 **d.** 2
9. Permanent magnets are commonly used for what part of the starter?
   a. Armature **c.** Field coils
   b. Solenoid **d.** Commutator
10. What unit contains a hold-in winding and a pull-in winding?
    a. Field coil **c.** Armature
    b. Starter solenoid **d.** Ignition switch

chapter 53

CRANKING SYSTEM DIAGNOSIS AND SERVICE

OBJECTIVES: After studying Chapter 53, the reader will be able to: • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "C" (Starting System Diagnosis and Repair). • Explain how to disassemble and reassemble a starter motor and solenoid. • Discuss how to perform a voltage drop test on the cranking circuit. • Describe how to perform cranking system repair procedures. • Describe testing and repair procedures of the cranking circuit and components.

KEY TERMS: Bench testing 571 • Growler 571 • Shims 572 • Voltage drop 566

STARTING SYSTEM TROUBLESHOOTING PROCEDURE

OVERVIEW The proper operation of the starting system depends on a good battery, good cables and connections, and a good starter motor. Because a starting problem can be caused by a defective component anywhere in the starting circuit, it is important to check for the proper operation of each part of the circuit to diagnose and repair the problem quickly.

STEPS INVOLVED Following are the steps involved in the diagnosis of a fault in the cranking circuit.

STEP 1 **Verify the customer concern.** Sometimes the customer is not aware of how the cranking system is supposed to work, especially if it is computer controlled.

STEP 2 **Visually inspect the battery and battery connections.** The starter is the highest amperage draw device used in a vehicle and any faults, such as corrosion on battery terminals, can cause cranking system problems.

STEP 3 **Test battery condition.** Perform a battery load or conductance test on the battery to be sure that the battery is capable of supplying the necessary current for the starter.

STEP 4 **Check the control circuit.** An open or high resistance anywhere in the control circuit can cause the starter motor to not engage. Items to check include:

- "S" terminal of the starter solenoid
- Neutral safety or clutch switch
- Starter enable relay (if equipped)
- Antitheft system fault (If the engine does not crank or start and the theft indicator light is on or flashing, there is likely a fault in the theft deterrent system. Check service information for the exact procedures to follow before attempting to service the cranking circuit. ● **SEE FIGURE 53–1.**)

STEP 5 **Check voltage drop of the starter circuit.** Any high resistance in either the power side or ground side of the starter circuit will cause the starter to rotate slowly or not at all.

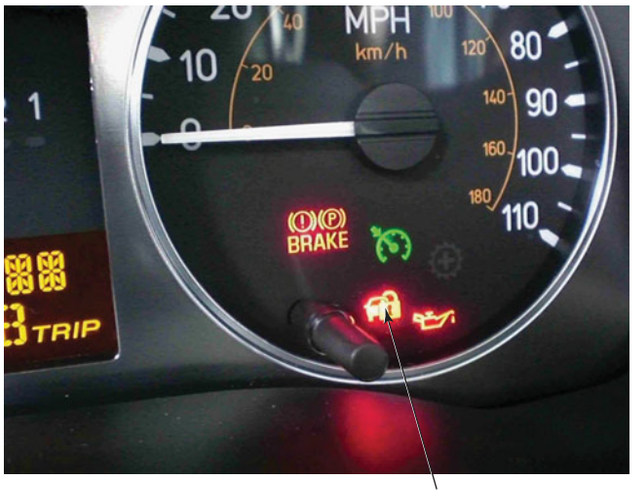


FIGURE 53–1 A theft deterrent indicator lamp on the dash. A flashing lamp usually indicates a fault in the system, and the engine may not start.

VOLTAGE DROP TESTING

PURPOSE **Voltage drop** is the drop in voltage that occurs when current is flowing through a resistance. For example, a voltage drop is the difference between voltage at the source and voltage at the electrical device to which it is flowing. The higher the voltage drop is, the greater the resistance in the circuit. Even though voltage drop testing can be performed on any electrical circuit, the most common areas of testing include the cranking circuit and the charging circuit wiring and connections. Voltage drop testing should be performed on both the power side and ground side of the circuit.

A high voltage drop (high resistance) in the cranking circuit wiring can cause slow engine cranking with less than normal starter amperage drain as a result of the excessive circuit resistance. If the voltage drop is high enough, such as that caused by dirty battery terminals, the starter may not operate. A typical symptom of high resistance in the cranking circuit is a "clicking" of the starter solenoid.

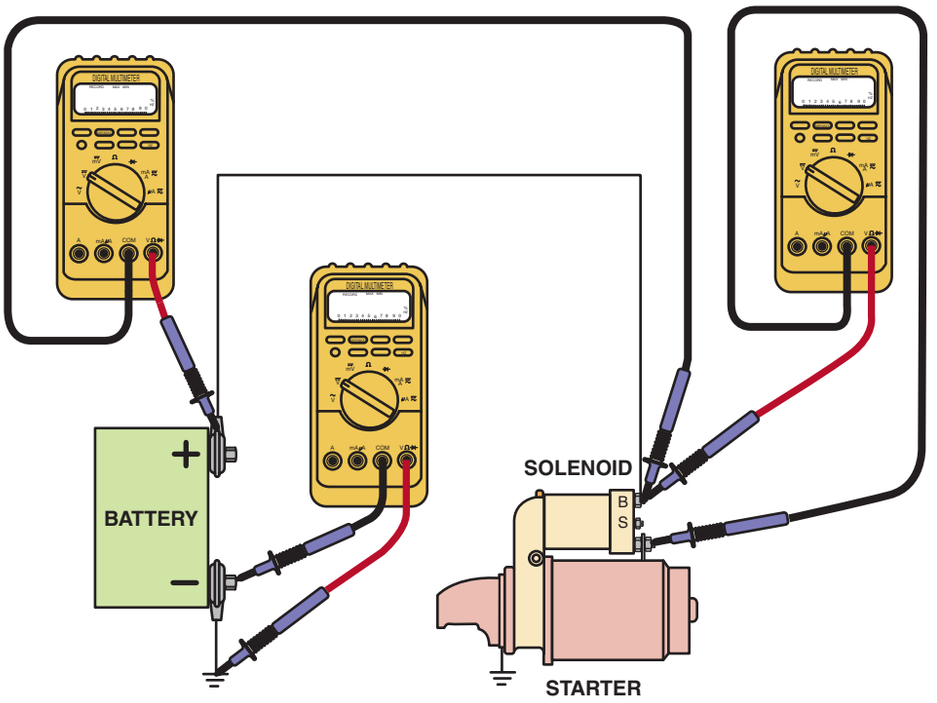


FIGURE 53–2 Voltmeter hookups for voltage drop testing of a solenoid-type cranking circuit.

TECH TIP

Voltage Drop Is Resistance

Many technicians have asked, "Why measure voltage drop when the resistance can be easily measured using an ohmmeter?" Think of a battery cable with all the strands of the cable broken, except for one strand. If an ohmmeter were used to measure the resistance of the cable, the reading would be very low, probably less than 1 ohm. However, the cable is not capable of conducting the amount of current necessary to crank the engine. In less severe cases, several strands can be broken, thereby affecting the operation of the starter motor. Although the resistance of the battery cable will not indicate an increase, the restriction to current flow will cause heat and a drop of voltage available at the starter. Because resistance is not effective until current flows, measuring the voltage drop (differences in voltage between two points) is the most accurate method of determining the true resistance in a circuit.

How much is too much? According to Bosch Corporation, all electrical circuits should have a maximum of 3% loss of the circuit voltage to resistance. Therefore, in a 12 volt circuit, the maximum loss of voltage in cables and connections should be 0.36 volt (12 × 0.03 = 0.36 volt). The remaining 97% of the circuit voltage (11.64 volts) is available to operate the electrical device (load). Just remember:

- Low-voltage drop = Low resistance
- High-voltage drop = High resistance

TECH TIP

A Warm Cable Equals High Resistance

If a cable or connection is warm to the touch, there is electrical resistance in the cable or connection. The resistance changes electrical energy into heat energy. Therefore, if a voltmeter is not available, touch the battery cables and connections while cranking the engine. If any cable or connection is hot to the touch, it should be cleaned or replaced.

TEST PROCEDURE Voltage drop testing of the wire involves connecting a voltmeter set to read DC volts to the suspected high-resistance cable ends and cranking the engine. ● **SEE FIGURES 53–2 THROUGH 53–4.**

NOTE: Before a difference in voltage (voltage drop) can be measured between the ends of a battery cable, current must be flowing through the cable. *Resistance is not effective unless current is flowing.* If the engine is not being cranked, current is not flowing through the battery cables and the voltage drop cannot be measured.

STEP 1 Disable the ignition or fuel injection as follows:

- Disconnect the primary (low-voltage) electrical connection(s) from the ignition module or ignition coils.
- Remove the fuel-injection fuse or relay, or the electrical connection leading to all of the fuel injectors.

CAUTION: Never disconnect the high-voltage ignition wires unless they are connected to ground. The high voltage that could occur when cranking can cause the ignition coil to fail (arc internally).

STEP 2 Connect one lead of the voltmeter to the starter motor battery terminal and the other end to the positive battery terminal.

STEP 3 Crank the engine and observe the reading while cranking. (Disregard the first higher reading.) The reading should be less than 0.20 volt (200 mV).

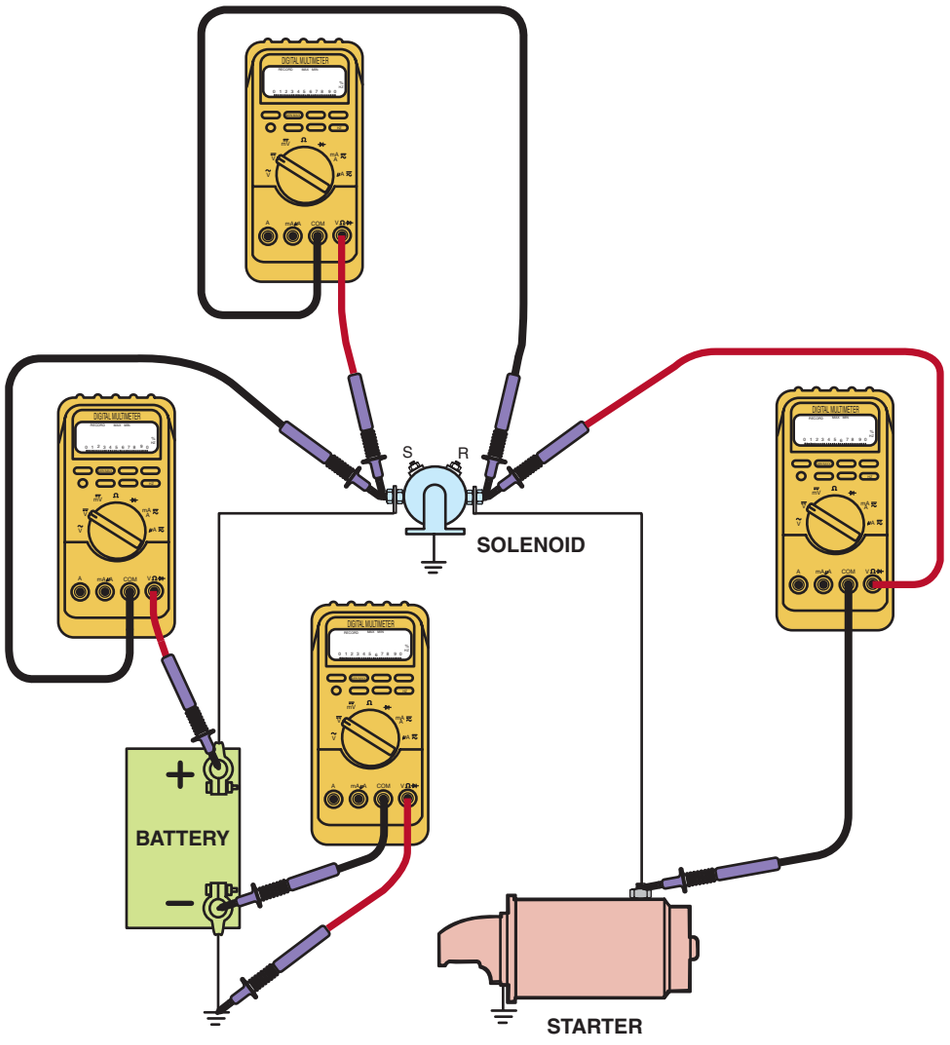


FIGURE 53–3 Voltmeter hookups for voltage drop testing of a Ford cranking circuit.



FIGURE 53–4 To test the voltage drop of the battery cable connection, place one voltmeter lead on the battery terminal and the other voltmeter lead on the cable end and crank the engine. The voltmeter will read the difference in voltage between the two leads, which should not exceed 0.20 volt (200 mV).

STEP 4 If accessible, test the voltage drop across the "B" and "M" terminals of the starter solenoid with the engine cranking. The voltage drop should be less than 0.20 volt (200 mV).

STEP 5 Repeat the voltage drop on the ground side of the cranking circuit by connecting one voltmeter lead to the negative battery terminal and the other at the starter housing. Crank the engine and observe the voltmeter display. The voltage drop should be less than 0.2 volt (200 mV).

CONTROL CIRCUIT TESTING

PARTS INVOLVED The control circuit for the starting circuit includes the battery, ignition switch, neutral or clutch safety switch, theft deterrent system, and starter solenoid. When the ignition switch is rotated to the start position, current flows through the ignition switch and neutral safety switch to activate the solenoid. High current then flows directly from the battery through the solenoid and to the starter motor. Therefore, an open or break anywhere in the control circuit will prevent the operation of the starter motor.

If a starter is inoperative, first check for voltage at the "S" (start) terminal of the starter solenoid. Check for faults with the following:

- Neutral safety or clutch switch
- Blown crank fuse
- Open at the ignition switch in the crank position

Some models with antitheft controls use a relay to open this control circuit to prevent starter operation.

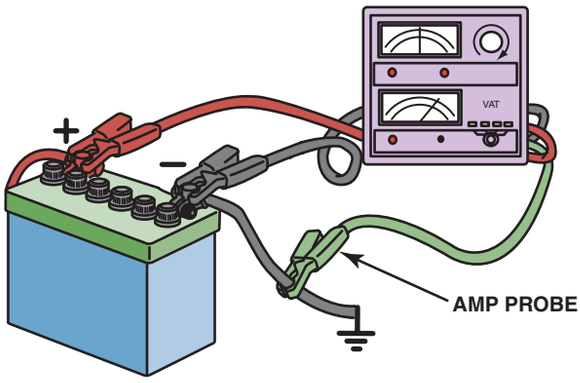


FIGURE 53–5 A starter amperage tester uses an amp probe around the positive or negative battery cables.

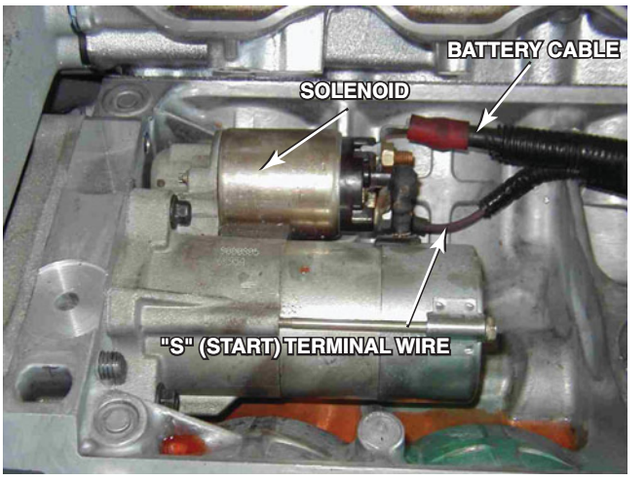


FIGURE 53–6 The starter is located under the intake manifold on this Cadillac Northstar engine.

TECH TIP

Watch the Dome Light

When diagnosing any starter-related problem, open the door of the vehicle and observe the brightness of the dome or interior light(s).

The brightness of any electrical lamp is proportional to the voltage of the battery.

Normal operation of the starter results in a slight dimming of the dome light.

If the light remains bright, the problem is usually an open in the control circuit.

If the light goes out or almost goes out, there could be a problem with the following:

- A shorted or grounded armature of field coils inside the starter
- Loose or corroded battery connections or cables
- Weak or discharged battery

STARTER AMPERAGE TEST

REASON FOR A STARTER AMPERAGE TEST A starter should be tested to see if the reason for slow or no cranking is due to a fault with the starter motor or another problem. A voltage drop test is used to find out if the battery cables and connections are okay. A starter amperage draw test determines if the starter motor is the cause of a no or slow cranking concern.

TEST PREPARATION Before performing a starter amperage test, be certain that the battery is sufficiently charged (75% or more) and capable of supplying adequate starting current. Connect a starter amperage tester following the tester's instructions. ● **SEE FIGURE 53–5.**

A starter amperage test should be performed when the starter fails to operate normally (is slow in cranking) or as part of a routine electrical system inspection.

SPECIFICTIONS Some service manuals specify normal starter amperage for starter motors being tested on the vehicle; however, most service manuals only give the specifications for bench testing a starter without a load applied. These specifications are helpful in making certain that a repaired starter meets exact specifications, but they do not apply to starter testing on the vehicle. If exact specifications are not available, the following can be used as general *maximum* amperage draw specifications for testing a starter on the vehicle.

- **4-cylinder engines** = 150 to 185 amperes (normally less than 100 A) at room temperature
- **6-cylinder engines** = 160 to 200 amperes (normally less than 125 A) at room temperature
- **8-cylinder engines** = 185 to 250 amperes (normally less than 150 A) at room temperature

Excessive current draw may indicate one or more of the following:

1. Binding of starter armature as a result of worn bushings
2. Oil too thick (viscosity too high) for weather conditions
3. Shorted or grounded starter windings or cables
4. Tight or seized engine
5. Shorted starter motor (usually caused by fault with the field coils or armature)
   - High mechanical resistance = High starter amperage draw
   - High electrical resistance = Low starter amperage draw

Lower amperage draw and slow or no cranking may indicate one or more of the following:

- Dirty or corroded battery connections
- High internal resistance in the battery cable(s)
- High internal starter motor resistance
- Poor ground connection between the starter motor and the engine block

STARTER REMOVAL

PROCEDURE After testing has confirmed that a starter motor may need to be replaced, most vehicle manufacturers recommend the following general steps and procedures.

STEP 1 Disconnect the negative battery cable.

STEP 2 Hoist the vehicle safely.

NOTE: This step may not be necessary. Check service information for the specified procedure for the vehicle being serviced. Some starters are located under the intake manifold. ● **SEE FIGURE 53–6.**

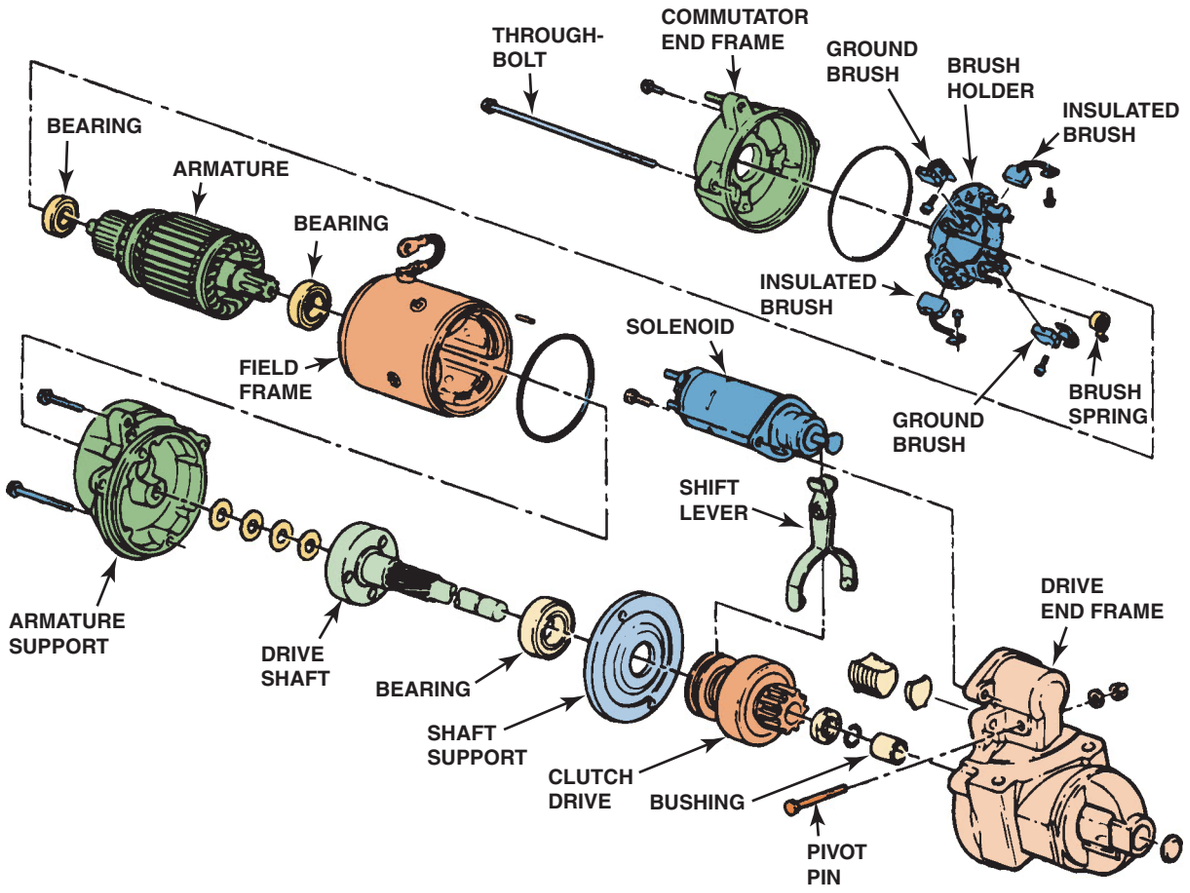


FIGURE 53–7 An exploded view of a typical solenoid-operated starter.

STEP 3 Remove the starter retaining bolts and lower the starter to gain access to the wire(s) connection(s) on the starter.

STEP 4 Disconnect and label the wire(s) from the starter and remove the starter.

STEP 5 Inspect the flywheel (flexplate) for ring gear damage. Also check that the mounting holes are clean and the mounting flange is clean and smooth. Service as needed.

STARTER MOTOR SERVICE

PURPOSE Most starter motors are replaced as an assembly or not easily disassembled or serviced. However, some starters, especially on classic muscle or collector vehicles, can be serviced.

DISASSEMBLY PROCEDURE Disassembly of a starter motor usually includes the following steps.

STEP 1 Remove the starter solenoid assembly.

STEP 2 Mark the location of the through bolts on the field housing to help align them during reassembly.

STEP 3 Remove the drive-end housing and then the armature assembly.

● **SEE FIGURE 53–7.**

INSPECTION AND TESTING The various parts should be inspected and tested to see if the components can be used to restore the starter to serviceable condition.

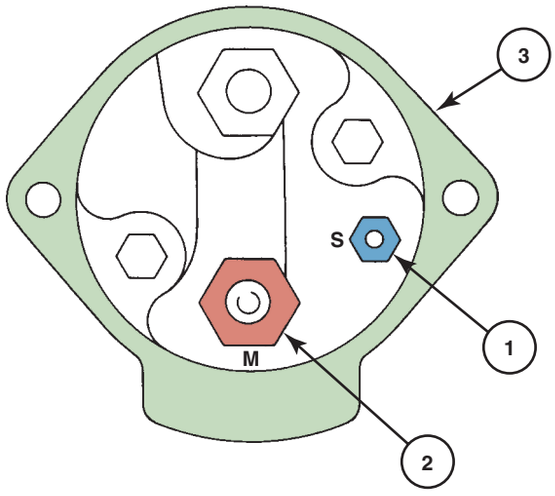


FIGURE 53–8 GM solenoid ohmmeter check. The reading between 1 and 3 (S terminal and ground) should be 0.4 to 0.6 ohm (hold-in winding). The reading between 1 and 2 (S terminal and M terminal) should be 0.2 to 0.4 ohm (pull-in winding).

- **Solenoid.** Check the resistance of the solenoid winding. The solenoid can be tested using an ohmmeter to check for the proper resistance in the hold-in and pull-in windings. ● **SEE FIGURE 53–8.**

Most technicians replace the solenoid whenever the starter is replaced and is usually included with a replacement starter.

- **Starter armature.** After the starter drive has been removed from the armature, it can be checked for runout using a dial indicator and V-blocks, as shown in ● **FIGURE 53–9.**

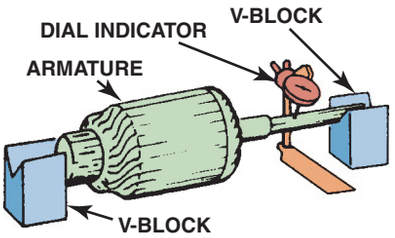


FIGURE 53–9 Measuring an armature shaft for runout using a dial indicator and V-blocks.

- **Growler.** Because the loops of copper wire are interconnected in the armature of a starter, an armature can be accurately tested only by use of a **growler.** A growler is a 110 volt AC test unit that generates an alternating (60 hertz) magnetic field around an armature. A starter armature is placed into the V-shaped top portion of a laminated soft-iron core surrounded by a coil of copper wire. Plug the growler into a 110 volt outlet and then follow the instructions for testing the armature.
- **Starter motor field coils.** With the armature removed from the starter motor, the field coils should be tested for opens and grounds using a powered test light or an ohmmeter. To test for a grounded field coil, touch one lead of the tester to a field brush (insulated or hot) and the other end to the starter field housing. The ohmmeter should indicate infinity (no continuity), and the test light should *not* light. If there is continuity, replace the field coil housing assembly. The ground brushes should show continuity to the starter housing.

  NOTE: Many starters use removable field coils. These coils must be rewound using the proper equipment and insulating materials. Usually, the cost involved in replacing defective field coils exceeds the cost of a replacement starter.

- **Starter brush inspection.** Starter brushes should be replaced if the brush length is less than half of its original length (less than 0.5 in. [13 mm]). On some models of starter motors, the field brushes are serviced with the field coil assembly and the ground brushes with the brush holder. Many starters use brushes that are held in with screws and are easily replaced, whereas other starters may require soldering to remove and replace the brushes. ● **SEE FIGURE 53–10.**

BENCH TESTING

Every starter should be tested before installation in a vehicle. **Bench testing** is the usual method and involves clamping the starter in a vise to prevent rotation during operation and connecting heavy-gauge jumper wires (minimum 4 gauge) to both a battery known to be good and the starter. The starter motor should rotate as fast as specifications indicate and not draw more than the free-spinning amperage permitted. A typical amperage specification for a starter being tested on a bench (not installed in a vehicle) usually ranges from 60 to 100 amperes.

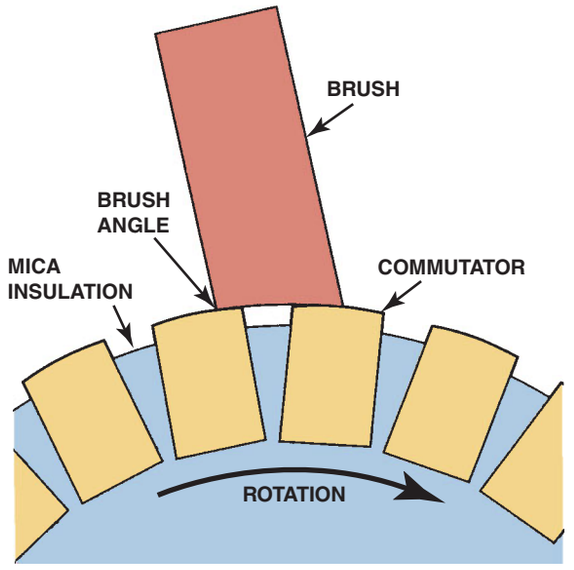


FIGURE 53–10 Replacement starter brushes should be installed so the beveled edge matches the rotation of the commutator.

STARTER INSTALLATION

After verifying that the starter assembly is functioning correctly, verify that the negative battery cable has been disconnected. Then safely hoist the vehicle, if necessary. Following are the usual steps to install a starter. Be sure to check service information for the exact procedures to follow for the vehicle being serviced.

STEP 1 Check service information for the exact wiring connections to the starter and/or solenoid.

STEP 2 Verify that all electrical connections on the starter motor and/or solenoid are correct for the vehicle and that they are in good condition.

NOTE: Be sure that the locking nuts for the studs are tight. Often, the retaining nut that holds the wire to the stud will be properly tightened, but if the stud itself is loose, cranking problems can occur.

STEP 3 Attach the power and control wires.

STEP 4 Install the starter, and torque all the fasteners to factory specifications and tighten evenly.

STEP 5 Perform a starter amperage draw test and check for proper engine cranking.

CAUTION: Be sure to install all factory heat shields to help ensure problem starter operation under all weather and driving conditions.

STARTER DRIVE-TO-FLYWHEEL CLEARANCE

NEED FOR SHIMS For the proper operation of the starter and absence of abnormal starter noise, there must be a slight clearance between the starter pinion and the engine flywheel ring gear. Many

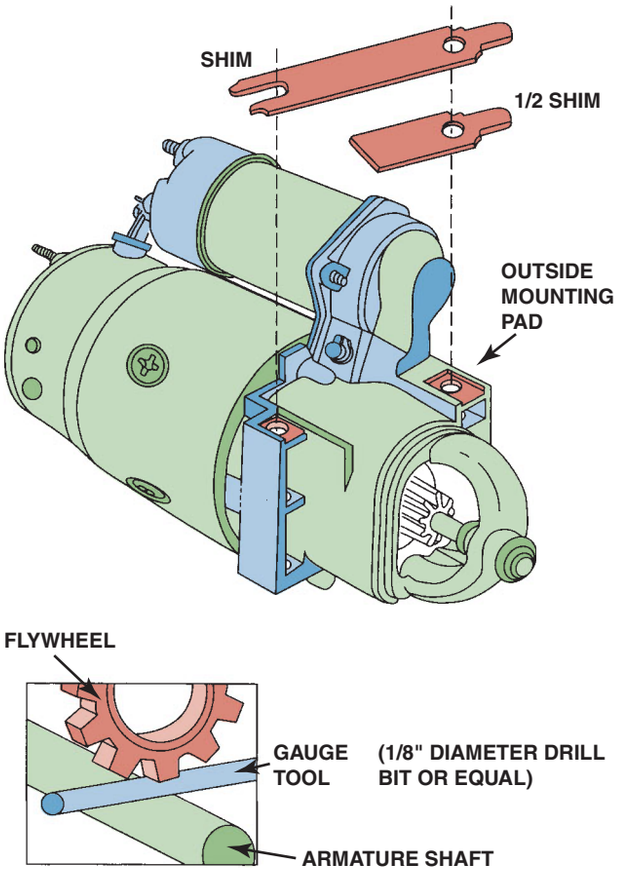


FIGURE 53–11 A shim (or half shim) may be needed to provide the proper clearance between the flywheel teeth of the engine and the pinion teeth of the starter.

starters use **shims,** which are thin metal strips between the flywheel and the engine block mounting pad to provide the proper clearance. ● **SEE FIGURE 53–11.**

Some manufacturers use shims under the starter drive-end housings during production. Other manufacturers *grind* the mounting pads at the factory for proper starter pinion gear clearance. If a GM starter is replaced, the starter pinion should be checked and corrected as necessary to prevent starter damage and excessive noise.

SYMPTOMS OF CLEARANCE PROBLEMS

- If the clearance is too great, the starter will produce a high-pitched whine *during* cranking.
- If the clearance is too small, the starter may bind, crank slowly, or produce a high-pitched whine *after* the engine starts, just as the ignition key is released.

PROCEDURE FOR PROPER CLEARANCE

To be sure that the starter is shimmed correctly, use the following procedure.

STEP 1 Place the starter in position and finger-tighten the mounting bolts.

STEP 2 Use a 1/8 in. diameter drill bit (or gauge tool) and insert between the armature shaft and a tooth of the engine flywheel.

STEP 3 If the gauge tool cannot be inserted, use a full-length shim across both mounting holes to move the starter away from the flywheel.

STEP 4 Remove a shim (or shims) if the gauge tool is loose between the shaft and the tooth of the engine flywheel.

TECH TIP

Reuse Drive-End Housing to Be Sure

Most GM starter motors use a pad mount and attach to the engine with bolts through the drive-end (nose) housing. Many times when a starter is replaced on a GM vehicle, the starter makes noise because of improper starter pinion-to-engine flywheel ring gear clearance. Instead of spending a lot of time shimming the new starter, simply remove the drive-end housing from the original starter and install it on the replacement starter. Service the bushing in the drive-end housing if needed. Because the original starter did not produce excessive gear engagement noise, the replacement starter will also be okay. Reuse any shims that were used with the original starter. This is preferable to removing and reinstalling the replacement starter several times until the proper clearance is determined.

STEP 5 If no shims have been used and the fit of the gauge tool is too loose, add a half shim to the outside pad only. This moves the starter closer to the teeth of the engine flywheel.

STARTING SYSTEM SYMPTOM GUIDE

The following list will assist technicians in troubleshooting starting systems.

Problem	Possible Causes
1. Starter motor whines	1. Possible defective starter drive; worn starter drive engagement yoke; defective flywheel; improper starter drive to flywheel clearance
2. Starter rotates slowly	2. Possible high resistance in the battery cables or connections; possible defective or discharged battery; possible worn starter bushings, causing the starter armature to drag on the field coils; possible worn starter brushes or weak brush springs; possible defective (open or shorted) field coil
3. Starter fails to rotate	3. Possible defective ignition switch or neutral safety switch, or open in the starter motor control circuit; theft deterrent system fault; possible defective starter solenoid
4. Starter produces grinding noise	4. Possible defective starter drive unit; possible defective flywheel; possible incorrect distance between the starter pinion and the flywheel; possible cracked or broken starter drive-end housing; worn or damaged flywheel or ring gear teeth
5. Starter clicks when engaged	5. Low battery voltage; loose or corroded battery connections



1 This dirty and greasy starter can be restored to useful service.



2 The connecting wire between the solenoid and the starter is removed.



3 An old starter field housing is being used to support the drive-end housing of the starter as it is being disassembled. This rebuilder is using an electric impact wrench to remove the solenoid fasteners.



4 A Torx driver is used to remove the solenoid attaching screws.

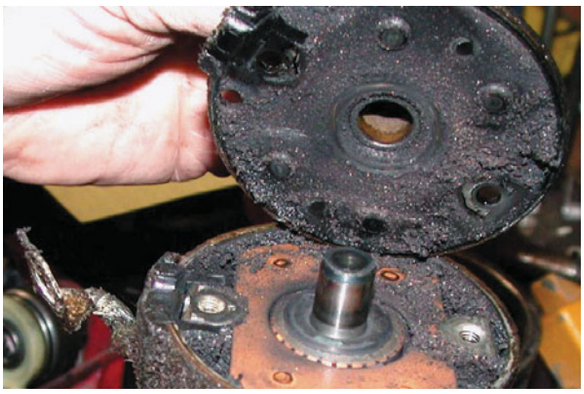


5 After the retaining screws have been removed, the solenoid can be separated from the starter motor. This rebuilder always replaces the solenoid.

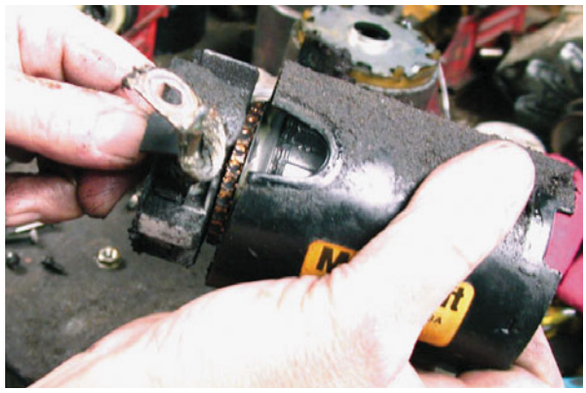


6 The through-bolts are being removed.

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7 The brush end plate is removed.



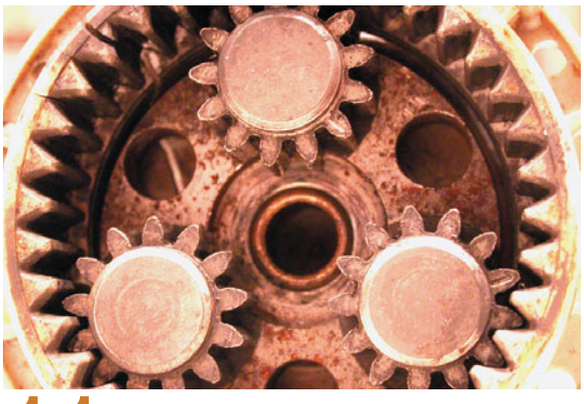
8 The armature assembly is removed from the field frame.



9 Notice that the length of a direct-drive starter armature (top) is the same length as the overall length of a gear-reduction armature except smaller in diameter.



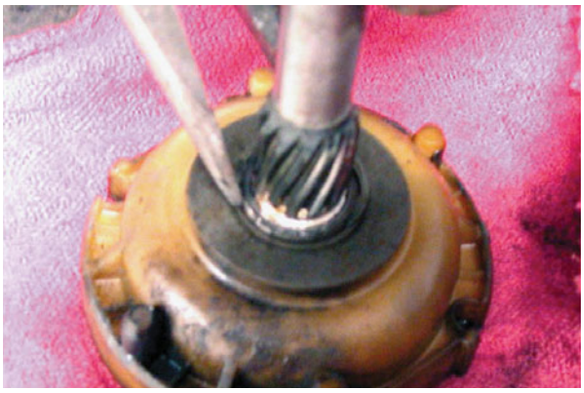
10 A light tap with a hammer dislodges the armature thrust ball (in the palm of the hand) from the center of the gear reduction assembly.



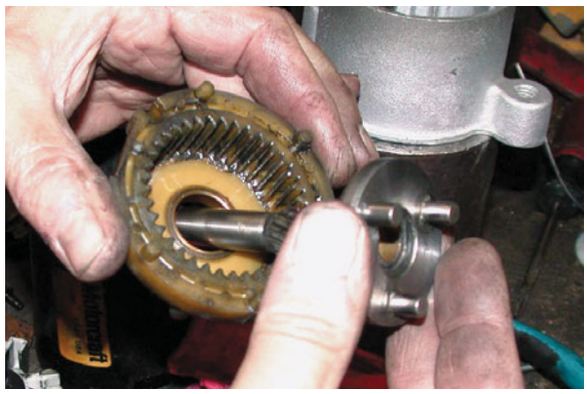
11 This figure shows the planetary ring gear and pinion gears.



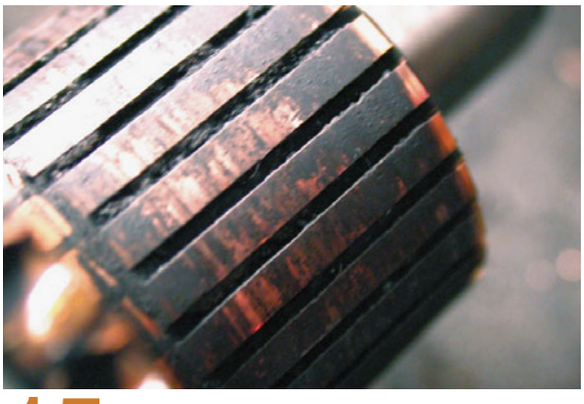
12 A close-up of one of the planetary gears, which shows the small needle bearings on the inside.



13 The clip is removed from the shaft so the planetary gear assembly can be separated and inspected.



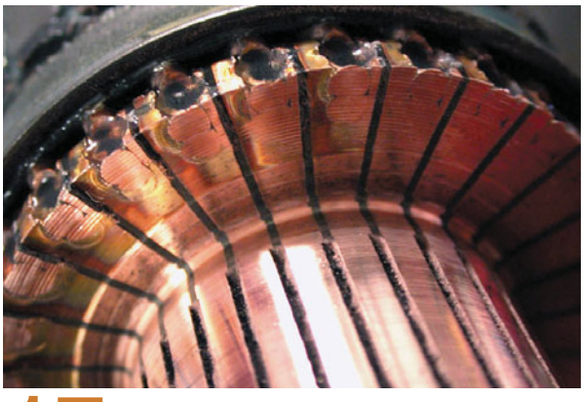
14 The shaft assembly is being separated from the stationary gear assembly.



15 The commutator on the armature is discolored and the brushes may not have been making good contact with the segments.



16 All of the starter components are placed in a tumbler with water-based cleaner. The armature is installed in a lathe and the commutator is resurfaced using emery cloth.

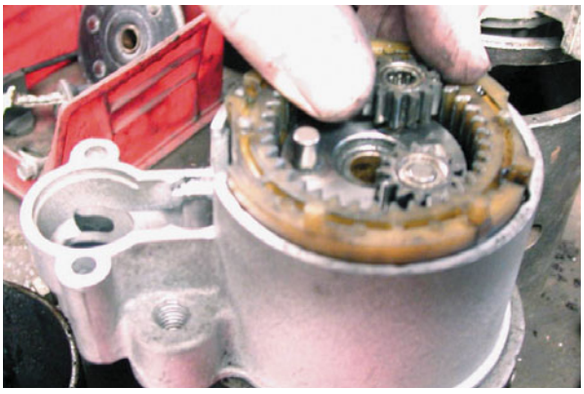


17 The finished commutator looks like new.

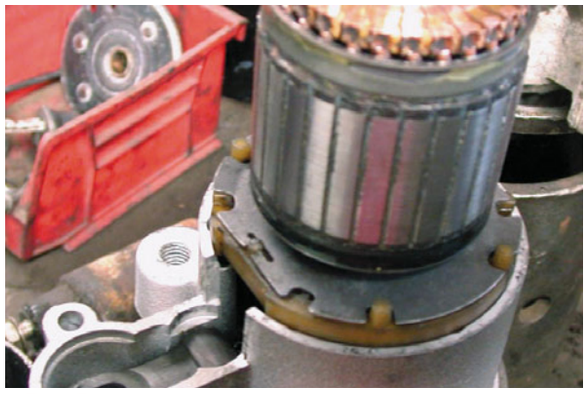


18 Starter reassembly begins by installing a new starter drive on the shaft assembly. The stop ring and stop ring retainer are then installed.

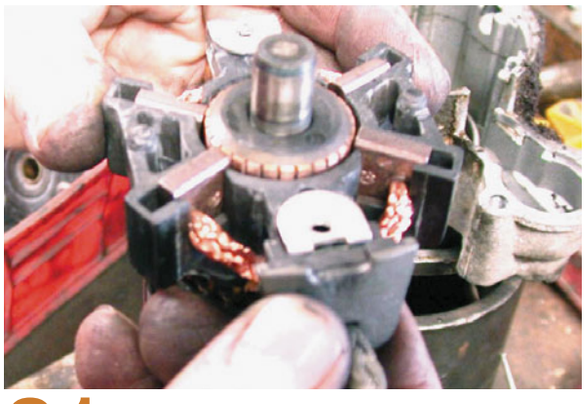
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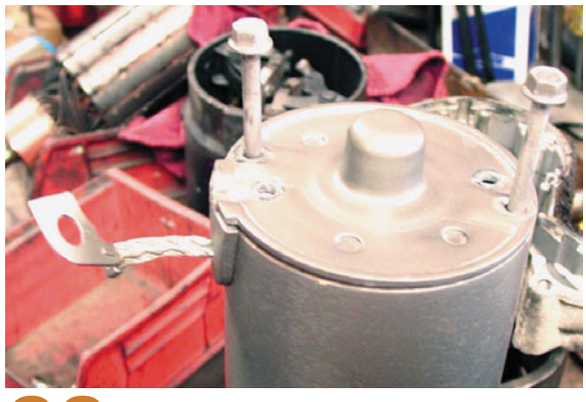
19 The gear-reduction assembly is positioned along with the shift fork (drive lever) into the cleaned drive-end housing.



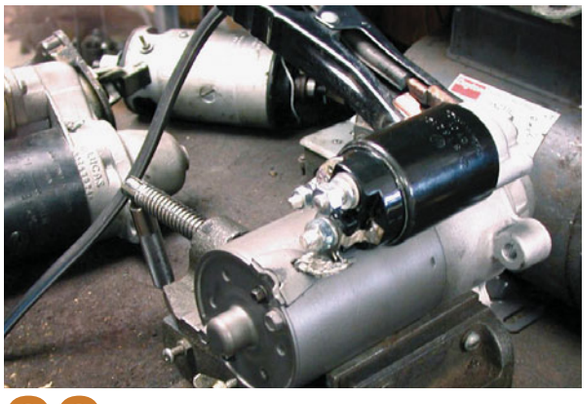
20 After gear retainer has been installed over the gear reduction assembly, the armature is installed.



21 New brushes are being installed into the brush holder assembly.



22 The brush end plate and the through-bolts are installed, being sure that the ground connection for the brushes is clean and tight.



23 This starter was restored to useful service by replacing the solenoid, the brushes, and the starter drive assembly plus a thorough cleaning and attention to detail in the reassembly.

REVIEW QUESTIONS

1. What are the parts of the cranking circuit?
2. What are the steps taken to perform a voltage drop test of the cranking circuit?
3. What are the steps necessary to replace a starter?

CHAPTER QUIZ

1. A growler is used to test what starter component?
   a. Field coils **c.** Commutator
   b. Armatures **d.** Solenoid
2. Two technicians are discussing what could be the cause of slow cranking and excessive current draw. Technician A says that an engine mechanical fault could be the cause. Technician B says that the starter motor could be binding or defective. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
3. A V-6 is being checked for starter amperage draw. The initial surge current was about 210 amperes and about 160 amperes during cranking. Technician A says the starter is defective and should be replaced because the current flow exceeds 200 amperes. Technician B says this is normal current draw for a starter motor on a V-6 engine. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
4. What component or circuit can keep the engine from cranking?
   a. Antitheft **c.** Ignition switch
   b. Solenoid **d.** All of the above
5. Technician A says that a discharged battery (lower than normal battery voltage) can cause solenoid clicking. Technician B says that a discharged battery or dirty (corroded) battery cables can cause solenoid clicking. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
6. Slow cranking by the starter can be caused by all *except* _____.
   a. A low or discharged battery
   b. Corroded or dirty battery cables
   c. Engine mechanical problems
   d. An open neutral safety switch
7. Bench testing of a starter should be done _____.
   a. After reassembling an old starter
   b. Before installing a new starter
   c. After removing the old starter
   d. Both a and b
8. If the clearance between the starter pinion and the engine flywheel is too great, _____.
   a. The starter will produce a high-pitched whine during cranking
   b. The starter will produce a high-pitched whine after the engine starts
   c. The starter drive will not rotate at all
   d. The solenoid will not engage the starter drive unit
9. A technician connects one lead of a digital voltmeter to the positive (1) terminal of the battery and the other meter lead to the battery terminal (B) of the starter solenoid and then cranks the engine. During cranking, the voltmeter displays a reading of 878 mV. Technician A says that this reading indicates that the positive battery cable has too high resistance. Technician B says that this reading indicates that the starter is defective. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. A vehicle equipped with a V-8 engine does not crank fast enough to start. Technician A says the battery could be discharged or defective. Technician B says that the negative cable could be loose at the battery. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

chapter 54 CHARGING SYSTEM

OBJECTIVES: **After studying Chapter 54, the reader will be able to:** • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "D" (Charging System Diagnosis and Repair). • List the parts of a typical alternator. • Describe how an alternator works. • Explain how the powertrain control module (PCM) controls the charging circuit.

KEY TERMS: Alternator 578 • Claw poles 580 • Delta winding 583 • Diodes 580 • Drive-end (DE) housing 578 • Duty cycle 585 • EPM 585 • IDP 578 • OAD 578 • OAP 578 • Rectifier 581 • Rotor 579 • Slip-ring-end (SRE) housing 578 • Stator 580 • Thermistor 585

PRINCIPLES OF ALTERNATOR OPERATION

TERMINOLOGY It is the purpose and function of the charging system to keep the battery fully charged. The Society of Automotive Engineers (SAE) term for the unit that generates electricity is *generator.* The term **alternator** is most commonly used in the trade and will be used in this title.

PRINCIPLES All electrical alternators use the principle of electromagnetic induction to generate electrical power from mechanical power. Electromagnetic induction involves the generation of an electrical current in a conductor when the conductor is moved through a magnetic field. The amount of current generated can be increased by the following factors.

1. Increasing the *speed* of the conductors through the magnetic field
2. Increasing the *number* of conductors passing through the magnetic field
3. Increasing the *strength* of the magnetic field

CHANGING AC TO DC An alternator generates an alternating current (AC) because the current changes polarity during the alternator's rotation. However, a battery cannot "store" alternating current; therefore, this alternating current is changed to direct current (DC) by diodes inside the alternator. Diodes are one-way electrical check valves that permit current to flow in only one direction.

ALTERNATOR CONSTRUCTION

HOUSING An alternator is constructed using a two-piece cast aluminum housing. Aluminum is used because of its lightweight, nonmagnetic properties and heat transfer properties needed to help keep the alternator cool. A front ball bearing is pressed into the front housing, called the **drive-end (DE) housing,** to provide the support and friction reduction necessary for the belt-driven rotor assembly. The rear housing, or the **slip-ring-end (SRE) housing,** usually contains either a roller bearing or ball bearing support for the rotor and mounting for the brushes, diodes, and internal voltage regulator (if so equipped). ● **SEE FIGURES 54–1 AND 54–2.**

ALTERNATOR OVERRUNNING PULLEYS

PURPOSE AND FUNCTION Many alternators are equipped with an **overrunning alternator pulley (OAP),** also called an *overrunning clutch pulley* or an *alternator clutch pulley*. The purpose of this pulley is to help eliminate noise and vibration in the accessory drive belt system, especially when the engine is at idle speed. At idle, engine impulses are transmitted to the alternator through the accessory drive belt. The mass of the rotor of the alternator tends to want to keep spinning, but the engine crankshaft speeds up and slows down slightly due to the power impulses. Using a one-way clutch in the alternator pulley allows the belt to apply power to the alternator in only one direction, thereby reducing fluctuations in the belt. ● **SEE FIGURES 54–3 AND 54–4.**



FIGURE 54–1 A typical alternator on a Chevrolet V-8 engine.

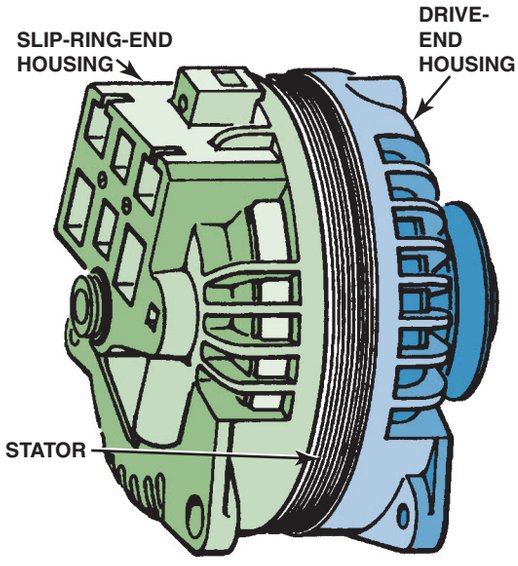


FIGURE 54–2 The end frame toward the drive belt is called the drive-end housing and the rear section is called the slip-ring-end housing.

A conventional drive pulley attaches to the alternator (rotor) shaft with a nut and lock washer. In the overrunning clutch pulley, the inner race of the clutch acts as the nut as it screws on to the shaft. Special tools are required to remove and install this type of pulley.

Another type of alternator pulley uses a dampener spring inside, plus a one-way clutch. These units have the following names.

- **Isolating Decoupler Pulley (IDP)**
- Active Alternator Pulley (AAP)
- Alternator Decoupler Pulley (ADP)
- Alternator Overrunning Decoupler Pulley
- **Overrunning Alternator Dampener (OAD)** (most common term)

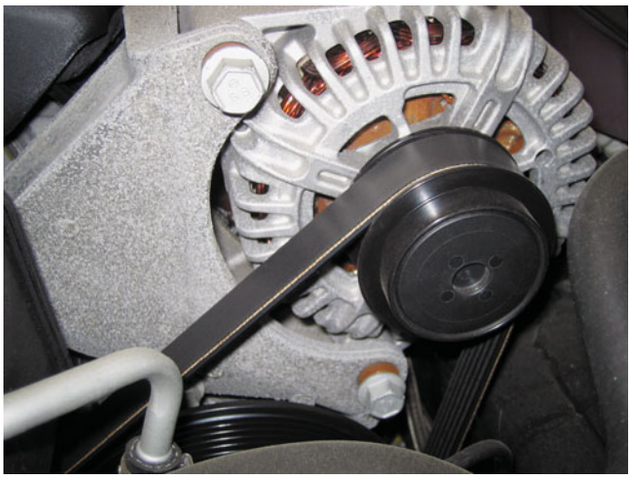


FIGURE 54–3 An OAP on a Chevrolet Corvette alternator.

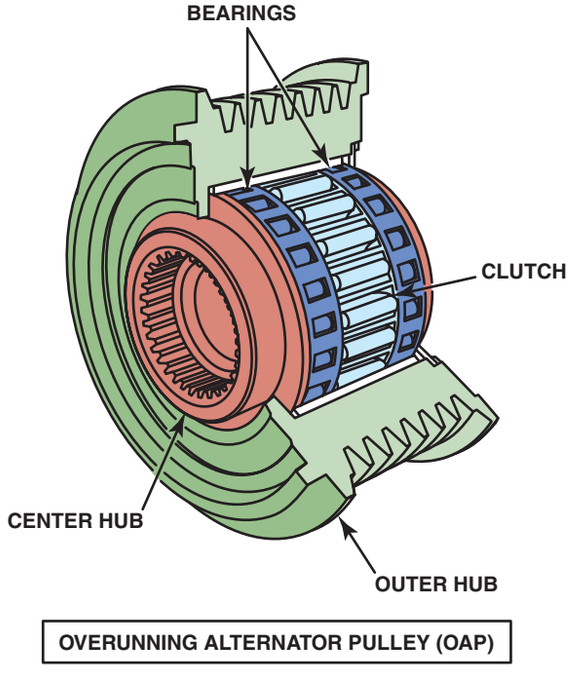


FIGURE 54–4 An exploded view of an overrunning alternator pulley showing all of the internal parts.

OAP or OAD pulleys are primarily used on vehicles equipped with diesel engines or on luxury vehicles where noise and vibration need to be kept at a minimum. Both are designed to:

- Reduce accessory drive belt noise
- Improve the life of the accessory drive belt
- Improve fuel economy by allowing the engine to be operated at a low idle speed

ALTERNATOR COMPONENTS AND OPERATION

ROTOR CONSTRUCTION The **rotor** is the rotating part of the alternator and is driven by the accessory drive belt. The rotor creates the magnetic field of the alternator and produces a current by

TECH TIP

Alternator Horsepower and Engine Operation

Many technicians are asked how much power certain accessories require. A 100 ampere alternator requires about 2 horsepower from the engine. One horsepower is equal to 746 watts. Watts are calculated by multiplying amperes times volts.

Power in watts = 100 A × 14.5 V = 1,450 W
1 hp = 746 W

Therefore, 1,450 watts is about 2 horsepower.

Allowing about 20% for mechanical and electrical losses adds another 0.4 horsepower. Therefore, when someone asks how much power it takes to produce 100 amperes from an alternator, the answer is 2.4 horsepower.

Many alternators delay the electrical load to prevent the engine from stumbling when a heavy electrical load is applied. The voltage regulator or vehicle computer is capable of gradually increasing the output of the alternator over a period of several minutes. Even though 2 horsepower does not sound like much, a sudden demand for 2 horsepower from an idling engine can cause the engine to run rough or stall. The difference in part numbers of various alternators is often an indication of the time interval over which the load is applied. Therefore, using the wrong replacement alternator could cause the engine to stall!

FREQUENTLY ASKED QUESTION

Can I Install an OAP or an OAD to My Alternator?

Usually, no. An alternator needs to be equipped with the proper shaft to allow the installation of an OAP or OAD. This also means that a conventional pulley often cannot be used to replace a defective overrunning alternator pulley or dampener with a conventional pulley. Check service information for the exact procedure to follow.

TECH TIP

Always Check the OAP or OAD First

Overrunning alternator pulleys and overrunning alternator dampeners can fail. The most common factor is the one-way clutch. If it fails, it can freewheel and not power the alternator or it can lock up and not provide the dampening as designed. If the charging system is not working, the OAP or OAD could be the cause, rather than a fault in the alternator itself.

In most cases, the entire alternator assembly will be replaced because each OAP or OAD is unique for each application and both require special tools to remove and replace.

SEE FIGURE 54–5.

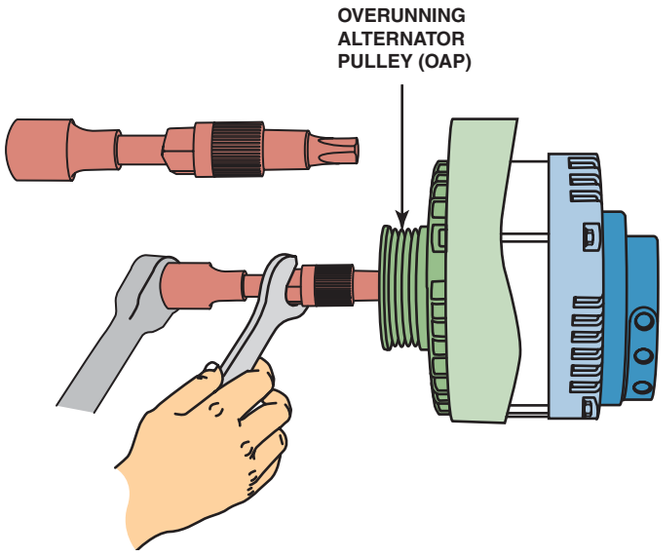


FIGURE 54–5 A special tool is needed to remove and install overrunning alternator pulleys or dampeners.

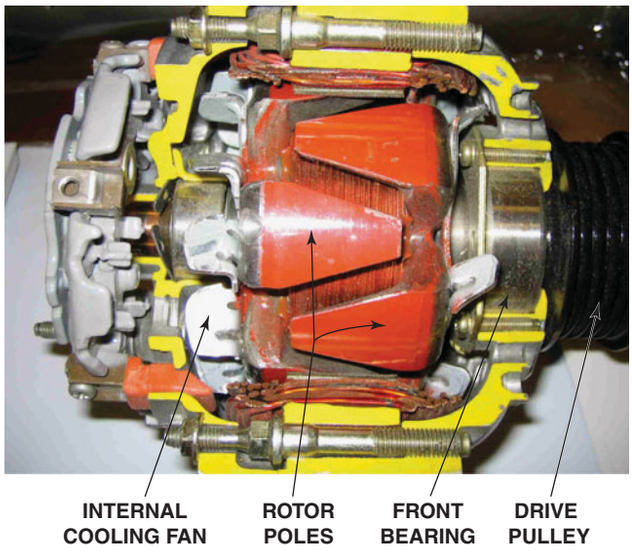


FIGURE 54–6 A cutaway of an alternator, showing the rotor and cooling fan that is used to force air through the unit to remove the heat created when it is charging the battery and supplying electrical power for the vehicle.

electromagnetic induction in the stationary stator windings. The rotor is constructed of many turns of copper wire coated with a varnish insulation wound over an iron core. The iron core is attached to the rotor shaft.

At both ends of the rotor windings are heavy-gauge metal plates bent over the windings with triangular fingers called **claw poles.** These pole fingers do not touch, but alternate or interlace, as shown in ● **FIGURE 54–6.**

HOW ROTORS CREATE MAGNETIC FIELDS

The two ends of the rotor winding are connected to the rotor's slip rings. Current for the rotor flows from the battery into one brush that rides on one of the slip rings, then flows through the rotor winding, then exits the rotor through the other slip ring and brush. One alternator brush is considered to be the "positive" brush and one is considered to be the "negative" or "ground" brush. The voltage regulator is connected to either the positive or the negative brush and controls the field current through the rotor that controls the output of the alternator.

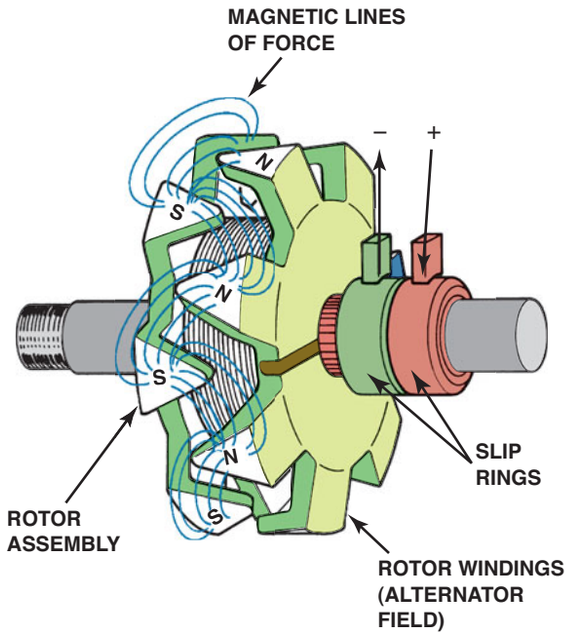


FIGURE 54–7 Rotor assembly of a typical alternator. Current through the slip rings causes the "fingers" of the rotor to become alternating north and south magnetic poles. As the rotor revolves, these magnetic lines of force induce a current in the stator windings.

If current flows through the rotor windings, the metal pole pieces at each end of the rotor become electromagnets. Whether a north or a south pole magnet is created depends on the *direction* in which the wire coil is wound. Because the pole pieces are attached to each end of the rotor, one pole piece will be a north pole magnet. The other pole piece is on the opposite end of the rotor and therefore is viewed as being wound in the opposite direction, creating a south pole. Therefore, the rotor fingers are alternating north and south magnetic poles. The magnetic fields are created between the alternating pole piece fingers. These individual magnetic fields produce a current by electromagnetic induction in the stationary stator windings. ● **SEE FIGURE 54–7.**

ROTOR CURRENT

The current necessary for the field (rotor) windings is conducted through slip rings with carbon brushes. The maximum rated alternator output in amperes depends on the number and gauge of the rotor windings. Substituting rotors from one alternator to another can greatly affect maximum output. Many commercially rebuilt alternators are tested and then display a sticker to indicate their tested output. The original rating stamped on the housing is then ground off.

The current for the field is controlled by the voltage regulator and is conducted to the slip rings through carbon brushes. The brushes conduct only the field current which is usually between 2 and 5 amperes.

STATOR CONSTRUCTION

The **stator** consists of the stationary coil windings inside the alternator. The stator is supported between the two halves of the alternator housing, with three copper wire windings that are wound on a laminated metal core.

As the rotor revolves, its moving magnetic field induces a current in the stator windings. ● **SEE FIGURE 54–8.**

DIODES

Diodes are constructed of a semiconductor material (usually silicon) and operate as a one-way electrical check valve that permits the current to flow in only one direction. Alternators often

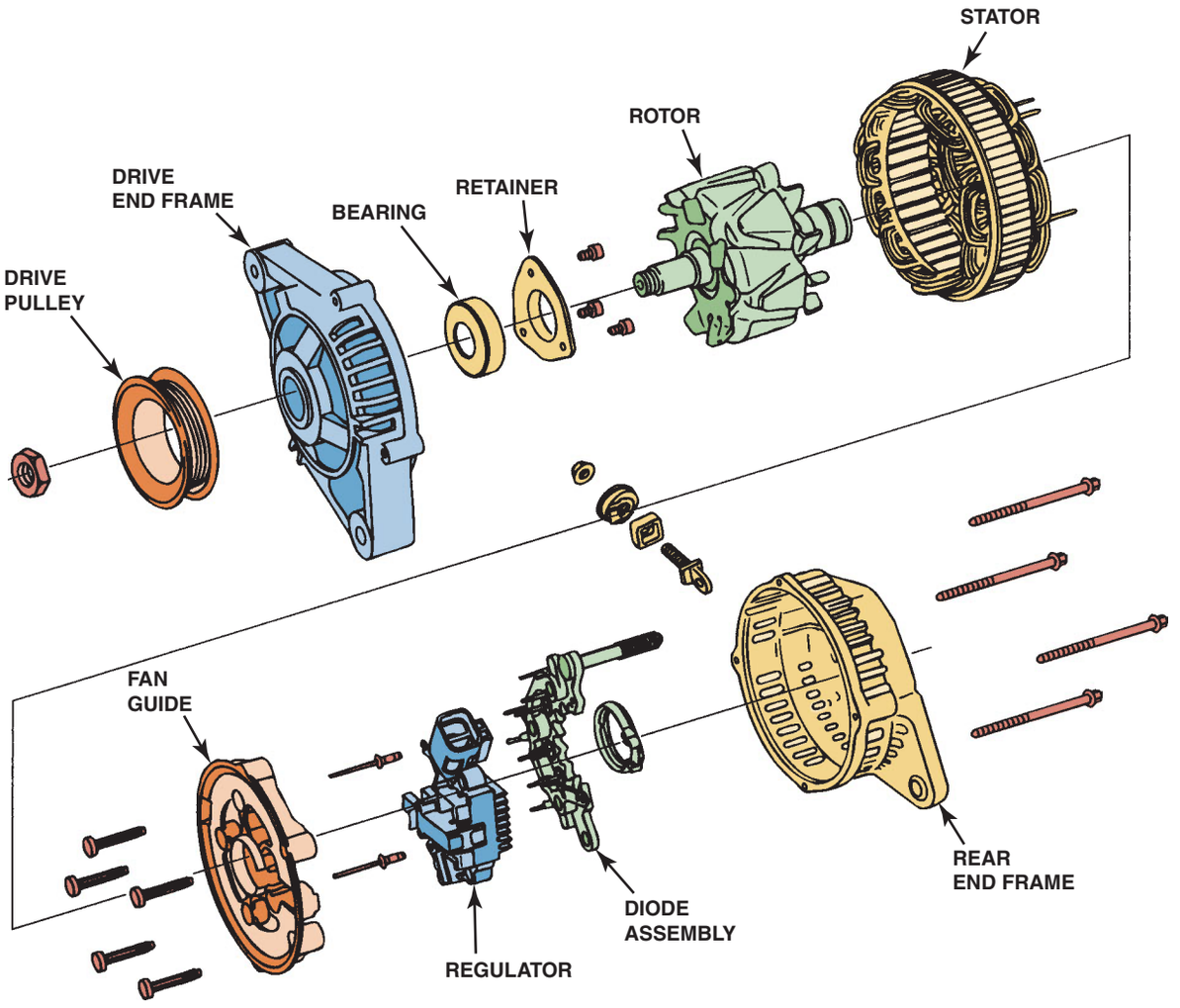


FIGURE 54–8 An exploded view of a typical alternator showing all of its internal parts including the stator windings.

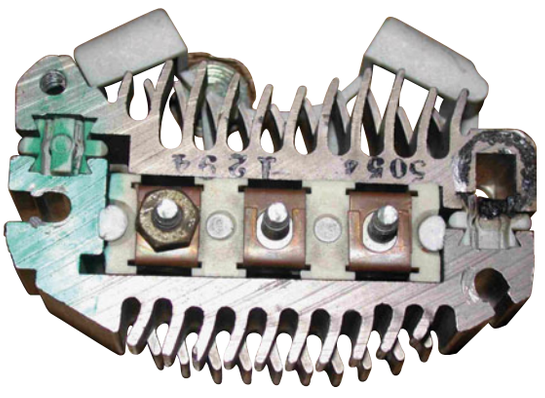


FIGURE 54–9 A rectifier usually includes six diodes in one assembly and is used to rectify AC voltage from the stator windings into DC voltage suitable for use by the battery and electrical devices in the vehicle.

use six diodes (one positive and one negative set for each of the three stator windings) to convert alternating current to direct current.

Diodes used in alternators are included in a single part called a **rectifier,** or *rectifier bridge*. A rectifier not only includes the diodes (usually six), but also the cooling fins and connections for the stator windings and the voltage regulator. ● **SEE FIGURE 54–9.**

DIODE TRIO Some alternators are equipped with a diode trio that supplies current to the brushes from the stator windings. A diode trio uses three diodes, in one housing, with one diode for each of the three stator windings and then one output terminal.

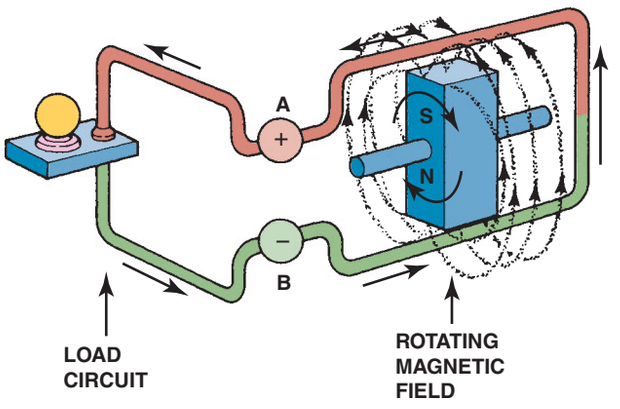


FIGURE 54–10 Magnetic lines of force cutting across a conductor induce a voltage and current in the conductor.

HOW AN ALTERNATOR WORKS

FIELD CURRENT IS PRODUCED A rotor inside an alternator is turned by a belt and drive pulley which are turned by the engine. The magnetic field of the rotor generates a current in the stator windings by electromagnetic induction. ● **SEE FIGURE 54–10.**

Field current flowing through the slip rings to the rotor creates an alternating north and south pole on the rotor, with a magnetic field between each finger of the rotor.

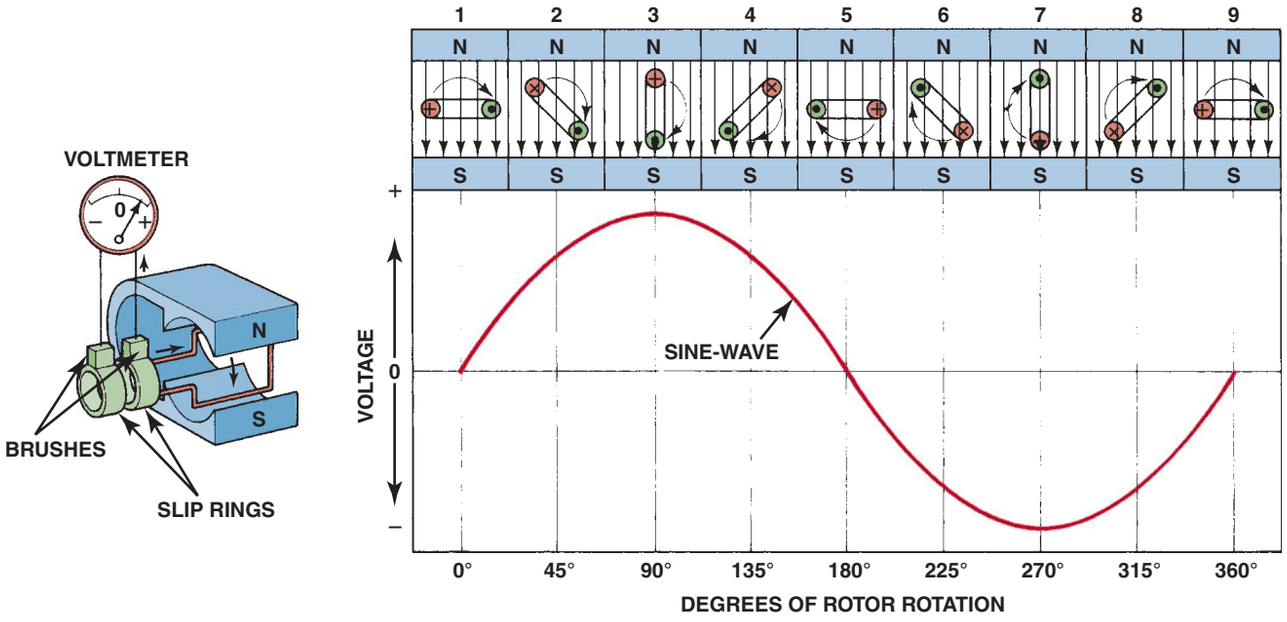


FIGURE 54–11 A sine wave (shaped like the letter *S* on its side) voltage curve is created by one revolution of a winding as it rotates in a magnetic field.

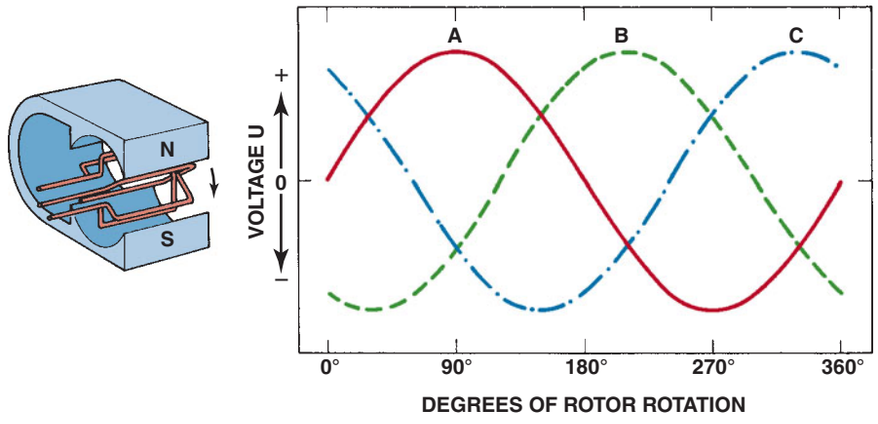


FIGURE 54–12 When three windings (A, B, and C) are present in a stator, the resulting current generation is represented by the three sine waves. The voltages are 120 degrees out of phase. The connection of the individual phases produces a three-phase alternating voltage.

CURRENT IS INDUCED IN THE STATOR

The induced current in the stator windings is an alternating current because of the alternating magnetic field of the rotor. The induced current starts to increase as the magnetic field starts to induce current in each winding of the stator. The current then peaks when the magnetic field is the strongest and starts to decrease as the magnetic field moves away from the stator winding. Therefore, the current generated is described as being of a sine wave or alternating current pattern. ● **SEE FIGURE 54–11.**

As the rotor continues to rotate, this sine wave current is induced in each of the three windings of the stator.

Because each of the three windings generates a sine wave current, as shown in ● **FIGURE 54–12,** the resulting currents combine to form a three-phase voltage output.

The current induced in the stator windings connects to diodes (one-way electrical check valves) that permit the alternator output current to flow in only one direction. All alternators contain six diodes, one pair (a positive and a negative diode) for each of the three stator windings. Some alternators contain eight diodes with another pair connected to the center connection of a wye-type stator.

WYE-CONNECTED STATORS

The Y (pronounced "wye" and generally so written) type or star pattern is the most commonly used alternator stator winding connection. ● **SEE FIGURE 54–13.**

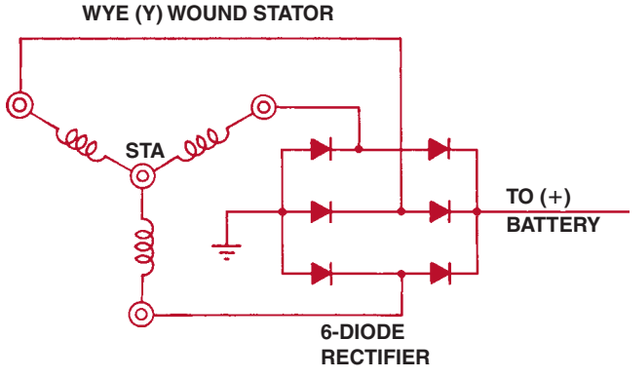


FIGURE 54–13 Wye-connected stator winding.

The output current with a wye-type stator connection is constant over a broad alternator speed range.

Current is induced in each winding by electromagnetic induction from the rotating magnetic fields of the rotor. In a wye-type stator connection, the currents must combine because two windings are always connected in series. ● **SEE FIGURE 54–14.**

The current produced in each winding is added to the other windings' current and then flows through the diodes to the alternator output terminal. One-half of the current produced is available at the

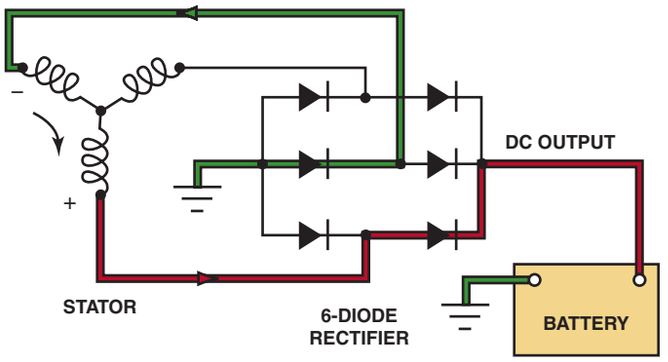


FIGURE 54–14 As the magnetic field, created in the rotor, cuts across the windings of the stator, a current is induced. Notice that the current path includes passing through one positive (+) diode on the way to the battery and one negative (−) diode as a complete circuit is completed through the rectifier and stator.

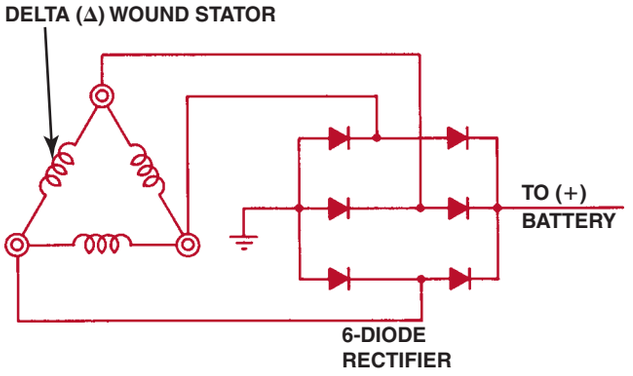


FIGURE 54–15 Delta-connected stator winding.

neutral junction (usually labeled "STA" for stator). The voltage at this center point is used by some alternator manufacturers (especially Ford) to control the charge indicator light or is used by the voltage regulator to control the rotor field current.

DELTA-CONNECTED STATORS The **delta winding** is connected in a triangular shape. Delta is a Greek letter shaped like a triangle. ● **SEE FIGURE 54–15.**

Current induced in each winding flows to the diodes in a parallel circuit. More current can flow through two parallel circuits than can flow through a series circuit (as in a wye-type stator connection).

Delta-connected stators are used on alternators where high output at high-alternator RPM is required. The delta-connected alternator can produce 73% more current than the same alternator with wye-type stator connections. For example, if an alternator with a wye-connected stator can produce 55 A, the *same* alternator with delta-connected stator windings can produce 73% more current, or 95 A (55 × 1.73 = 95). The delta-connected alternator, however, produces lower current at low speed and must be operated at high speed to produce its maximum output.

ALTERNATOR OUTPUT FACTORS

The output voltage and current of an alternator depend on the following factors.

1. **Speed of rotation.** Alternator output is increased with alternator rotational speed up to the alternator's maximum possible ampere output. Alternators normally rotate at a speed two to three times faster than engine speed, depending on the relative pulley sizes used for the belt drive. For example, if an engine is operating at 5000 RPM, the alternator will be rotating at about 15,000 RPM.
2. **Number of conductors.** A high-output alternator contains more turns of wire in the stator windings. Stator winding connections (whether wye or delta) also affect the maximum alternator output. ● **SEE FIGURE 54–16** for an example of a stator that has six rather than three windings, which greatly increases the amperage output of the alternator.
3. **Strength of the magnetic field.** If the magnetic field is strong, a high output is possible because the current generated by electromagnetic induction is dependent on the number of magnetic lines of force that are cut.
   a. The strength of the magnetic field can be increased by increasing the number of turns of conductor wire wound on the rotor. A higher output alternator rotor has more turns of wire than an alternator rotor with a low rated output.
   b. The strength of the magnetic field also depends on the current through the field coil (rotor). Because magnetic field strength is measured in ampere-turns, the greater the amperage or the number of turns, or both, the greater the alternator output.



FIGURE 54–16 A stator assembly with six, rather than the normal three, windings.

ALTERNATOR VOLTAGE REGULATION

PRINCIPLES An automotive alternator must be able to produce electrical pressure (voltage) higher than battery voltage to charge the battery. Excessively high voltage can damage the battery, electrical components, and the lights of a vehicle. Basic principles include the following:

- If no (zero) amperes of current existed throughout the field coil of the alternator (rotor), alternator output would be zero because without field current a magnetic field does not exist.
- The field current required by most automotive alternators is less than 3 amperes. It is the *control* of the *field* current that controls the output of the alternator.
- Current for the rotor flows from the battery positive post, through the rotor positive brush, into the rotor field winding, and exits the rotor winding through the rotor ground brush. Most voltage regulators control field current by controlling the amount of field current through the ground brush.
- The voltage regulator simply opens the field circuit if the voltage reaches a predetermined level, then closes the field

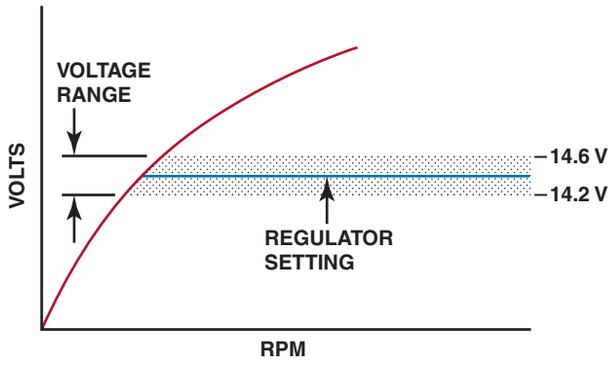


FIGURE 54–17 Typical voltage regulator range.

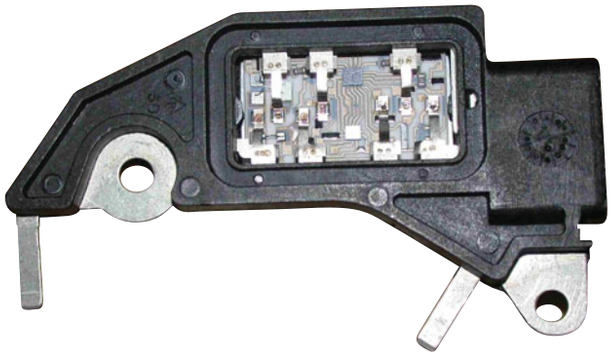


FIGURE 54–18 A typical electronic voltage regulator with the cover removed showing the circuits inside.

circuit again as necessary to maintain the correct charging voltage. ● **SEE FIGURE 54–17.**

- The electronic circuit of the voltage regulator cycles between 10 and 7,000 times per *second* as needed to accurately control the field current through the rotor, and therefore control the alternator output.

REGULATOR OPERATION

- The control of the field current is accomplished by opening and closing the *ground* side of the field circuit through the rotor on most alternators.
- The zener diode is a major electronic component that makes voltage regulation possible. A zener diode blocks current flow until a specific voltage is reached, then it permits current to flow. Alternator voltage from the stator and diodes is first sent through a thermistor, which changes resistance with temperature, and then to a zener diode. When the upper-limit voltage is reached, the zener diode conducts current to a transistor, which then opens the field (rotor) circuit. The electronics are usually housed in a separate part inside the alternator. ● **SEE FIGURES 54–18 AND 54–19.**

BATTERY CONDITION AND CHARGING VOLTAGE If the automotive battery is discharged, its voltage will be lower than the voltage of a fully charged battery. The alternator will supply charging current, but it may not reach the maximum charging voltage. For example, if a vehicle is jump started and run at a fast idle (2,000 RPM), the charging voltage may be only 12 volts. In this case, the following may occur.

- As the battery becomes charged and the battery voltage increases, the charging voltage will also increase, until the voltage regulator limit is reached.

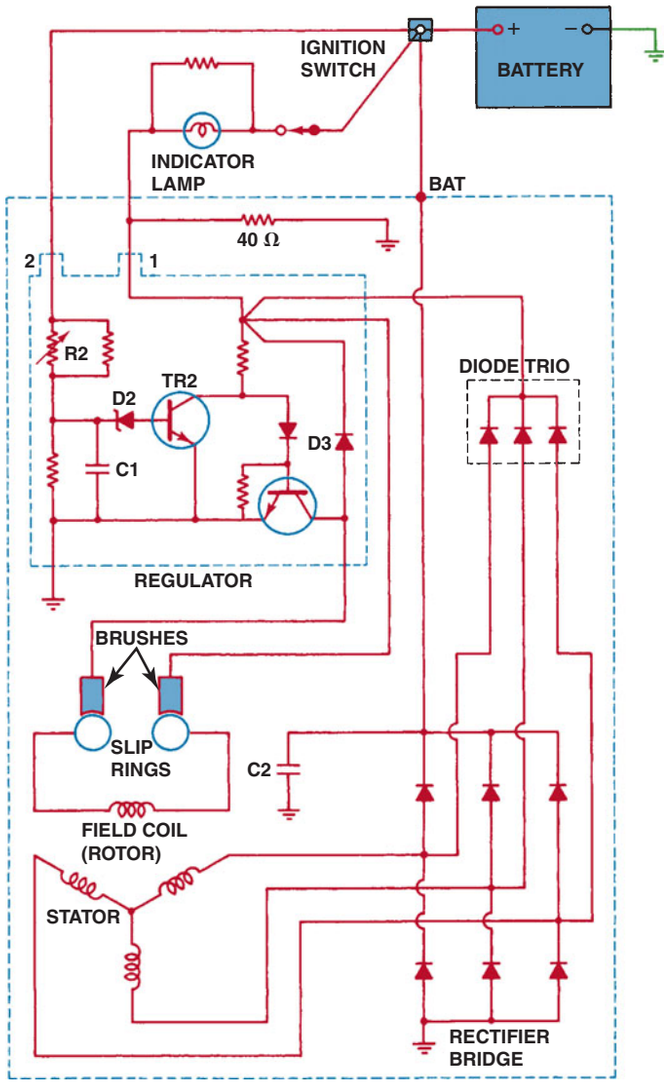


FIGURE 54–19 Typical General Motors SI-style alternator with an integral voltage regulator. Voltage present at terminal 2 is used to reverse bias the zener diode (D2) that controls TR2. The positive brush is fed by the ignition current (terminal I) plus current from the diode trio.

- Then the voltage regulator will start to control the charging voltage. A good, but discharged, battery should be able to convert into chemical energy all the current the alternator can produce. As long as alternator voltage is higher than battery voltage, current will flow from the alternator (high voltage) to the battery (lower voltage).
- Therefore, if a voltmeter is connected to a discharged battery with the engine running, it may indicate charging voltage that is lower than normally acceptable.

In other words, the condition and voltage of the battery *do* determine the charging rate of the alternator. It is often stated that the battery is the true "voltage regulator" and that the voltage regulator simply acts as the upper-limit voltage control. This is the reason why all charging system testing *must* be performed with a reliable and known to be good battery, at least 75% charged, to be assured of accurate test results. If a discharged battery is used during charging system testing, tests could mistakenly indicate a defective alternator and/or voltage regulator and could cause the stator windings to overheat.

TEMPERATURE COMPENSATION All voltage regulators (mechanical or electronic) provide a method for increasing the charging

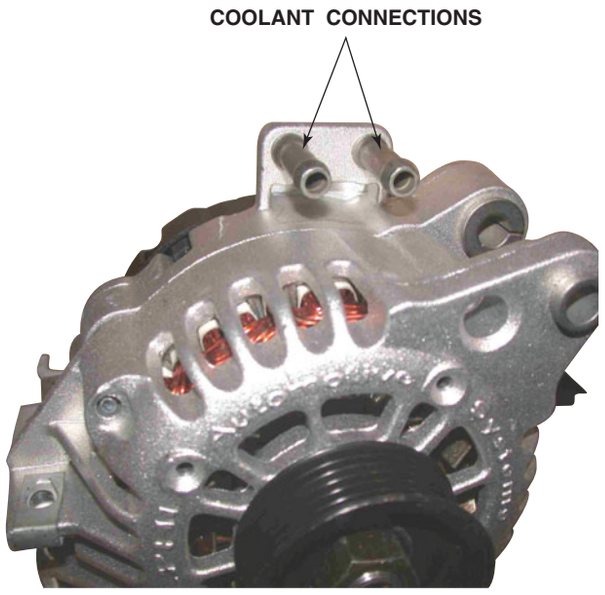


FIGURE 54–20 A coolant-cooled alternator showing the hose connections where coolant from the engine flows through the rear frame of the alternator.

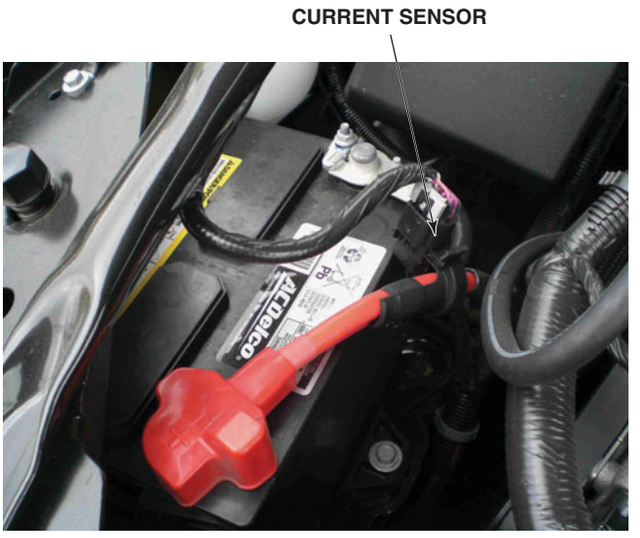


FIGURE 54–21 A Hall-effect current sensor attached to the positive battery cable is used as part of the EPM system.

voltage slightly at low temperatures and for lowering the charging voltage at high temperatures. A battery requires a higher charging voltage at low temperatures because of the resistance to chemical reaction changes. However, the battery would be overcharged if the charging voltage were not reduced during warm weather. Electronic voltage regulators use a temperature-sensitive resistor in the regulator circuit. This resistor, called a **thermistor,** provides lower resistance as the temperature increases. A thermistor is used in the electronic circuits of the voltage regulator to control charging voltage over a wide range of underhood temperatures.

NOTE: Voltmeter test results may vary according to temperature. Charging voltage tested at 32°F (0°C) will be higher than for the same vehicle tested at 80°F (27°C) because of the temperature-compensation factors built into voltage regulators.

ALTERNATOR COOLING

Alternators create heat during normal operation and this heat must be removed to protect the components inside, especially the diodes and voltage regulator. The types of cooling include:

- External fan
- Internal fan(s)
- Both an external fan and an internal fan
- Coolant cooled (● **SEE FIGURE 54–20.**)

COMPUTER-CONTROLLED ALTERNATORS

TYPES OF SYSTEMS

Computers can interface with the charging system in three ways.

1. The computer can *activate* the charging system by turning on and off the field current to the rotor. In other words, the computer, usually the powertrain control module (PCM), controls the field current to the rotor.
2. The computer can *monitor* the operation of the alternator and increase engine speed if needed during conditions when a heavy load is demanded by the alternator.
3. The computer can *control* the alternator by controlling alternator output to match the needs of the electrical system. This system detects the electrical needs of the vehicle and commands the alternator to charge only when needed to improve fuel economy.

GM ELECTRICAL POWER MANAGEMENT SYSTEM

A typical system used on some General Motors vehicles is called **electrical power management (EPM).** It uses a Hall-effect sensor attached to the negative or positive battery cable to measure the current leaving and entering the battery. ● **SEE FIGURE 54–21.**

The engine control module (ECM) controls the alternator by changing the on-time of the current through the rotor. ● **SEE FIGURE 54–22.**

The on-time, called **duty cycle,** varies from 5% to 95%. ● **SEE CHART 54–1.**

This system has six modes of operation.

1. **Charge mode.** The charge mode is activated when any of the following occurs.
   - Electric cooling fans are on high speed.
   - Rear window defogger is on.
   - Battery state of charge (SOC) is less than 80%.
   - Outside (ambient) temperature is less than 32°F (0°C).
2. **Fuel economy mode.** This mode reduces the load on the engine from the alternator for maximum fuel economy. This mode is activated when the following conditions are met.
   - Ambient temperature is above 32°F (0°C).
   - The state of charge of the battery is 80% or higher.
   - The cooling fans and rear defogger are off.

   The target voltage is 13 volts and will return to the charge mode, if needed.
3. **Voltage reduction mode.** This mode is commanded to reduce the stress on the battery during low-load conditions. This mode is activated when the following conditions are met.
   - Ambient temperature is above 32°F (0°C).
   - Battery discharge rate is less than 7 amperes.
   - Rear defogger is off.
   - Cooling fans are on low or off.
   - Target voltage is limited to 12.7 volts.

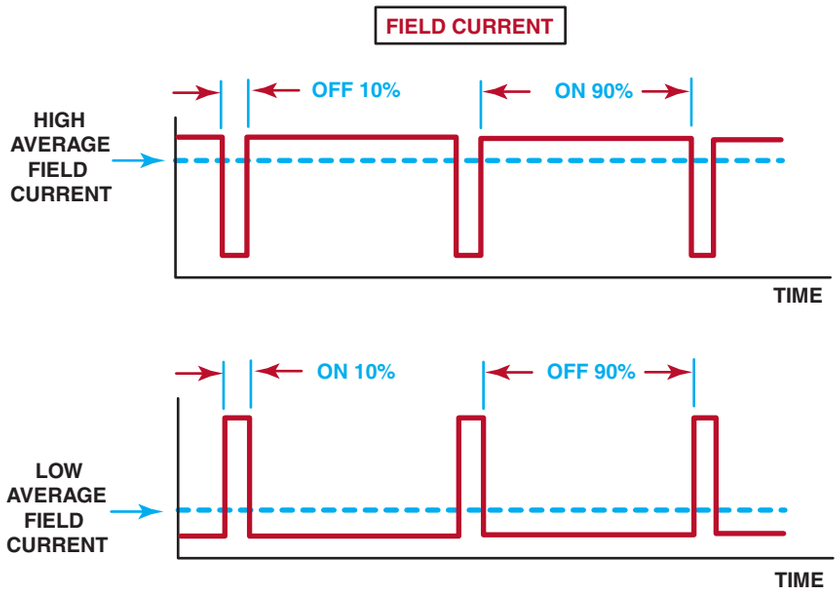


FIGURE 54–22 The amount of time current is flowing through the field (rotor) determines the alternator output.

COMMAND DUTY CYCLE	ALTERNATOR OUTPUT VOLTAGE
10%	11.0 V
20%	11.6 V
30%	12.1 V
40%	12.7 V
50%	13.3 V
60%	13.8 V
70%	14.4 V
80%	14.9 V
90%	15.5 V

CHART 54–1

The output voltage is controlled by varying the duty cycle as controlled by the PCM.

TECH TIP

The Voltage Display Can Be a Customer Concern

A customer may complain that the voltmeter reading on the dash fluctuates up and down. This may be normal as the computer-controlled charging system commands various modes of operation based on the operating conditions. Follow the vehicle manufacturer's recommended procedures to verify proper operation.

4. **Start-up mode.** This mode is selected after engine start and commands a charging voltage of 14.5 volts for 30 seconds. After 30 seconds, the mode is changed depending on conditions.
5. **Battery sulfation mode.** This mode is commanded if the output voltage is less than 13.2 volts for 45 minutes, which can indicate that sulfated plates could be the cause. The target voltage is 13.9 to 15.5 volts for three minutes. After three minutes, the system returns to another mode based on conditions.
6. **Headlight mode.** This mode is selected when the headlights are on and the target voltage is 14.5 volts.

COMPUTER-CONTROLLED CHARGING SYSTEMS

Computer control of the charging system has the following advantages.

1. The computer controls the field of the alternator, which can pulse it on or off as needed for maximum efficiency, thereby saving fuel.

   NOTE: Some vehicle manufacturers, such as Honda/Acura, use an *electronic load control (ELC)*, which turns on the alternator when decelerating, where the additional load on the engine is simply used to help slow the vehicle. This allows the battery to be charged without placing a load on the engine, helping to increase fuel economy.

2. Engine idle can also be improved by turning on the alternator slowly, rather than all at once, if an electrical load is switched on, such as the air-conditioning system.
3. Most computers can also reduce the load on the electrical system if the demand exceeds the capacity of the charging system by reducing fan speed, shutting off rear window defoggers, or increasing engine speed to cause the alternator to increase the amperage output.

   NOTE: A commanded higher-than-normal idle speed may be the result of the computer compensating for an abnormal electrical load. This higher idle speed could indicate a defective battery or other electrical system faults.

4. The computer can monitor the charging system and set diagnostic trouble codes (DTCs) if a fault is detected. Many systems allow the service technician to control the charging of the alternator using a scan tool.
5. Because the charging system is computer controlled, it can be checked using a scan tool. Some vehicle systems allow the scan tool to activate the alternator field and then monitor the output to help detect fault locations. Always follow the vehicle manufacturer's diagnostic procedure.

REVIEW QUESTIONS

1. How can a small electronic voltage regulator control the output of a typical 100 ampere alternator?
2. What are the component parts of a typical alternator?
3. How is the computer used to control an alternator?
4. Why do voltage regulators include temperature compensation?
5. How is AC voltage inside the alternator changed to DC voltage at the output terminal?
6. What is the purpose of an OAP or OAD?

CHAPTER QUIZ

1. Technician A says that the diodes regulate the alternator output voltage. Technician B says that the field current can be computer controlled. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. A magnetic field is created in the _____ in an alternator (AC alternator).
   a. Stator **c.** Rotor
   b. Diodes **d.** Drive-end frame
3. The voltage regulator controls current through the _____.
   a. Alternator brushes **c.** Alternator field
   b. Rotor **d.** All of the above
4. Technician A says that two diodes are required for each stator winding lead. Technician B says that diodes change alternating current into direct current. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
5. The alternator output current is produced in the _____.
   a. Stator **c.** Brushes
   b. Rotor **d.** Diodes (rectifier bridge)
6. Alternator brushes are constructed from _____.
   a. Copper **c.** Carbon
   b. Aluminum **d.** Silver-copper alloy
7. How much current flows through the alternator brushes?
   a. All of the alternator output flows through the brushes
   b. 25 to 35 A, depending on the vehicle
   c. 10 to 15 A
   d. 2 to 5 A
8. Technician A says that an alternator overrunning pulley is used to reduce vibration and noise. Technician B says that an overrunning alternator pulley or dampener uses a one-way clutch. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. Operating an alternator in a vehicle with a defective battery can harm the _____.
   a. Diodes (rectifier bridge)
   b. Stator
   c. Voltage regulator
   d. Brushes
10. Technician A says that a wye-wound stator produces more maximum output than the same alternator equipped with a delta-wound stator. Technician B says that an alternator equipped with a delta-wound stator produces more maximum output than a wye-wound stator. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

chapter 55

CHARGING SYSTEM DIAGNOSIS AND SERVICE

OBJECTIVES: **After studying Chapter 55, the reader will be able to:** • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "D" (Charging System Diagnosis and Repair). • Describe how to perform a charging voltage test. • Discuss how to perform an AC ripple voltage test. • Explain how to perform an alternator output test. • Explain how to disassemble an alternator and test its component parts. • Discuss how to check the wiring from the alternator to the battery. • Describe how to test the operation of a computer-controlled charging system.

KEY TERMS: AC ripple voltage 590 • Alternator output test 592 • Charging voltage test 588 • Cores 597



FIGURE 55–1 The digital multimeter should be set to read DC volts, with the red lead connected to the positive (+) battery terminal and the black meter lead connected to the negative (−) battery terminal.



FIGURE 55–2 A scan tool can be used to diagnose charging system problems.

CHARGING SYSTEM TESTING AND SERVICE

BATTERY STATE OF CHARGE

The charging system can be tested as part of a routine vehicle inspection or to determine the reason for a no-charge or reduced charging circuit performance. The battery *must* be at least 75% charged before testing the alternator and the charging system. A weak or defective battery will cause inaccurate test results. If in doubt, replace the battery with a known good shop battery for testing.

CHARGING VOLTAGE TEST

The **charging voltage test** is the easiest way to check the charging system voltage at the battery. Use a digital multimeter to check the voltage, as follows:

STEP 1 Select DC volts.

STEP 2 Connect the red meter lead to the positive (+) terminal of the battery and the black meter lead to the negative (−) terminal of the battery.

NOTE: The polarity of the meter leads is not too important when using a digital multimeter. If the meter leads are connected backward on the battery, the resulting readout will simply have a negative (−) sign in front of the voltage reading.

STEP 3 Start the engine and increase the engine speed to about 2000 RPM (fast idle) and record the charging voltage. ● **SEE FIGURE 55–1**.

Specifications for charging voltage = 13.5 to 15 V

- If the voltage is too high, check that the alternator is properly grounded.
- If the voltage is lower than specifications, then there is a fault with the wiring or the alternator.
- If the wiring and the connections are okay, then additional testing is required to help pinpoint the root cause. Replacement of the alternator and/or battery is often required if the charging voltage is not within factory specifications.

? FREQUENTLY ASKED QUESTION

What Is a Full-Fielding Test?

Full fielding is a procedure used on older noncomputerized vehicles for bypassing the voltage regulator that could be used to determine if the alternator is capable of producing its designed output. This test is no longer performed for the following reasons.

- The voltage regulator is built into the alternator, therefore requiring that the entire assembly be replaced even if just the regulator is defective.
- When the regulator is bypassed, the alternator can produce a high voltage (over 100 volts in some cases) which could damage all of the electronic circuits in the vehicle.

Always follow the vehicle manufacturer's recommended testing procedures.

SCAN TESTING THE CHARGING CIRCUIT

Most vehicles that use a computer-controlled charging system can be diagnosed using a scan tool. Not only can the charging voltage be monitored, but also in many vehicles, the field circuit can be controlled and the output voltage monitored to check that the system is operating correctly. ● **SEE FIGURE 55–2**.

NOTE: Some charging systems, such as those on many Honda/Acura vehicles, use an electronic load detection circuit that energizes the field circuit only when an electrical load is detected. For example, if the engine is running and there are no accessories on, the voltage read at the battery may be 12.6 V, which could indicate that the charging system is not operating. In this situation, turning on the headlights or an accessory should cause the computer to activate the field circuit, and the alternator should produce normal charging voltage.

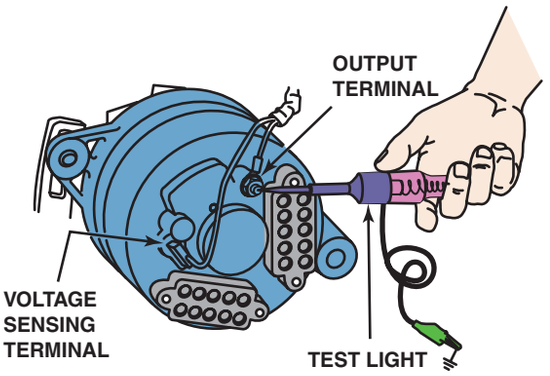


FIGURE 55–3 Before replacing an alternator, the wise technician checks that battery voltage is present at the output and battery voltage sense terminals. If not, then there is a fault in the wiring.

TECH TIP

Use a Test Light to Check for a Defective Fusible Link

Most alternators use a fusible link or mega fuse between the output terminal and the positive (+) terminal of the battery. If this fusible link or fuse is defective (blown), then the charging system will not operate at all. Many alternators have been replaced repeatedly because of a blown fusible link that was not discovered until later. A quick and easy test to check if the fusible link is okay is to touch a test light to the output terminal. With the other end of the test light attached to a good ground, the fusible link or mega fuse is okay if the light lights. This test confirms that the circuit between the alternator and the battery has continuity. ● **SEE FIGURE 55–3**.

DRIVE BELT INSPECTION AND ADJUSTMENT

BELT VISUAL INSPECTION It is generally recommended that all belts be inspected regularly and replaced as needed. Replace any serpentine belt that has more than three cracks in any one rib that appears in a 3 in. span. Check service information for the specified procedure and recommended replacement interval. ● **SEE FIGURE 55–4**.

BELT TENSION MEASUREMENT If the vehicle does not use a belt tensioner, then a belt tension gauge is needed to achieve the specified belt tension. Install the belt and operate the engine with all of the accessories turned on to "run-in" the belt for at least five minutes. Adjust the tension of the accessory drive belt to factory specifications or use the following table for an example of the proper tension based on the size of the belt.

There are four ways that vehicle manufacturers specify that the belt tension is within factory specifications.

1. **Belt tension gauge.** A belt tension gauge is needed to determine if it is at the specified belt tension. Install the belt and operate the engine with all of the accessories turned on to "run-in" the belt for at least five minutes. Adjust the tension of the accessory drive belt to factory specifications, or see ● **CHART 55–1** for an example of the proper tension based on the size of the belt.
2. **Marks on a tensioner.** Many tensioners have marks that indicate the normal operating tension range for the accessory drive belt. Check service information for the preferred location of the tensioner mark. ● **SEE FIGURE 55–5**.

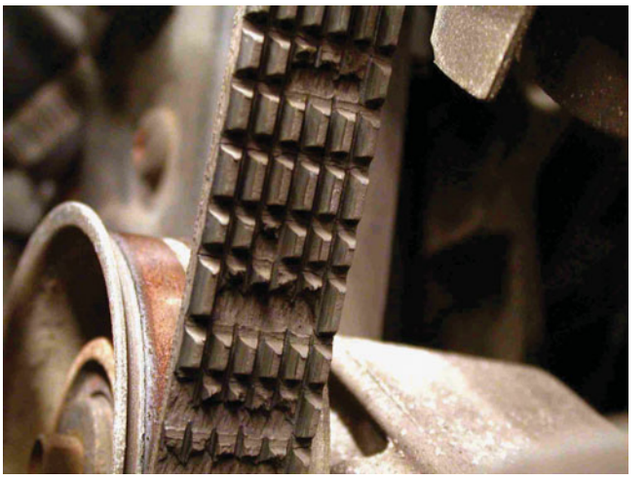


FIGURE 55–4 This accessory drive belt is worn and requires replacement. Newer belts are made from ethylene propylene diene monomer (EPDM). This rubber does not crack like older belts and may not show wear even though the ribs do wear and can cause slippage.

TECH TIP

The Hand Cleaner Trick

Lower-than-normal alternator output could be the result of a loose or slipping drive belt. All belts (V and serpentine multigroove) use an interference angle between the angle of the Vs of the belt and the angle of the Vs on the pulley. As the belt wears, the interference angles are worn off of both edges of the belt. As a result, the belt may start to slip and make a squealing sound even if tensioned properly.

A common trick used to determine if the noise is belt related is to use grit-type hand cleaner or scouring powder. With the engine off, sprinkle some powder onto the pulley side of the belt. Start the engine. The excess powder will fly into the air, so get away from under the hood when the engine starts. If the belts are now quieter, you know that it was the glazed belt that made the noise.

The noise can sound exactly like a noisy bearing. Therefore, before you start removing and replacing parts, try the hand cleaner trick.

Often, the grit from the hand cleaner will remove the glaze from the belt and the noise will not return. However, if the belt is worn or loose, the noise will return and the belt should be replaced. A fast, alternative method to see if the noise is from the belt is to spray water from a squirt bottle at the belt with the engine running. If the noise stops, the belt is the cause of the noise. The water quickly evaporates and, therefore, unlike the gritty hand cleaner, water simply finds the problem—it does not provide a short-term fix.

SERPENTINE BELTS	
NUMBER OF RIBS USED	TENSION RANGE (LB)
3	45–60
4	60–80
5	75–100
6	90–125
7	105–145
V-BELTS	
V-BELT TOP WIDTH (IN.)	TENSION RANGE (LB)
1/4	45–65
5/16	60–85
25/64	85–115
31/64	105–145

CHART 55–1

Typical belt tension for various widths of belts. Tension is the force needed to depress the belt as displayed on a belt tension gauge.



FIGURE 55–5 Check service information for the exact marks where the tensioner should be located for proper belt tension.

3. **Torque wrench reading.** Some vehicle manufacturers specify that a beam-type torque wrench be used to determine the torque needed to rotate the tensioner. If the torque reading is below specifications, the tensioner must be replaced.
4. **Deflection.** Depress the belt between the two pulleys that are the farthest apart; the flex or deflection should be 1/2 in. (13 mm).

AC RIPPLE VOLTAGE CHECK

PRINCIPLES A good alternator should produce very little AC voltage or current output. It is the purpose of the diodes in the alternator to rectify or convert most AC voltage into DC voltage. While it is normal to measure some AC voltage from an alternator, excessive AC voltage, called AC ripple, is undesirable and indicates a fault with the rectifier diodes or stator windings inside the alternator.

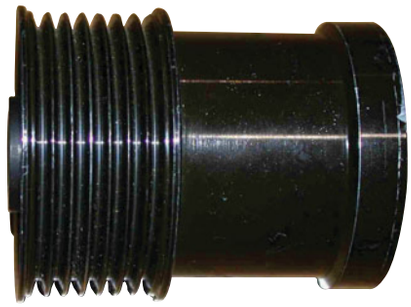


FIGURE 55–6 This overrunning alternator dampener (OAD) is longer than an overrunning alternator pulley (OAP) because it contains a dampener spring as well as a one way clutch. Be sure to check that it locks in one direction.

TECH TIP

Check the Overrunning Clutch

If low or no alternator output is found, remove the alternator drive belt and check the overrunning alternator pulley (OAP) or overrunning alternator dampener (OAD) for proper operation. Both types of overrunning clutches use a one-way clutch. Therefore, the pulley should freewheel in one direction and rotate the alternator rotor when rotated in the opposite direction. ● **SEE FIGURE 55–6.**

TESTING AC RIPPLE VOLTAGE The procedure to check for **AC ripple voltage** includes the following steps.

STEP 1 Set the digital meter to read AC volts.

STEP 2 Start the engine and operate it at 2000 RPM (fast idle).

STEP 3 Connect the voltmeter leads to the positive and negative battery terminals.

STEP 4 Turn on the headlights to provide an electrical load on the alternator.

NOTE: A more accurate reading can be obtained by touching the meter lead to the output or "battery" terminal of the alternator. ● SEE FIGURE 55–7.

The results should be interpreted as follows: If the rectifier diodes are good, the voltmeter should read *less* than 400 mV (0.4 volt) AC. If the reading is over 500 mV (0.5 volt) AC, the rectifier diodes are defective.

NOTE: Many conductance testers, such as Midtronic and Snap-On, automatically test for AC ripple.

TESTING AC RIPPLE CURRENT

All alternators should create direct current (DC) if the diodes and stator windings are functioning correctly. A mini clamp-on meter capable of measuring AC amperes can be used to check the alternator. A good alternator should produce less than 10% of its rated amperage output in AC ripple amperes. For example, an alternator rated at 100 amperes should not produce more than 10 amperes AC ripple (100 × 10% = 10). It is normal for a good alternator to produce 3 or 4 A of AC ripple current to the battery. Only if the AC ripple current exceeds 10% of the rating of the alternator should the alternator be repaired or replaced.

MEASURING THE AC RIPPLE FROM THE ALTERNATOR TELLS A LOT ABOUT ITS CONDITION. IF THE AC RIPPLE IS ABOVE 500 MILLIVOLTS, OR 0.5 VOLTS, LOOK FOR A PROBLEM IN THE DIODES OR STATOR. IF THE RIPPLE IS BELOW 500 MILLIVOLTS, CHECK THE ALTERNATOR OUTPUT TO DETERMINE ITS CONDITION.

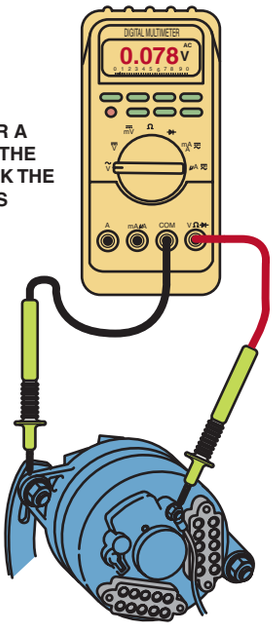


FIGURE 55–7 Testing AC ripple at the output terminal of the alternator is more accurate than testing at the battery due to the resistance of the wiring between the alternator and the battery. The reading shown on the meter, set to AC volts, is only 78 mV (0.078 V), far below what the reading would be if a diode were defective.



FIGURE 55–8 Charging system voltage can be easily checked at the lighter plug by connecting a lighter plug to the voltmeter through a double banana plug.

TECH TIP

The Lighter Plug Trick

Battery voltage measurements can be read through the lighter socket. Simply construct a test tool using a lighter plug at one end of a length of two-conductor wire and the other end connected to a double banana plug. The double banana plug will fit most meters in the common (COM) terminal and the volt terminal of the meter. This is handy to use while road testing the vehicle under real-life conditions. Both DC voltage and AC ripple voltage can be measured. ● **SEE FIGURE 55–8**.



FIGURE 55–9 A mini clamp-on meter can be used to measure alternator output as shown here (105.2 Amp). Then the meter can be used to check AC current ripple by selecting AC Amps on the rotary dial. AC ripple current should be less than 10% of the DC current output.

TEST PROCEDURE To measure the AC current to the battery, perform the following steps.

STEP 1 Start the engine and turn on the lights to create an electrical load on the alternator.

STEP 2 Using a mini clamp-on digital multimeter, place the clamp around either all of the positive (+) battery cables or all of the negative (−) battery cables.

An AC/DC current clamp adapter can also be used with a conventional digital multimeter set on the DC millivolts scale.

STEP 3 To check for AC current ripple, switch the meter to read AC amperes and record the reading. Read the meter display.

STEP 4 The results should be within 10% of the specified alternator rating. A reading of greater than 10 amperes AC indicates defective alternator diodes. ● **SEE FIGURE 55–9**.

CHARGING SYSTEM VOLTAGE DROP TESTING

ALTERNATOR WIRING For the proper operation of any charging system, there must be good electrical connections between the battery positive terminal and the alternator output terminal. The alternator must also be properly grounded to the engine block.

Many manufacturers of vehicles run the lead from the output terminal of the alternator to other connectors or junction blocks that are electrically connected to the positive terminal of the battery. If there is high resistance (a high voltage drop) in these connections or in the wiring itself, the battery will not be properly charged.

VOLTAGE DROP TEST PROCEDURE When there is a suspected charging system problem (with or without a charge indicator light on), simply follow these steps to measure the voltage drop of the insulated (power-side) charging circuit.

STEP 1 Start the engine and run it at a fast idle (about 2000 engine RPM).

STEP 2 Turn on the headlights to ensure an electrical load on the charging system.

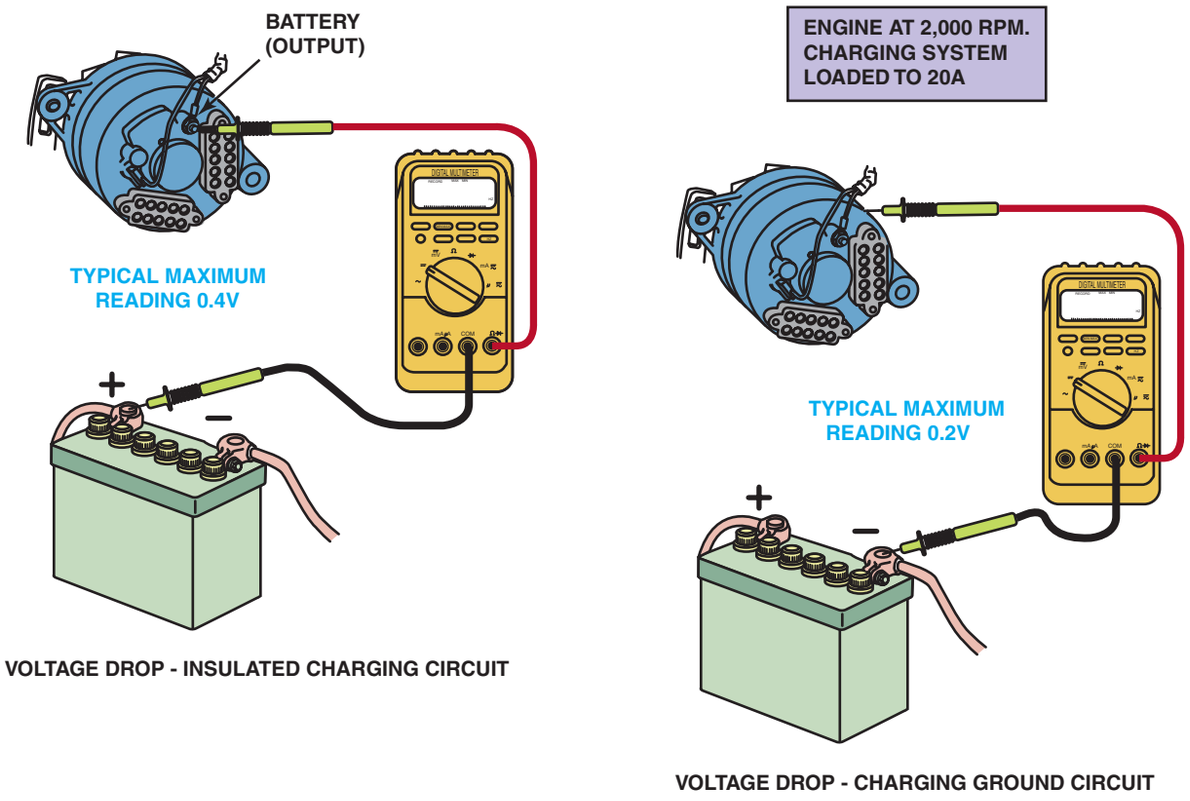


FIGURE 55–10 Voltmeter hookup to test the voltage drop of the charging circuit.

STEP 3 Using any voltmeter set to read DC volts, connect the positive test lead (red) to the output terminal of the alternator. Attach the negative test lead (black) to the positive post of the battery.

The results should be interpreted as follows:

1. If there is less than a 0.4 volt (400 mV) reading, then all wiring and connections are satisfactory.
2. If the voltmeter reads higher than 0.4 volt, there is excessive resistance (voltage drop) between the alternator output terminal and the positive terminal of the battery.
3. If the voltmeter reads battery voltage (or close to battery voltage), there is an open circuit between the battery and the alternator output terminal.

To determine whether the alternator is correctly grounded, maintain the engine speed at 2000 RPM with the headlights on. Connect the positive voltmeter lead to the case of the alternator and the negative voltmeter lead to the negative terminal of the battery. The voltmeter should read less than 0.2 volt (200 mV) if the alternator is properly grounded. If the reading is over 0.2 volt, connect one end of an auxiliary ground wire to the case of the alternator and the other end to a good engine ground. ● **SEE FIGURE 55–10**.



FIGURE 55–11 A typical tester used to test batteries as well as the cranking and charging system. Always follow the operating instructions.

ALTERNATOR OUTPUT TEST

PRELIMINARY CHECKS

An **alternator output test** measures the current (amperes) of the alternator. A charging circuit may be able to produce correct charging circuit voltage, but not be able to produce adequate amperage output. If in doubt about charging system output, first check the condition of the alternator drive belt. With the engine off, attempt to rotate the fan of the alternator by hand. Replace or tighten the drive belt if the alternator fan can be rotated this way.

CARBON PILE TEST PROCEDURE

A carbon pile tester uses plates of carbon to create an electrical load. A carbon pile test is used to load test a battery and/or an alternator. ● **SEE FIGURE 55–11**.

The testing procedure for alternator output is as follows:

STEP 1 Connect the starting and charging test leads according to the manufacturer's instructions, which usually include installing the amp clamp around the output wire near the alternator.

STEP 2 Turn off all electrical accessories to be sure that the tester is measuring the true output of the alternator.

STEP 3 Start the engine and operate it at 2000 RPM (fast idle). Turn the load increase control slowly to obtain the highest reading on the ammeter scale. Do not allow the voltage to drop below 12.6 volts. Note the ampere reading.

STEP 4 Add 5 to 7 amperes to the reading because this amount of current is used by the ignition system to operate the engine.

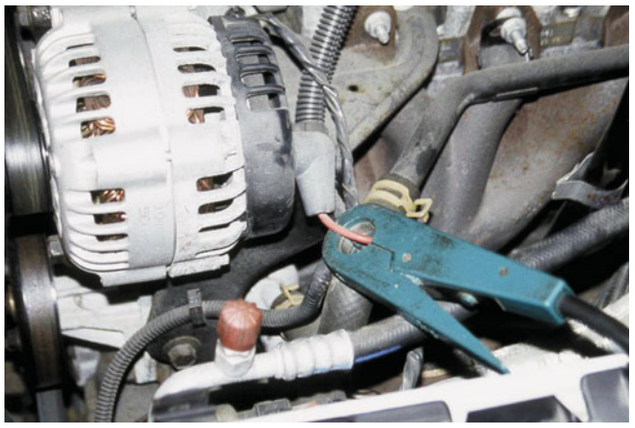


FIGURE 55–12 The best place to install a charging system tester amp probe is around the alternator output terminal wire, as shown.

STEP 5 Compare the output reading to factory specifications. The rated output may be stamped on the alternator or can be found in service information.

CAUTION: *NEVER* disconnect a battery cable with the engine running. All vehicle manufacturers warn not to do this, because this was an old test, before alternators, to see if a generator could supply current to operate the ignition system without a battery. When a battery cable is removed, the alternator (or PCM) will lose the battery voltage sense signal. Without a battery voltage sense circuit, the alternator will do one of two things, depending on the make and model of vehicle.

- **The alternator output can exceed 100 volts. This high voltage may not only damage the alternator but also electrical components in the vehicle, including the PCM and all electronic devices.**
- **The alternator stops charging as a fail safe measure to protect the alternator and all of the electronics in the vehicle from being damaged due to excessively high voltage.**

MINIMUM REQUIRED ALTERNATOR OUTPUT

PURPOSE All charging systems must be able to supply the electrical demands of the electrical system. If lights and accessories are used constantly and the alternator cannot supply the necessary ampere output, the battery will be drained. To determine the minimum electrical load requirements, connect an inductive ammeter probe around either battery cable or the alternator output cable. ● **SEE FIGURE 55–12.**

NOTE: If using an inductive pickup ammeter, be certain that the pickup is over *all* the wires leaving the battery terminal.

Failure to include the small body ground wire from the negative battery terminal to the body or the small positive wire (if testing from the positive side) will *greatly decrease* the current flow readings.

PROCEDURE After connecting an ammeter correctly in the battery circuit, continue as follows:

1. Start the engine and operate to about 2000 RPM (fast idle).
2. Turn the heat selector to air conditioning (if the vehicle is so equipped).

TECH TIP

Use a Fused Jumper Wire as a Diagnostic Tool

When diagnosing an alternator charging problem, try using a fused jumper wire to connect the positive and negative terminals of the alternator directly to the positive and negative terminals of the battery. If a definite improvement is noticed, the problem is in the wiring of the vehicle. High resistance, due to corroded connections or loose grounds, can cause low alternator output, repeated regulator failures, slow cranking, and discharged batteries. A voltage drop test of the charging system can also be used to locate excessive resistance (high voltage drop) in the charging circuit, but using a fused jumper wire is often faster and easier.

TECH TIP

Bigger Is Not Always Better

Many technicians are asked to install a higher output alternator to allow the use of emergency equipment or other high-amperage equipment such as a high-wattage sound system.

Although many higher output units can be physically installed, it is important not to forget to upgrade the wiring and the fusible link(s) in the alternator circuit. Failure to upgrade the wiring could lead to overheating. The usual failure locations are at junctions or electrical connectors.

3. Turn the blower motor to high speed.
4. Turn the headlights on bright.
5. Turn on the rear defogger.
6. Turn on the windshield wipers.
7. Turn on any other accessories that may be used continuously (do not operate the horn, power door locks, or other units that are not used for more than a few seconds).
8. Observe the ammeter. The current indicated is the electrical load that the alternator is able to exceed to keep the battery fully charged.

TEST RESULTS The minimum acceptable alternator output is 5 amperes greater than the accessory load. A negative (discharge) reading indicates that the alternator is not capable of supplying the current (amperes) that may be needed.

ALTERNATOR REMOVAL

After diagnosis of the charging system has determined that there is a fault with the alternator, it must be removed safely from the vehicle. Always check service information for the exact procedure to follow on the vehicle being serviced. A typical removal procedure includes the following steps.

STEP 1 Before disconnecting the negative battery cable, use a test light or a voltmeter and check for battery voltage at the output terminal of the alternator. A complete circuit must



FIGURE 55–13 Replacing an alternator is not always as easy as it is from a Buick with a 3800 V-6, where the alternator is easy to access. Many alternators are difficult to access, and require the removal of other components.

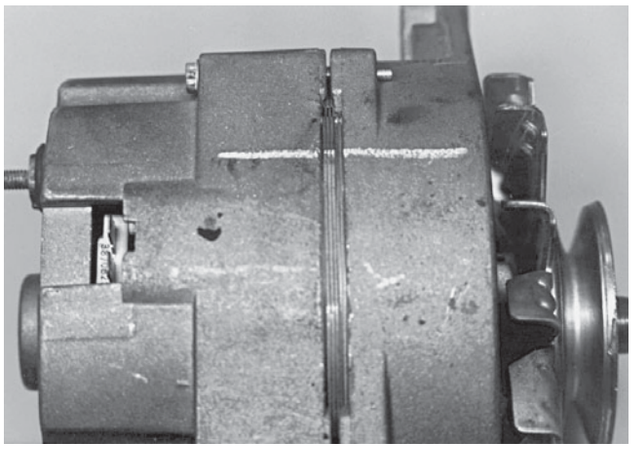


FIGURE 55–14 Always mark the case of the alternator before disassembly to be assured of correct reassembly.

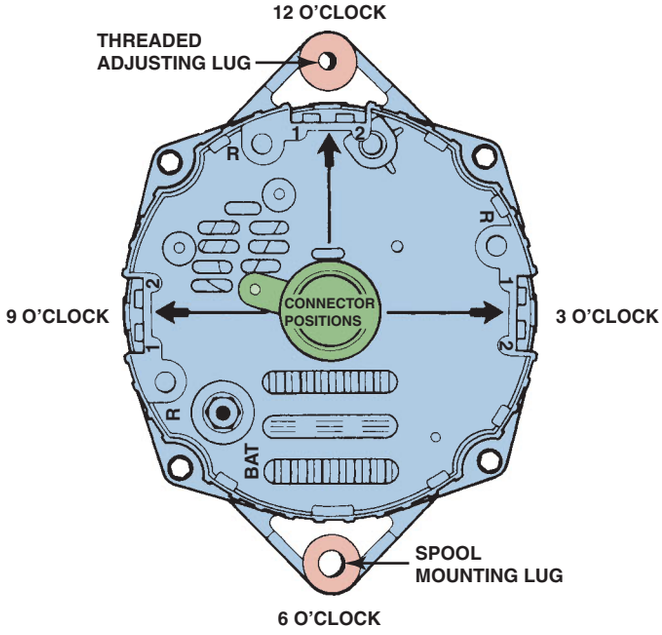


FIGURE 55–15 Explanation of clock positions. Because the four through bolts are equally spaced, it is possible for an alternator to be installed in one of four different clock positions. The connector position is determined by viewing the alternator from the diode end with the threaded adjusting lug in the up or 12 o'clock position. Select the 3 o'clock, 6 o'clock, 9 o'clock, or 12 o'clock position to match the unit being replaced.

TECH TIP

The Sniff Test

When checking for the root cause of an alternator failure, one test that a technician could do is to sniff (smell) the alternator. If the alternator smells like a dead rat (rancid smell), the stator windings have been overheated by trying to charge a discharged or defective battery. If the battery voltage is continuously low, the voltage regulator will continue supplying full-field current to the alternator. The voltage regulator is designed to cycle on and off to maintain a narrow charging system voltage range.

If the battery voltage is continually below the cutoff point of the voltage regulator, the alternator is continually producing current in the stator windings. This constant charging can often overheat the stator and burn the insulating varnish covering the stator windings. If the alternator fails the sniff test, the technician should replace the stator and other alternator components that are found to be defective and replace or recharge and test the battery.

exist between the alternator and the battery. If there is no voltage at the alternator output terminal, check for a blown fusible link or other electrical circuit fault.

STEP 2 Disconnect the negative (−) terminal from the battery. (Use a memory saver to maintain radio, memory seats, and other functions.)

STEP 3 Remove the accessory drive belt that drives the alternator.

STEP 4 Remove electrical wiring, fasteners, spacers, and brackets, as necessary, and remove the alternator from the vehicle. ● **SEE FIGURE 55–13**.

ALTERNATOR DISASSEMBLY

DISASSEMBLY PROCEDURE

STEP 1 Mark the case with a scratch or with chalk to ensure proper reassembly of the alternator case. ● **SEE FIGURE 55–14**.

STEP 2 After the through bolts have been removed, carefully separate the two halves. The stator windings must stay with the

FREQUENTLY ASKED QUESTION

What Is a "Clock Position"?

Most alternators of a particular manufacturer can be used on a variety of vehicles, which may require wiring connections placed in various locations. For example, a Chevrolet and a Buick alternator may be identical except for the position of the rear section containing the electrical connections. The four through bolts that hold the two halves together are equally spaced; therefore, the rear alternator housing *can* be installed in any one of four positions to match the wiring needs of various models. Always check the clock position of the original and be sure that it matches the replacement unit. ● **SEE FIGURE 55–15**.

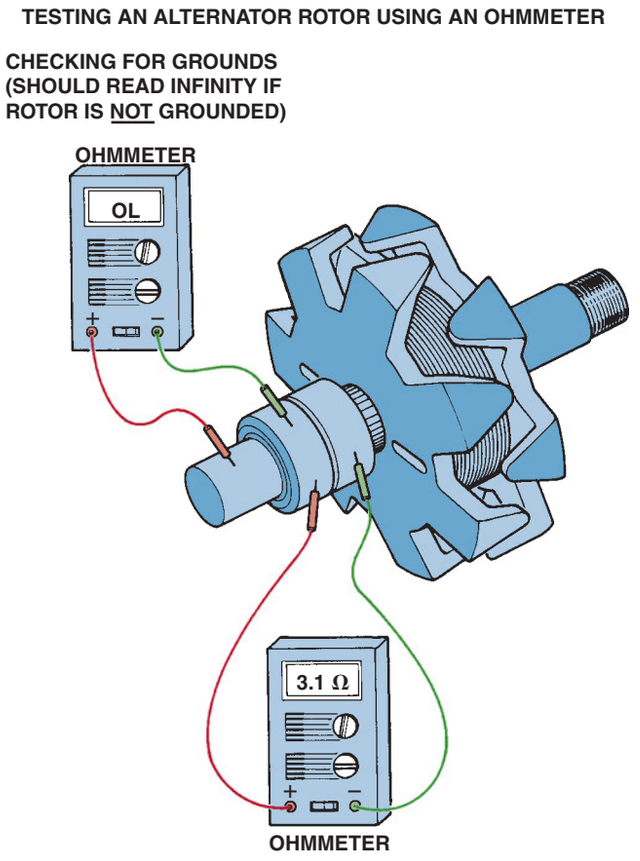


FIGURE 55–16 Testing an alternator rotor using an ohmmeter.

rear case. When this happens, the brushes and springs will fall out.

STEP 3 Remove the rectifier assembly and voltage regulator.

ROTOR TESTING

The slip rings on the rotor should be smooth and round (within 0.002 in. of being perfectly round).

- If grooved, the slip rings can be machined to provide a suitable surface for the brushes. Do not machine beyond the minimum slip-ring dimension as specified by the manufacturer.
- If the slip rings are discolored or dirty, they can be cleaned with 400-grit or fine emery (polishing) cloth. The rotor must be turned while being cleaned to prevent flat spots on the slip rings.
- Measure the resistance between the slip rings using an ohmmeter. Typical resistance values and results include the following:

1. The resistance measured between either slip ring and the steel rotor shaft should be infinity (OL). If there is continuity, then the rotor is shorted to ground.
2. Rotor resistance range is normally between 2.4 and 6 ohms.
3. If the resistance is below specification, the rotor is shorted.
4. If the resistance is above specification, the rotor connections are corroded or open.

If the rotor is found to be bad, it must be replaced or repaired at a specialized shop. ● **SEE FIGURE 55–16**.

NOTE: The cost of a replacement rotor may exceed the cost of an entire rebuilt alternator. Be certain, however, that the rebuilt alternator is rated at the same output as the original or higher.

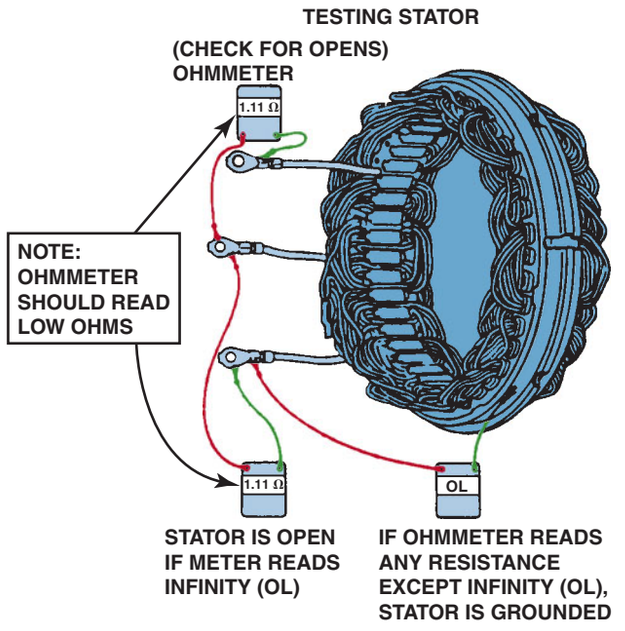


FIGURE 55–17 If the ohmmeter reads infinity between any two of the three stator windings, the stator is open and, therefore, defective. The ohmmeter should read infinity between any stator lead and the steel laminations. If the reading is less than infinity, the stator is grounded. Stator windings cannot be tested if shorted because the normal resistance is very low.

STATOR TESTING

The stator must be disconnected from the diodes (rectifiers) before testing. Because all three windings of the stator are electrically connected (either wye or delta), an ohmmeter can be used to check a stator.

- There should be low resistance at all three stator leads (continuity).
- There should *not* be continuity (in other words, there should be a meter reading of infinity ohms) when the stator is tested between any stator lead and the metal stator core.
- If there is continuity, the stator is shorted-to-ground and must be repaired or replaced. ● **SEE FIGURE 55–17**.

NOTE: Because the resistance is very low for a normal stator, it is generally *not* possible to test for a *shorted* (copper-to-copper) stator. A shorted stator will, however, greatly reduce alternator output. An ohmmeter cannot detect an open stator if the stator is delta wound. The ohmmeter will still indicate low resistance because all three windings are electrically connected.

TESTING THE DIODE TRIO

Many alternators are equipped with a diode trio. A diode is an electrical one-way check valve that permits current to flow in only one direction. Because *trio* means "three," a diode trio is three diodes connected together. ● **SEE FIGURE 55–18**.

The diode trio is connected to all three stator windings. The current generated in the stator flows through the diode trio to the internal voltage regulator. The diode trio is designed to supply current for the field (rotor) and turns off the charge indicator light when the alternator voltage equals or exceeds the battery voltage. If one of the three diodes in the diode trio is defective (usually open), the alternator may produce close-to-normal output; however, the charge indicator light will be on dimly.

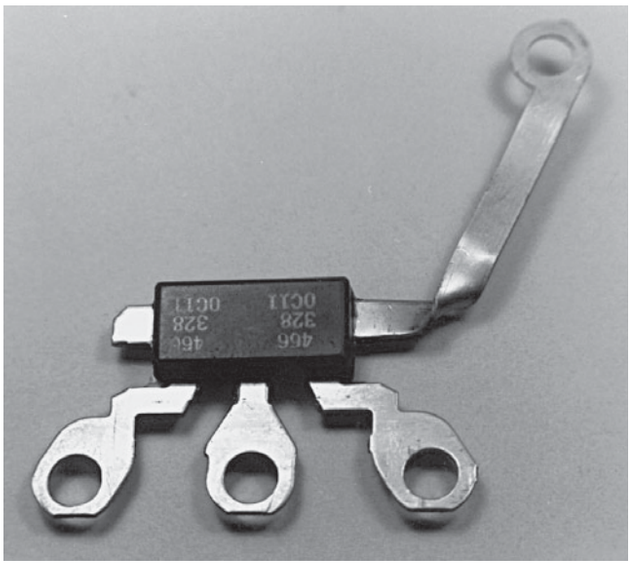


FIGURE 55–18 Typical diode trio. If one leg of a diode trio is open, the alternator may produce close to normal output, but the charge indicator light on the dash will be on dimly.

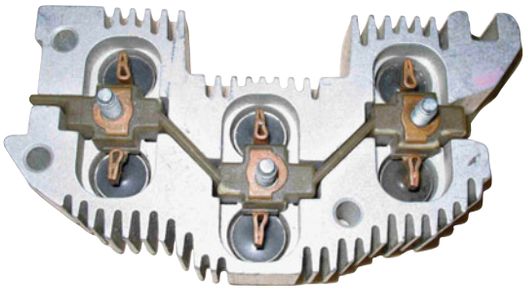


FIGURE 55–19 A typical rectifier bridge that contains all six diodes in one replaceable assembly.

A diode trio should be tested with a digital multimeter. The meter should be set to the diode-check position. The multimeter should indicate 0.5 to 0.7 V (500 to 700 mV) one way and OL (overlimit) after reversing the test leads and touching all three connectors of the diode trio.

TESTING THE RECTIFIER

TERMINOLOGY The rectifier assembly usually is equipped with six diodes including three positive diodes and three negative diodes (one positive and one negative for each winding of the stator).

METER SETUP The rectifier(s) (diodes) should be tested using a multimeter that is set to "diode check" position on the digital multimeter (DMM).

Because a diode (rectifier) should allow current to flow in only one direction, each diode should be tested to determine if the diode allows current flow in one direction and blocks current flow in the opposite direction. To test some alternator diodes, it may be necessary to unsolder the stator connections. ● **SEE FIGURE 55–19**.

Accurate testing is not possible unless the diodes are separated electrically from other alternator components.

TESTING PROCEDURE Connect the leads to the leads of the diode (pigtail and housing of the rectifier bridge). Read the meter.

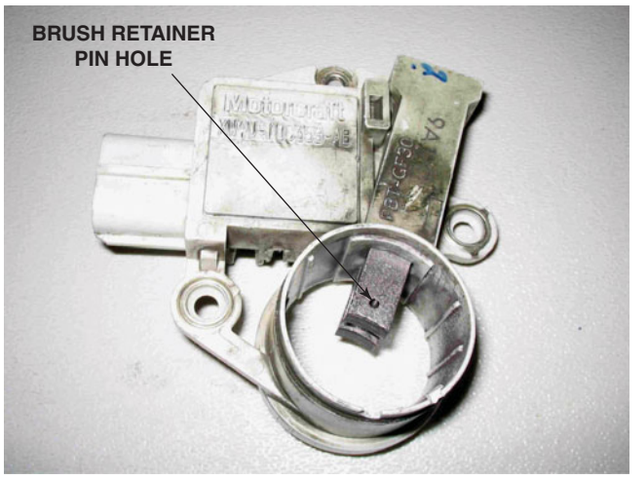


FIGURE 55–20 A brush holder assembly with new brushes installed. The holes in the brushes are used to hold the brushes up in the holder when it is installed in the alternator. After the rotor has been installed, the retaining pin is removed which allows the brushes to contact the slip rings of the rotor.

Reverse the test leads. A good diode should have high resistance (OL) one way (reverse bias) and low voltage drop of 0.5 to 0.7 V (500 to 700 mV) the other way (forward bias).

RESULTS Open or shorted diodes must be replaced. Most alternators group or combine all positive and all negative diodes in the one replaceable rectifier component.

REASSEMBLING THE ALTERNATOR

BRUSH HOLDER REPLACEMENT Alternator carbon brushes often last for many years and require no scheduled maintenance. The life of the alternator brushes is extended because they conduct only the field (rotor) current, which is normally only 2 to 5 amperes. The alternator brushes should be inspected when the alternator is disassembled and should be replaced when worn to less than 1/2 in. long. Brushes are commonly purchased assembled together in a brush holder. After the brushes are installed (usually retained by two or three screws) and the rotor is installed in the alternator housing, a brush retainer pin can be pulled out through an access hole in the rear of the alternator, allowing the brushes to be pressed against the slip rings by the brush springs. ● **SEE FIGURE 55–20**.

BEARING SERVICE AND REPLACEMENT The bearings of an alternator must be able to support the rotor and reduce friction. An alternator must be able to rotate at up to 15,000 RPM and withstand the forces created by the drive belt. The front bearing is usually a ball bearing type and the rear can be either a smaller roller or ball bearing.

The old or defective bearing can sometimes be pushed out of the front housing and the replacement pushed in by applying pressure with a socket or pipe against the outer edge of the bearing (outer race). Replacement bearings are usually prelubricated and seated. Many alternator front bearings must be removed from the rotor using a special puller.

REAL WORLD FIX

The Two-Minute Alternator Repair

A Chevrolet pickup truck was brought to a shop for routine service. The customer stated that the battery required a jump start after a weekend of sitting. The technician tested the battery and charging system voltage using a small handheld digital multimeter. The battery voltage was 12.4 volts (about 75% charged), but the charging voltage was also 12.4 volts at 2000 RPM. Because normal charging voltage should be 13.5 to 15 volts, it was obvious that the charging system was not operating correctly.

The technician checked the dash and found that the "charge" light was *not* on. Before removing the alternator for service, the technician checked the wiring connection on the alternator. When the connector was removed, it was discovered to be rusty. After the contacts were cleaned, the charging system was restored to normal operation. The technician had learned that the simple things should always be checked first before tearing into a big (or expensive) repair.

ALTERNATOR ASSEMBLY After testing or servicing, the alternator rectifier(s), regulator, stator, and brush holder must be reassembled using the following steps.

STEP 1 If the brushes are internally mounted, insert a wire through the holes in the brush holder to hold the brushes against the springs.

STEP 2 Install the rotor and front-end frame in proper alignment with the mark made on the outside of the alternator housing. Install the through bolts. Before removing the wire pin holding the brushes, spin the alternator pulley. If the alternator is noisy or not rotating freely, the alternator can easily be disassembled again to check for the cause. After making certain the alternator is free to rotate, remove the brush holder pin and spin the alternator again by hand. The noise level may be slightly higher with the brushes released onto the slip rings.

STEP 3 Alternators should be tested on a bench tester, if available, before they are reinstalled on a vehicle. When installing the alternator on the vehicle, be certain that all mounting bolts and nuts are tight. The battery terminal should be covered with a plastic or rubber protective cap to help prevent accidental shorting to ground, which could seriously damage the alternator.

REMANUFACTURED ALTERNATORS

Remanufactured or rebuilt alternators are totally disassembled and rebuilt. Even though there are many smaller rebuilders who may not replace all worn parts, the major national remanufacturers *totally* remanufacture the alternator. Old alternators (called **cores**) are totally disassembled and cleaned. Both bearings are replaced and all components are tested. Rotors are rewound to original specifications if required. The rotor windings are not counted but are rewound on the rotor "spool," using the correct-gauge copper wire, to the *weight* specified by the original manufacturer. New slip rings are replaced as required, soldered to the rotor spool windings, and machined. The rotors are also balanced and measured to ensure that the outside diameter of the rotor meets specifications. An undersized rotor will produce less alternator output because the field must be close to the stator windings for maximum output. Bridge rectifiers are replaced, if required. Every alternator is then assembled and tested for proper output, boxed, and shipped to a warehouse. Individual parts stores (called jobbers) purchase parts from various regional or local warehouses.

ALTERNATOR INSTALLATION

Before installing a replacement alternator, check service information for the exact procedure to follow for the vehicle being serviced. A typical installation procedure includes the following steps.

STEP 1 Verify that the replacement alternator is the correct unit for the vehicle.

STEP 2 Install the alternator wiring on the alternator and install the alternator.

STEP 3 Check the condition of the drive belt and replace, if necessary. Install the drive belt over the drive pulley.

STEP 4 Properly tension the drive belt.

STEP 5 Tighten all fasteners to factory specifications.

STEP 6 Double-check that all fasteners are correctly tightened and remove all tools from the engine compartment area.

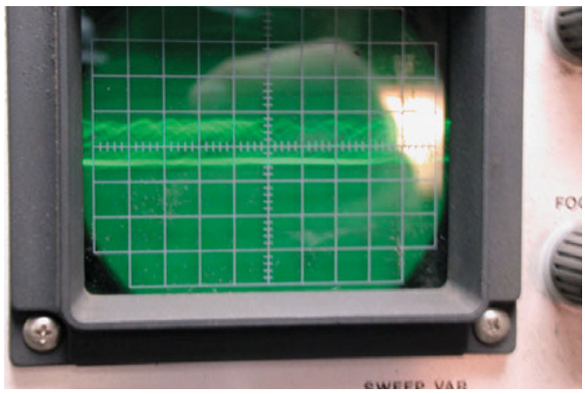
STEP 7 Reconnect the negative battery cable.

STEP 8 Start the engine and verify proper charging circuit operation.

ALTERNATOR OVERHAUL



1 Before the alternator is disassembled, it is spin tested and connected to a scope to check for possible defective components.



2 The scope pattern shows that the voltage output is far from being a normal pattern. This pattern indicates serious faults in the rectifier diodes.



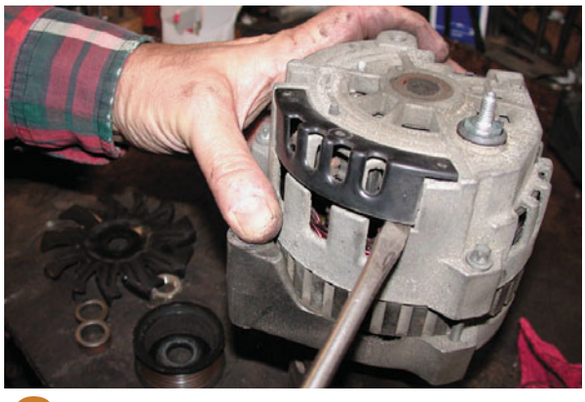
3 The first step is to remove the drive pulley. This rebuilder is using an electric impact wrench to accomplish the task.



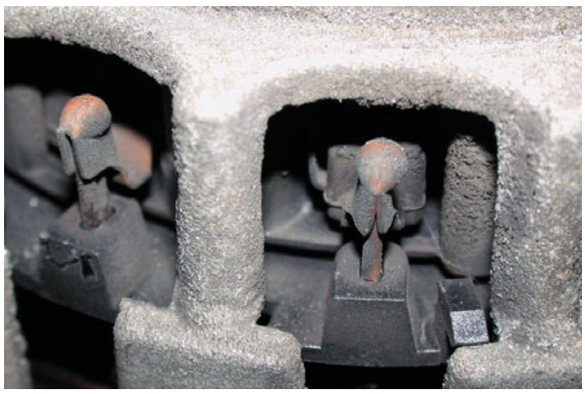
4 Carefully inspect the drive galley for damage of embedded rubber from the drive belt. The slightest fault can cause a vibration, noise, or possible damage to the alternator.



5 Remove the external fan (if equipped) and then the spacers as shown.



6 Next pop off the plastic cover (shield) covering the stator/rectifier connection.



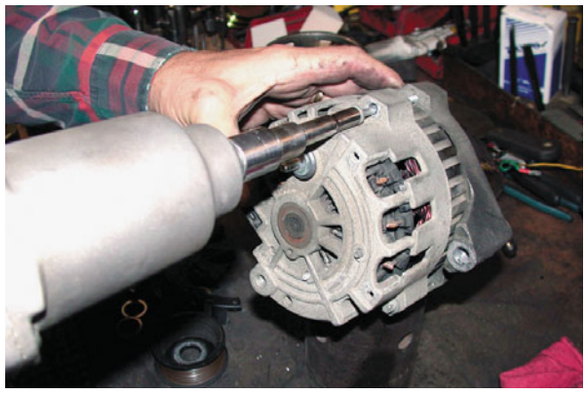
7 After the cover has been removed, the stator connections to the rectifier can be seen.



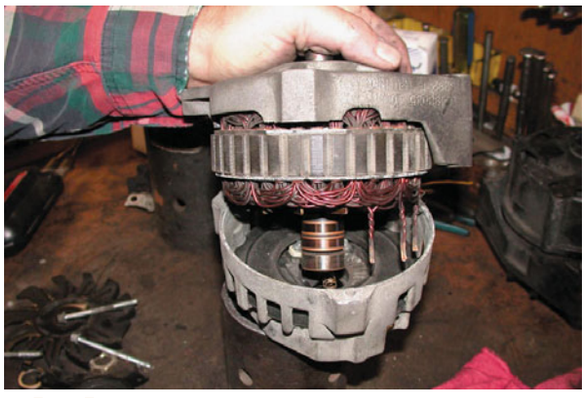
8 Using a diagonal cutter, cut the weld to separate the stator from the rectifier.



9 Before separating the halves of the case, this technician uses a punch to mark both halves.



10 After the case has been marked, the through-bolts are removed.



11 The drive-end housing and the stator are being separated from the rear (slip-ring-end) housing.



12 The stator is checked by visual inspection for discoloration or other physical damage, and then checked with an ohmmeter to see if the windings are shorted-to-ground.

CONTINUED ▶



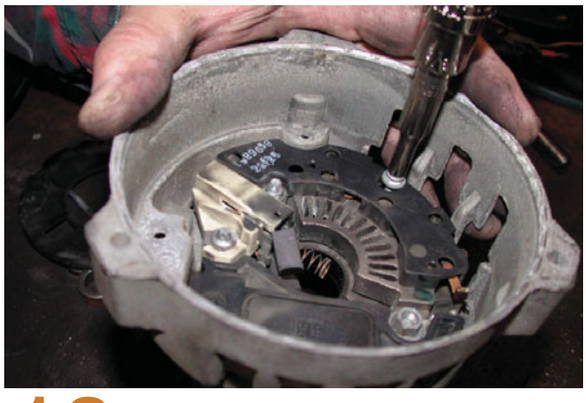
13 The front bearing is removed from the drive-end housing using a press.



14 A view of the slip-ring-end (SRE) housing showing the black plastic shield, which helps direct air flow across the rectifier.



15 A punch is used to dislodge the plastic shield retaining clips.



16 After the shield has been removed, the rectifier, regulator, and brush holder assembly can be removed by removing the retaining screws.



17 The hear transfer grease is visible when the rectifier assembly is lifted out of the rear housing.



18 The parts are placed into a tumbler where ceramic stones and a water-based solvent are used to clean the parts.



19 This rebuilder is painting the housing using a high-quality industrial grade spray paint to make the rebuilt alternator look like new.



20 The slip rings on the rotor are being machined on a lathe.



21 The rotor is being tested using an ohmmeter. The specifications for the resistance between the slip rings on the CS-130 are 2.2 to 3.5 ohms.



22 The rotor is also tested between the slip ring and the rotor shaft. This reading should be infinity.

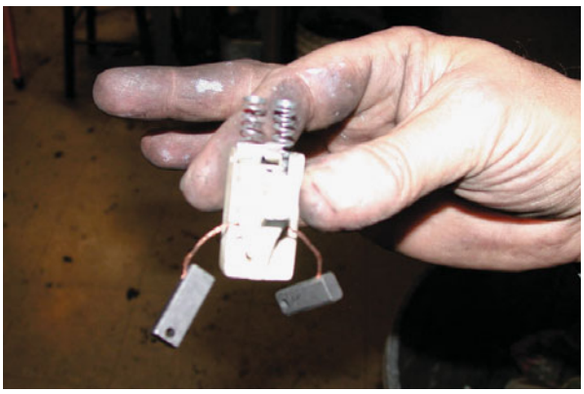


23 A new rectifier. This replacement unit is significantly different than the original but is designed to replace the original unit and meets the original factory specifications.



24 Silicone heat transfer compound is applied to the heat sink of the new rectifier.

CONTINUED ▶



25 Replacement brushes and springs are assembled into the brush holder.



26 The brushes are pushed into the brush holder and retained by a straight wire, which extends through the rear housing of the alternator. This wire is then pulled out when the unit is assembled.



27 Here is what the CS alternator looks like after installing the new brush holder assembly, rectifier bridge, and voltage regulator.



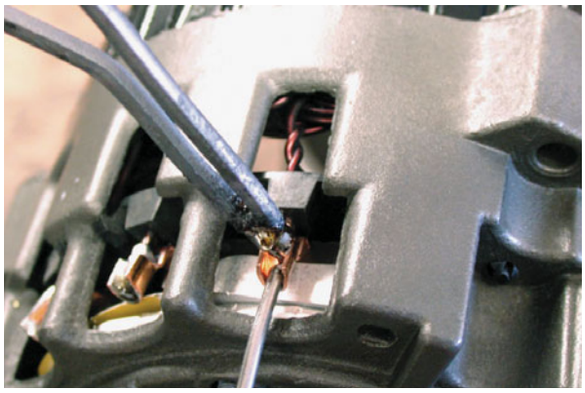
28 The junction between the rectifier bridge and the voltage regulator is soldered.



29 The plastic deflector shield is snapped back into location using a blunt chisel and a hammer. This shield directs the airflow from the fan over the rectifier bridge and voltage regulator.



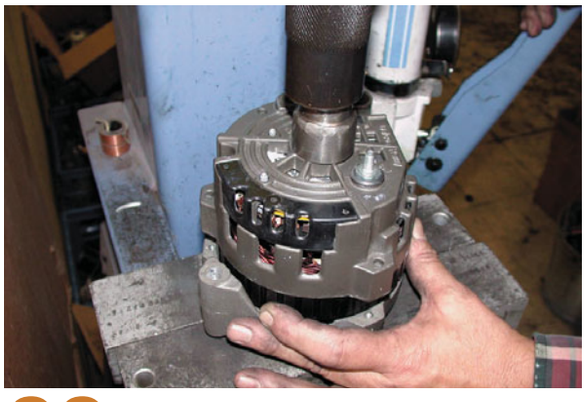
30 Before the stator windings can be soldered to the rectifier bridge, the varnish insulation is removed from the ends of the leads.



31 After the stator has been inserted into the rear housing the stator leads are soldered to the copper lugs of the rectifier bridge.



32 New bearings are installed. A spacer is placed between the bearing and the slip rings to help prevent the possibility that the bearing could move on the shaft and short against the slip ring.



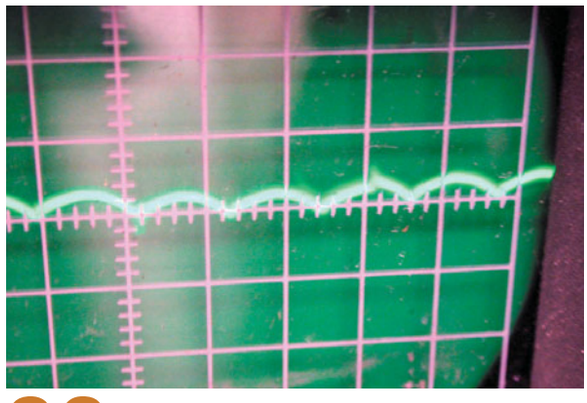
33 The slip-ring-end (SRE) housing is aligned with the marks made during disassembly and is pressed into the drive-end (DE) housing.



34 The retaining bolts, which are threaded into the drive-end housing from the back of the alternator are installed.



35 The external fan and drive pulley are installed and the retaining nut is tightened on the rotor shaft.



36 The scope pattern shows that the diodes and stator are functioning correctly and voltage check indicates that the voltage regulator is also functioning correctly.

REVIEW QUESTIONS

1. How does a technician test the voltage drop of the charging circuit?
2. How does a technician measure the amperage output of an alternator?
3. What tests can be performed to determine whether a diode or stator is defective before removing the alternator from the vehicle?

CHAPTER QUIZ

1. To check the charging voltage, connect a digital multimeter (DMM) to the positive (+) and the negative (−) terminals of the battery and select _____.
   a. DC volts **c.** DC amps
   b. AC volts **d.** AC amps
2. To check for ripple voltage from the alternator, connect a digital multimeter (DMM) and select _____.
   a. DC volts **c.** DC amps
   b. AC volts **d.** AC amps
3. The maximum allowable alternating current (AC) in amperes that is being sent to the battery from the alternator is _____.
   a. 0.4 A
   b. 1 to 3 A
   c. 3 to 4 A
   d. 10% of the rated output of the alternator
4. Why should the lights be turned on when checking for ripple voltage or alternating current from the alternator?
   a. To warm the battery
   b. To check that the battery is fully charged
   c. To create an electrical load for the alternator
   d. To test the battery before conducting other tests
5. An acceptable charging circuit voltage on a 12 volt system is _____.
   a. 13.5 to 15 volts **c.** 12 to 14 volts
   b. 12.6 to 15.6 volts **d.** 14.9 to 16.1 volts
6. Technician A says that the computer can be used to control the output of the alternator by controlling the field current. Technician B says that voltage regulators control the alternator output by controlling the field current through the rotor. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
7. Technician A says that a voltage drop test of the charging circuit should only be performed when current is flowing through the circuit. Technician B says to connect the leads of a voltmeter to the positive and negative terminals of the battery to measure the voltage drop of the charging system. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. When testing an alternator rotor, if an ohmmeter shows zero ohms with one meter lead attached to the slip rings and the other meter lead touching the rotor shaft, the rotor is _____.
   a. Okay (normal)
   b. Defective (shorted-to-ground)
   c. Defective (shorted-to-voltage)
   d. Okay (rotor windings are open)
9. An alternator diode is being tested using a digital multimeter set to the diode-check position. A good diode will read _____ if the leads are connected one way across the diode and _____ if the leads are reversed.
   a. 300/300 **c.** OL/OL
   b. 0.475/0.475 **d.** 0.551/OL
10. An alternator could test as producing lower-than-normal output, yet be okay, if the _____.
    a. Battery is weak or defective
    b. Engine speed is not high enough during testing
    c. Drive belt is loose or slipping
    d. All of the above

chapter 56

LIGHTING AND SIGNALING CIRCUITS

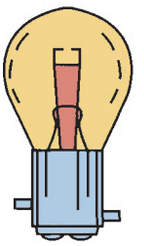
OBJECTIVES: **After studying Chapter 56, the reader will be able to**: • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "E" (Lighting System Diagnosis and Repair). • Read and interpret a bulb chart. • Describe how interior and exterior lighting systems work. • Read and interpret a bulb chart. • Discuss troubleshooting procedures for lighting and signaling circuits.

KEY TERMS: AFS 616 • Brake lights 608 • Candlepower 605 • CHMSL 609 • Color shift 614 • Composite headlight 613 • Courtesy lights 617 • DOT 610 • DRL 617 • Feedback 620 • Fiber optics 617 • Flasher relay 611 • Hazard warning 611 • HID 614 • Hybrid flasher 611 • Kelvin (K) 614 • LED 609 • Rheostat 612 • Trade number 605 • Troxler effect 619 • Xenon headlights 614

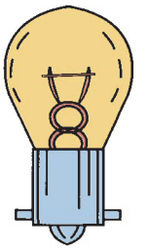
INTRODUCTION

The vehicle has many different lighting and signaling systems, each with its own specific components and operating characteristics. The major light-related circuits and systems covered include:

- Exterior lighting
- Headlights (halogen, HID, and LED)
- Bulb trade numbers
- Brake lights
- Turn signals and flasher units
- Courtesy lights
- Light-dimming rearview mirrors



DOUBLE CONTACT
1157/2057 BULBS



SINGLE CONTACT
1156 BULBS



WEDGE
194 BULB

FIGURE 56–1 Dual-filament (double-contact) bulbs contain both a low-intensity filament for taillights or parking lights and a high-intensity filament for brake lights and turn signals. Bulbs come in a variety of shapes and sizes. The numbers shown are the trade numbers.

EXTERIOR LIGHTING

HEADLIGHT SWITCH CONTROL Exterior lighting is controlled by the headlight switch, which is connected directly to the battery on most vehicles. Therefore, if the light switch is left on manually, the lights could drain the battery. Older headlight switches contained a built-in circuit breaker. If excessive current flows through the headlight circuit, the circuit breaker will momentarily open the circuit, then close it again. The result is headlights that flicker on and off rapidly. This feature allows the headlights to function, as a safety measure, in spite of current overload.

The headlight switch controls the following lights on most vehicles, usually through a module.

1. Headlights
2. Taillights
3. Side-marker lights
4. Front parking lights
5. Dash lights
6. Interior (dome) light(s)

COMPUTER-CONTROLLED LIGHTS Because these lights can easily drain the battery if accidentally left on, many newer vehicles control these lights through computer modules. The computer module keeps track of the time the lights are on and can turn them off if the time is excessive. The computer can control either the power side or the ground side of the circuit.

For example, a typical computer-controlled lighting system usually includes the following steps.

STEP 1 The driver depresses or rotates the headlight switch.

STEP 2 The signal from the headlight switch is sent to the nearest control module.

STEP 3 The control module then sends a request to the headlight control module to turn on the headlights as well as the front park and side-marker lights.
Through the data BUS, the rear control module receives the lights on signal and turns on the lights at the rear of the vehicle.

STEP 4 All modules monitor current flow through the circuit and will turn on a bulb failure warning light if it detects an open bulb or a fault in the circuit.

STEP 5 After the ignition has been turned off, the modules will turn off the lights after a time delay to prevent the battery from being drained.

BULB NUMBERS

TRADE NUMBER The number used on automotive bulbs is called the bulb **trade number,** as recorded with the American National Standards Institute (ANSI). The number is the same regardless of the manufacturer. ● **SEE FIGURE 56–1**.

CANDLEPOWER The trade number also identifies the size, shape, number of filaments, and amount of light produced, measured in **candlepower.** For example, the 1156 bulb, commonly used for backup lights, is 32 candlepower. A 194 bulb, commonly used for dash or side-marker lights, is rated at only 2 candlepower. The amount of light produced by a bulb is determined by the resistance of the filament wire, which also affects the amount of current (in amperes) required by the bulb.

It is important that the correct trade number of bulb always be used for replacement to prevent circuit or component damage. The correct replacement bulb for a vehicle is usually listed in the owner or service manual. ● **REFER TO CHART 56–1** for a listing of common bulbs and their specifications used in most vehicles.

BULB NUMBER SUFFIXES Many bulbs have suffixes that indicate some feature of the bulb, while keeping the same size and light output specifications.

Typical bulb suffixes include:

- NA: natural amber (amber glass)
- A: amber (painted glass)
- HD: heavy duty
- LL: long life
- IF: inside frosted



FIGURE 56–2 Bulbs that have the same trade number have the same operating voltage and wattage. The NA means that the bulb uses a natural amber glass ampoule with clear turn signal lenses.

- R: red
- B: blue
- G: green

SEE FIGURE 56–2.

BULB NUMBER	FILAMENTS	AMPERAGE LOW/HIGH	WATTAGE LOW/HIGH	CANDLEPOWER LOW/HIGH
Headlights				
1255/H1	1	4.58	55.00	129.00
1255/H3	1	4.58	55.00	121.00
6024	2	2.73/4.69	35.00/60.00	27,000/35,000
6054	2	2.73/5.08	35.00/65.00	35,000/40,000
9003	2	4.58/5.00	55.00/60.00	72.00/120.00
9004	2	3.52/5.08	45.00/65.00	56.00/95.00
9005	1	5.08	65.00	136.00
9006	1	4.30	55.00	80.00
9007	2	4.30/5.08	55.00/65.00	80.00/107.00
9008	2	4.30/5.08	55.00/65.00	80.00/107.00
9011	1	5.08	65.00	163.50
Headlights (HID—Xenon)				
D2R	Air Gap	0.41	35.00	222.75
D2S	Air Gap	0.41	35.00	254.57
Taillights, Stop, and Turn Lamps				
1156	1	2.10	26.88	32.00
1157	2	0.59/2.10	8.26/26.88	3.00/32.00
2057	2	0.49/2.10	6.86/26.88	2.00/32.00
3057	2	6.72/26.88	0.48/2.10	1.50/24.00
3155	1	1.60	20.48	21.00
3157	2	0.59/2.10	8.26/26.88	2.20/24.00
4157	2	0.59/2.10	8.26/26.88	3.00/32.00
7440	1	1.75	21.00	36.60
7443	2	0.42/1.75	5.00/21.00	2.80/36.60
17131	1	0.33	4.00	2.80
17635	1	1.75	21.00	37.00
17916	2	0.42/1.75	5.00/21.00	1.20/35.00
Parking, Daytime Running Lamps				
24	1	0.24	3.36	2.00
67	1	0.59	7.97	4.00
168	1	0.35	4.90	3.00
194	1	0.27	3.78	2.00
889	1	3.90	49.92	43.00
912	1	1.00	12.80	12.00
916	1	0.54	7.29	2.00
1034	2	0.59/1.80	8.26/23.04	3.00/32.00
1156	1	2.10	26.88	32.00
1157	2	0.59/2.10	8.26/26.88	3.00/32.00
2040	1	0.63	8.00	10.50
2057	2	0.49/2.10	6.86/26.88	1.50/24.00
2357	2	0.59/2.23	8.26/28.54	3.00/40.00
3157	2	0.59/2.10	8.26/26.88	3.00/32.00
3357	2	0.59/2.23	8.26/28.54	3.00/40.00
3457	2	0.59/2.23	8.26/28.51	3.00/40.00
3496	2	0.66/2.24	8.00/27.00	3.00/45.00
3652	1	0.42	5.00	6.00
4114	2	0.59/2/23	8.26/31.20	3.00/32.00
4157	2	0.59/2.10	8.26/26/88	3.00/32.00
7443	2	0.42/1.75	5.00/21.00	2.80/36.60
17131	1	0.33	4.00	2.80
17171	1	0.42	5.00	4.00
17177	1	0.42	5.00	4.00
17311	1	0.83	10.00	10.00
17916	2	0.42/1.75	5.00/21.00	1.20/35.00
68161	1	0.50	6.00	10.00
Center High-Mounted Stop Lamp (CHMSL)				
70	1	0.15	2.10	1.50
168	1	0.35	4.90	3.00
175	1	0.58	8.12	5.00
211-2	1	0.97	12.42	12.00
577	1	1.40	17.92	21.00
579	1	0.80	10.20	9.00
889	1	3.90	49.92	43.00
891	1	0.63	8.00	11.00
906	1	0.69	8.97	6.00
912	1	1.00	12.80	12.00
921	1	1.40	17.92	21.00
922	1	0.98	12.54	15.00
1141	1	1.44	18.43	21.00

CHART 56–1

Bulbs that have the same trade number have the same operating voltage and wattage. The NA means that the bulb uses a natural amber glass ampoule with clear turn signal lenses.

CONTINUED

BULB NUMBER	FILAMENTS	AMPERAGE LOW/HIGH	WATTAGE LOW/HIGH	CANDLEPOWER LOW/HIGH
1156	1	2.10	26.88	32.00
2723	1	0.20	2.40	1.50
3155	1	1.60	20.48	21.00
3156	1	2.10	26.88	32.00
3497	1	2.24	27.00	45.00
7440	1	1.75	21.00	36.60
17177	1	0.42	5.00	4.00
17635	1	1.75	21.00	37.00
License Plate, Glove Box, Dome, Side Marker, Trunk, Map, Ashtray, Step/Courtesy, Underhood				
37	1	0.09	1.26	0.50
67	1	0.59	7.97	4.00
74	1	0.10	1.40	.070
98	1	0.62	8.06	6.00
105	1	1.00	12.80	12.00
124	1	0.27	3.78	1.50
161	1	0.19	2.66	1.00
168	1	0.35	4.90	3.00
192	1	0.33	4.29	3.00
194	1	0.27	3.78	2.00
211-1	1	0.968	12.40	12.00
212-2	1	0.74	9.99	6.00
214-2	1	0.52	7.02	4.00
293	1	0.33	4.62	2.00
561	1	0.97	12.42	12.00
562	1	0.74	9.99	6.00
578	1	0.78	9.98	9.00
579	1	0.80	10.20	9.00
PC579	1	0.80	10.20	9.00
906	1	0.69	8.97	6.00
912	1	1.00	12.80	12.00
917	1	1.20	14.40	10.00
921	1	1.40	17.92	21.00
1003	1	0.94	12.03	15.00
1155	1	0.59	7.97	4.00
1210/H2	1	8.33	100.00	239.00
1210/H3	1	8.33	100.00	192.00
1445	1	0.14	2.02	0.70
1891	1	0.24	3.36	2.00
1895	1	0.27	3.78	2.00
3652	1	0.42	5.00	6.00
11005	1	0.39	5.07	4.00
11006	1	0.24	3.36	2.00
12100	1	0.77	10.01	9.55
13050	1	0.38	4.94	3.00
17036	1	0.10	1.20	0.48
17097	1	0.25	3.00	1.76
17131	1	0.33	4.00	2.80

CONTINUED

BULB NUMBER	FILAMENTS	AMPERAGE LOW/HIGH	WATTAGE LOW/HIGH	CANDLEPOWER LOW/HIGH
17177	1	0.42	5.00	4.00
17314	1	0.83	10.00	8.00
17916	2	0.42/1.75	5.00/21.00	1.20/35.00
47830	1	0.39	5.00	6.70
Instrument Panel				
37	1	0.09	1.26	0.50
73	1	0.08	1.12	0.30
74	1	0.10	1.40	0.70
PC74	1	0.10	1.40	0.70
PC118	1	0.12	1.68	0.70
124	1	0.27	3.78	1.50
158	1	0.24	3.36	2.00
161	1	0.19	2.66	1.00
192	1	0.33	4.29	3.00
194	1	0.27	3.78	2.00
PC194	1	0.27	3.78	2.00
PC195	1	0.27	3.78	1.80
1210/H1	1	8.33	100.00	217.00
1210/H3	1	8.33	100.00	192.00
17037	1	0.10	1.20	0.48
17097	1	0.25	3.00	1.76
17314	1	0.83	10.00	8.00
Backup, Cornering, Fog/Driving Lamps				
67	1	0.59	7.97	4.00
579	1	0.80	10.20	9.00
880	1	2.10	26.88	43.00
881	1	2.10	26.88	43.00
885	1	3.90	49.92	100.00
886	1	3.90	49.92	100.00
893	1	2.93	37.50	75.00
896	1	2.93	37.50	75.00
898	1	2.93	37.50	60.00
899	1	2.93	37.50	60.00
921	1	1.40	17.92	21.00
1073	1	1.80	23.04	32.00
1156	1	2.10	26.88	32.00
1157	2	0.59/2.10	8.26/26.88	3.00/32.00
1210/H1	1	8.33	100.00	217.00
1255/H1	1	4.58	55.00	129.00
1255/H3	1	4.58	55.00	121.00
1255/H11	1	4.17	55.00	107.00
2057	2	0.49/2.10	6.86/26.88	1.50/24.00
3057	2	0.48/2.10	6.72/26.88	2.00/32.00
3155	1	1.60	20.48	21.00
3156	1	2.10	26.88	32.00
3157	2	0.59/2.10	8.26/26.88	3.00/32.00
4157	2	0.59/2.10	8.26/26/88	3.00/32.00
7440	1	1.75	21.00	36.00
9003	2	4.58/5.00	55.00/60.00	72.00/120.00
9006	1	4.30	55.00	80.00
9145	1	3.52	45.00	65.00
17635	1	1.75	21.00	37.00

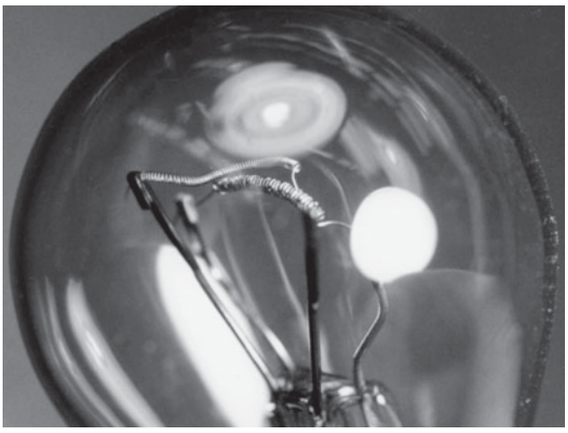


FIGURE 56–3 Close-up a 2057 dual-filament (double-contact) bulb that failed. Notice that the top filament broke from its mounting and melted onto the lower filament. This bulb caused the dash lights to come on whenever the brakes were applied.

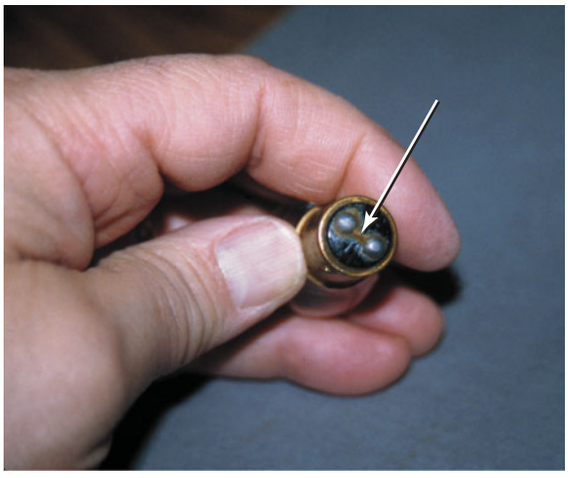


FIGURE 56–4 Corrosion caused the two terminals of this dual-filament bulb to be electrically connected.



FIGURE 56–5 Often the best diagnosis is a thorough visual inspection. This bulb was found to be filled with water, which caused weird problems.

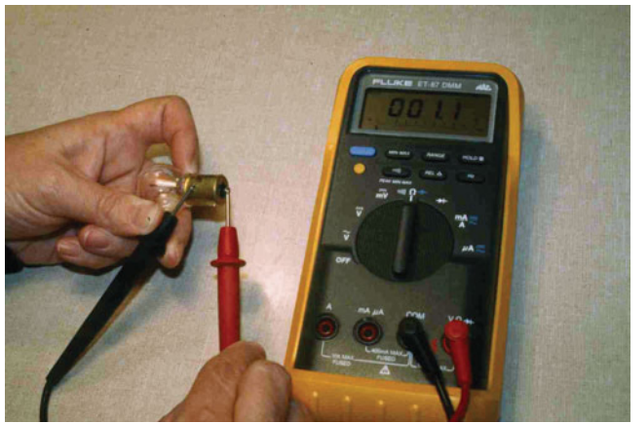


FIGURE 56–6 This single-filament bulb is being tested with a digital multimeter set to read resistance in ohms. The reading of 1.1 ohms is the resistance of the bulb when cold. As soon as current flows through the filament, the resistance increases about 10 times. It is the initial surge of current flowing through the filament when the bulb is cool that causes many bulbs to fail in cold weather as a result of the reduced resistance. As the temperature increases, the resistance increases.

REAL WORLD FIX

Weird Problem—Easy Solution

A General Motors minivan had the following electrical problems.

- The turn signals flashed rapidly on the left side.
- With the ignition key off, the lights-on warning chime sounded if the brake pedal was depressed.
- When the brake pedal was depressed, the dome light came on.

All of these problems were caused by *one* defective 2057 dual-filament bulb, as shown in ● **FIGURE 56–3.**

Apparently, the two filaments were electrically connected when one filament broke and then welded to the other filament. This caused the electrical current to feed back from the brake light filament into the taillight circuit, causing all the problems.

TESTING BULBS

Bulbs can be tested using two basic tests.

1. Perform a visual inspection of any bulb. Many faults, such as a shorted filament, corroded connector, or water, can cause weird problems that are often thought to be wiring issues.
   ● **SEE FIGURES 56–4 AND 56–5.**
2. Bulbs can be tested using an ohmmeter and checking the resistance of the filaments(s). Most bulbs will read low resistance at room temperature between 0.5 and 20 ohms depending on the bulb. Test results include:
   - **Normal resistance.** The bulb is good. Check both filaments if it is a two-filament bulb. ● **SEE FIGURE 56–6.**
   - **Zero ohms.** It is unlikely but possible for the bulb filament to be shorted.
   - **OL (electrically open).** The reading indicates that the bulb filament is broken.

BRAKE LIGHTS

OPERATION

Brake lights, also called stop lights, use the high-intensity filament of a double-filament bulb. (The low-intensity filament is for the taillights.) When the brakes are applied, the brake switch is closed and the brake lamps light. The brake switch receives current from a fuse that is hot all the time. The brake light switch is a normally open (N.O.) switch, but is closed when the driver depresses the brake

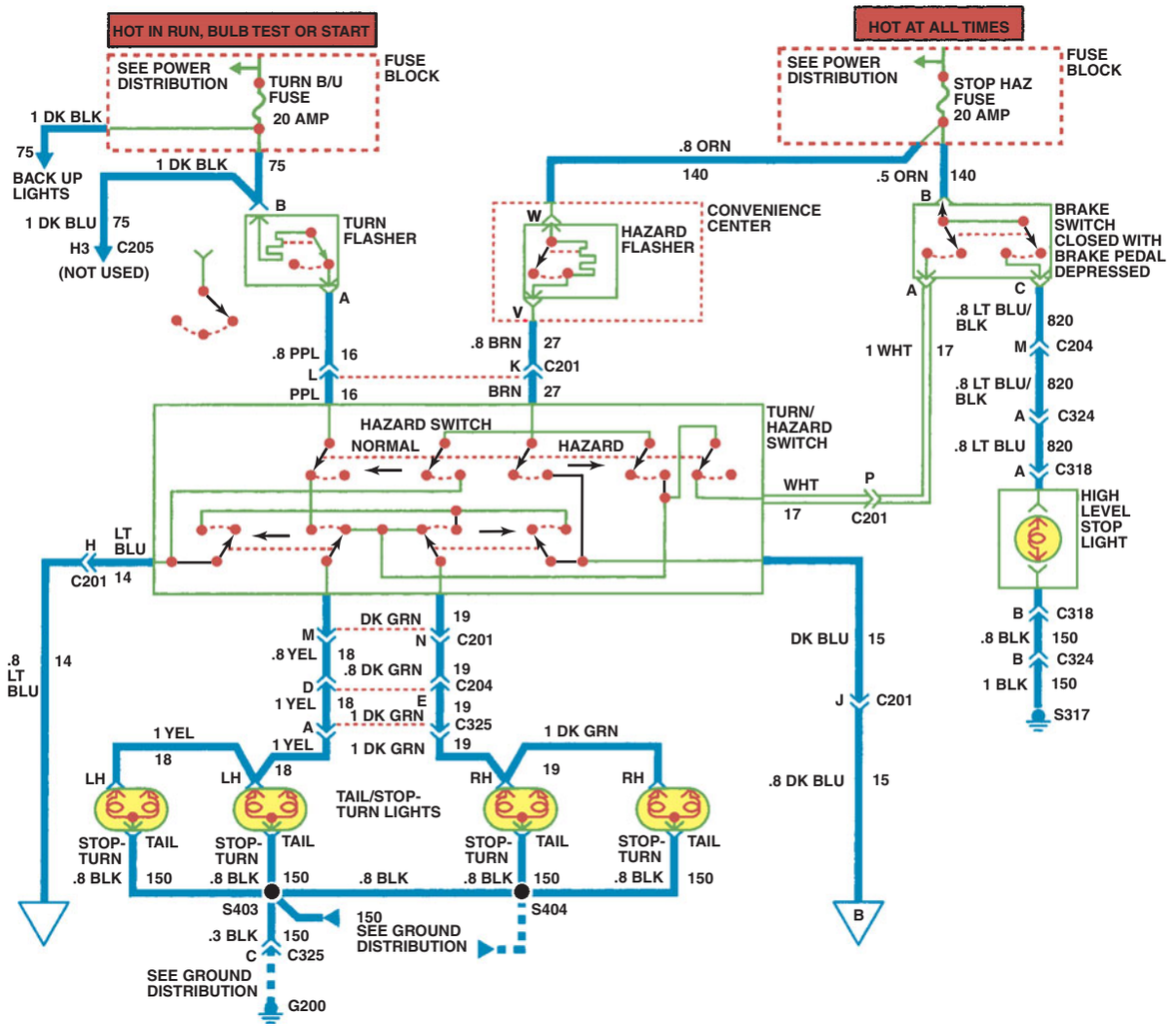


FIGURE 56–7 Typical brake light and taillight circuit showing the brake switch and all of the related circuit components.

pedal. Since 1986, all vehicles sold in the United States have a third brake light commonly referred to as the **center high-mounted stop light (CHMSL).** ● **SEE FIGURE 56–7.**

? FREQUENTLY ASKED QUESTION

Why Are LEDs Used for Brake Lights?

Light-emitting diode (LED) brake lights are frequently used for high-mounted stop lamps (CHMSLs) for the following reasons.

1. **Faster illumination.** An LED will light up to 200 milliseconds faster than an incandescent bulb, which requires some time to heat the filament before it is hot enough to create light. This faster illumination can mean the difference in stopping distances at 60 mph (100 km/h) by about 18 ft (6 m) due to the reduced reaction time for the driver of the vehicle behind.
2. **Longer service life.** LEDs are solid-state devices that do not use a filament to create light. As a result, they are less susceptible to vibration and will often last the life of the vehicle.

NOTE: Aftermarket replacement LED bulbs that are used to replace conventional bulbs may require the use of a different type of flasher unit due to the reduced current draw of the LED bulbs. ● **SEE FIGURE 56–8.**

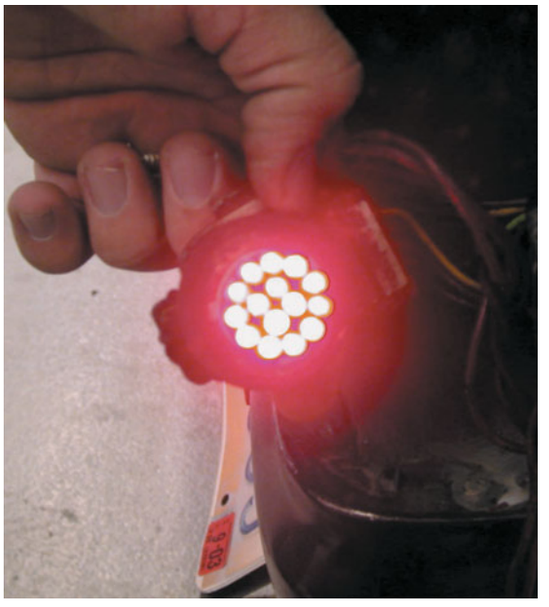


FIGURE 56–8 A replacement LED taillight bulb is constructed of many small, individual light-emitting diodes.

The brake switch is also used as an input switch (signal) for the following:

1. Cruise control (deactivates when the brake pedal is depressed)
2. Antilock brakes (ABS)
3. Brake shift interlock (prevents shifting from park position unless the brake pedal is depressed)

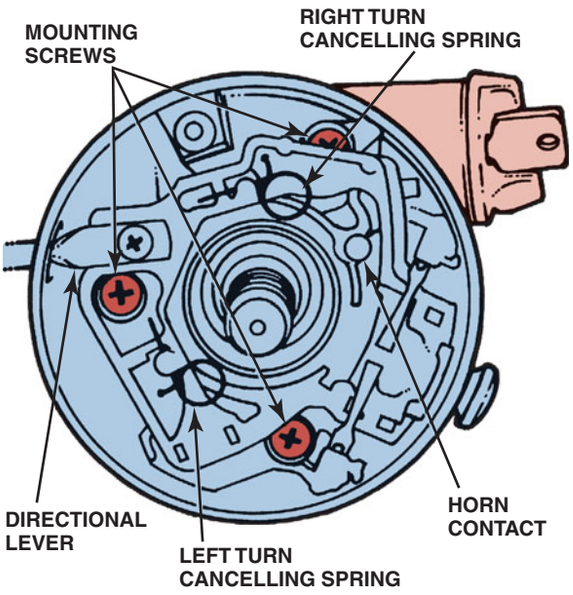


FIGURE 56–9 The typical turn signal switch includes various springs and cams to control the switch and to cause the switch to cancel after a turn has been completed.

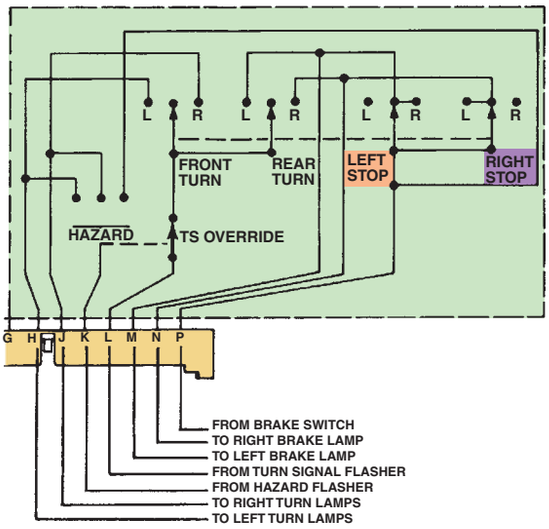


FIGURE 56–10 When the stop lamps and turn signals share a common bulb filament, stop light current flows through the turn signal switch.

TURN SIGNALS

OPERATION The turn signal circuit is supplied power from the ignition switch and operated by a lever and switch. ● **SEE FIGURE 56–9.**

When the turn signal switch is moved in either direction, the corresponding turn signal lamps receive current through the flasher unit. The flasher unit causes the current to start and stop as the turn signal lamp flashes on and off with the interrupted current.

ONE-FILAMENT STOP/TURN BULBS In many vehicles, the stop and turn signals are both provided by one filament. When the turn signal switch is turned on (closed), the filament receives interrupted current through the flasher unit. When the brakes are applied, the current first flows to the turn signal switch, except for the high-mounted stop, which is fed directly from the brake switch. If neither turn signal is on, then current through the turn signal switch flows to both rear brake lights. If the turn signal switch is operated (turned to either left or right), current flows through the flasher unit on the side that was selected and directly to the brake lamp on the opposite side. If the brake pedal is not depressed, then current flows through the flasher and only to one side. ● **SEE FIGURE 56–10.**

Moving the lever up or down completes the circuit through the flasher unit and to the appropriate turn signal lamps. A turn signal switch includes cams and springs that cancel the signal after the turn has been completed. As the steering wheel is turned in the signaled direction and then returns to its normal position, the cams and springs cause the turn signal switch contacts to open and break the circuit.

TWO-FILAMENT STOP/TURN BULBS In systems using separate filaments for the stop and turn lamps, the brake and turn signal switches are not connected. If the vehicle uses the same filament for both purposes, then brake switch current is routed through contacts within the turn signal switch. By linking certain contacts, the bulbs can receive either brake switch current or flasher current, depending upon which direction is being signaled. For example, ● **FIGURE 56–11** shows current flow through the switch when the brake switch is closed and a right turn is signaled.

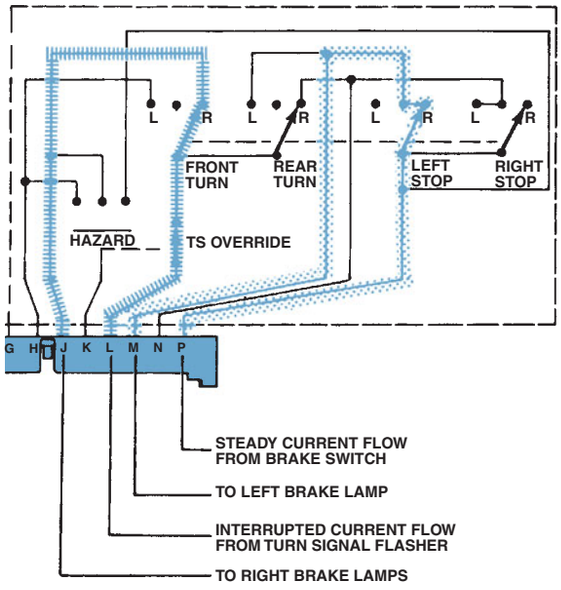


FIGURE 56–11 When a right turn in signaled, the turn signal switch contacts send flasher current to the right-hand filament and brake switch current to the left-hand filament.

Steady current through the brake switch is sent to the left brake lamp. Interrupted current from the turn signal is sent to the right turn lamps.

FLASHER UNITS A turn signal flasher unit is a metal or plastic can containing a switch that opens and closes the turn signal circuit. Vehicles can be equipped with many different types of flasher units. ● **SEE FIGURE 56–12.**

- **DOT flashers.** This turn signal flasher unit is often installed in a metal clip attached to the dash panel to allow the "clicking" noise of the flasher to be heard by the driver. The turn signal flasher is designed to transmit the current to light the front and rear bulbs on only one side at a time. The U.S. **Department of Transportation (DOT)** regulation requires that the driver be

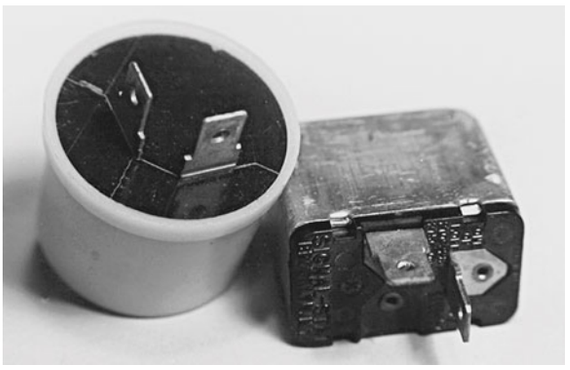


FIGURE 56–12 Two styles of two-prong flasher units.

alerted when a turn signal bulb is not working. This is achieved by using a series-type flasher unit. The flasher unit requires current flow through two bulbs (one in the front and one in the rear) in order to flash. If one bulb burns out, the current flow through only one bulb is not sufficient to make the unit flash; it will be a steady light. These turn signal units are often called DOT flashers.

- **Bimetal flashers.** The bimetal flashers have a lower cost and shorter life expectancy than hybrid or solid-state flashers. The operation of this flasher is current sensitive, which means that the flasher will stop flashing when one of the light bulbs is out and that it will flash at a faster rate when adding additional load, such as a trailer. The bimetal element is a sandwich of two different metals that distorts with temperature changes similar to a circuit breaker. The turn signal lamp current is passed through the bimetal element and causes heating. When the element is hot enough, the bimetal distorts, opening the contacts and turning off the lamps. After the bimetal cools, it returns to the original shape, closing the contacts and turning on the lamps again. This sequence is repeated until the load is removed. If one bulb burns out, the turn signal indicator lamp on the dash will remain lighted. The flasher will not flash because there is not enough current flow through the one remaining bulb to cause the flasher to become heated enough to open.
- **Hybrid flashers.** The **hybrid flashers** have an electronic flasher control circuit to operate the internal electromechanical relay and are commonly called a **flasher relay.** This type of flasher has a stable electronic timing circuitry that enables a wide operating voltage and temperature range with a reasonable cost. The life expectancy is considerably longer compared to bimetal units and is dependent on the load and relay used internally for switching the load. The hybrid flasher has a lamp current-sensing circuit which will cause the flash rate to double when a bulb is burned out.
- **Solid-state flashers.** The solid-state flashers have an internal electronic circuit for timing and solid-state power output devices for load switching. Life expectancy is longer than other flashers because there are no moving parts for mechanical breakdown. The biggest disadvantage of solid state is the higher cost. Solid-state units cause the turn indicator to flash rapidly if a bulb is burned out.

ELECTRONIC FLASHER REPLACEMENT UNITS Older vehicles (and a few newer ones) use thermal (bimetal) flashers that use heat to switch on and off. Most turn signal flasher units are mounted in a metal clip that is attached to the dash. The dash panel acts as a sounding board, increasing the sound of the flasher unit.

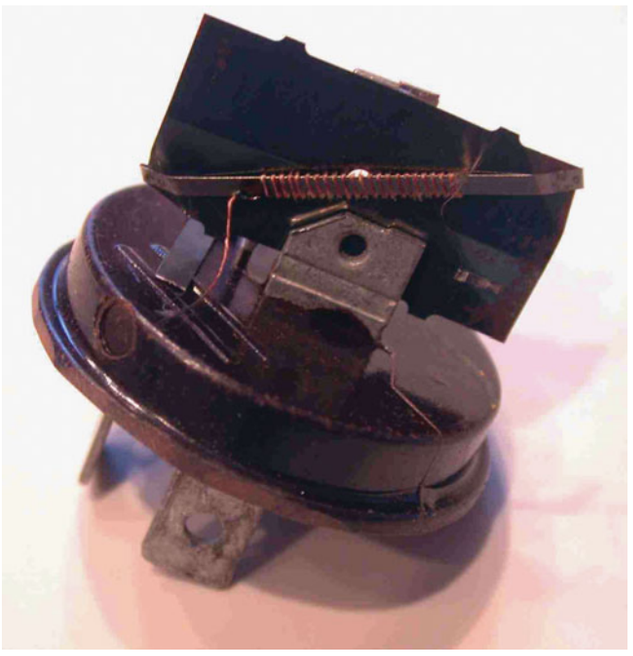


FIGURE 56–13 A hazard warning flasher uses a parallel resistor across the contacts to provide a constant flashing rate regardless of the number of bulbs used in the circuit.

Most four-way hazard flasher units are plugged into the fuse panel. Some turn signal flasher units are plugged into the fuse panel. How do you know for sure where the flasher unit is located? With both the turn signal and the ignition on, listen and/or feel for the clicking of the flasher unit. Some service manuals also give general locations for the placement of flasher units.

Newer vehicles have electronic flashers that use microchips to control the on/off function. Electronic flashers are compatible with older systems and are wise to use for the following reasons.

1. Electronic flashers do not burn out, and they provide a faster "flash" of the turn signals.
2. If upgrading to LED tail lamps, or lights, the LED bulbs only work with electronic flashers unless a resistor is added in the circuit.

HAZARD WARNING FLASHER The **hazard warning** flasher is a device installed in a vehicle lighting system with the primary function of causing both the left and right turn signal lamps to flash when the hazard warning switch is activated. Secondary functions may include visible dash indicators for the hazard system and an audible signal to indicate when the flasher is operating. A typical hazard warning flasher is also called a *parallel* or *variable-load* flasher because there is a resistor in parallel with the contacts to provide a control load and, therefore, a constant flash rate, regardless of the number of bulbs being flashed. ● **SEE FIGURE 56–13.**

COMBINATION TURN SIGNAL AND HAZARD WARNING FLASHER The combination flasher is a device that combines the functions of a turn signal flasher and a hazard warning flasher into one package, which often uses three electrical terminals.

HEADLIGHTS

HEADLIGHT SWITCHES The headlight switch operates the exterior and interior lights of most vehicles. On noncomputer-controlled lighting systems, the headlight switch is connected directly to the

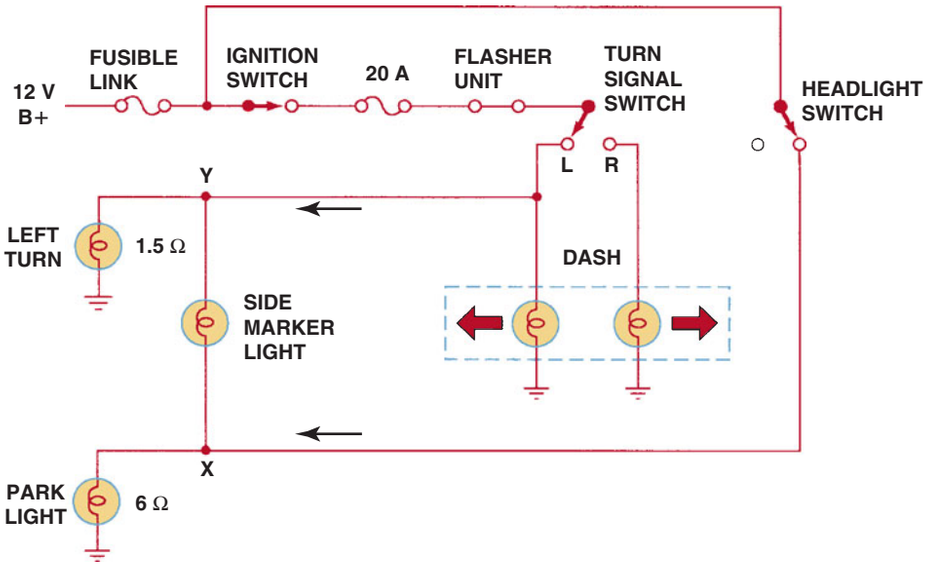


FIGURE 56–14 The side-marker light goes out whenever there is voltage at both points X and Y. These opposing voltages stop current flow through the side-marker light. The left turn light and left park light are actually the same bulb (usually 2057) and are shown separately to help explain how the side-marker light works on many vehicles.

FREQUENTLY ASKED QUESTION

How Do You Tell What Type of Flasher Is Being Used?

The easiest way to know which type of flasher can be used is to look at the type of bulb used in the tail lamps and turn signals. If it is a "wedge" style (plastic base, flat and rectangular), the vehicle has an electronic flasher. If it is a "twist and turn" bayonet-style (brass base) bulb, then either type of flasher can be used.

FREQUENTLY ASKED QUESTION

Why Does the Side-Marker Light Alternately Flash?

A question that service technicians are asked frequently is why the side-marker light alternately goes out when the turn signal is on, and is on when the turn signal is off. Some vehicle owners think that there is a fault with the vehicle, but this is normal operation. The side-marker light goes out when the lights are on and the turn signal is flashing because there are 12 volts on both sides of the bulb (see points X and Y in ● **FIGURE 56–14**).

Normally, the side-marker light gets its ground through the turn signal bulb.

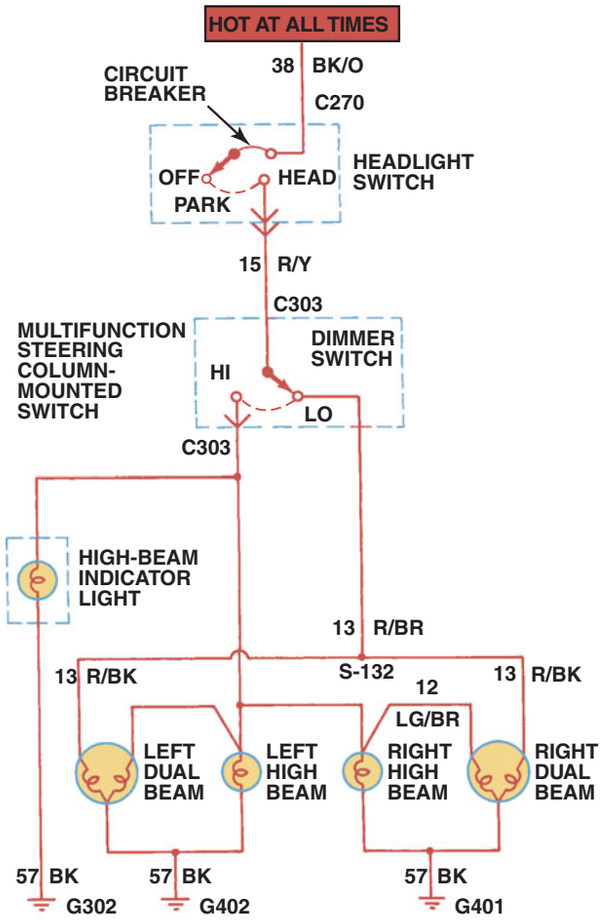


FIGURE 56–15 Typical headlight circuit diagram. Note that the headlight switch is represented by a dotted outline indicating that other circuits (such as dash lights) also operate from the switch.

battery through a fusible link, and has continuous power or is "hot" all the time. A circuit breaker is built into most older model headlight switches to protect the headlight circuit. ● **SEE FIGURE 56–15.**

The headlight switch may include the following:

- The interior dash lights can often be dimmed manually by rotating the headlight switch knob or by another rotary knob that controls a variable resistor (called a **rheostat**). The rheostat drops the voltage sent to the dash lights. Whenever there is a voltage drop (increased resistance), there is heat. A coiled resistance wire is built into a ceramic housing that is designed to insulate the rest of the switch from the heat and allow heat to escape.
- The headlight switch also contains a built-in circuit breaker that will rapidly turn the headlights on and off in the event of a short circuit. This prevents a total loss of headlights. If the headlights are rapidly flashing on and off, check the entire headlight circuit for possible shorts. The circuit breaker controls only the headlights. The other lights controlled by the headlight switch (taillights, dash lights, and parking lights) are fused separately. Flashing headlights also may be caused by a failure in the built-in circuit breaker, requiring replacement of the switch assembly.



FIGURE 56–16 A typical four-headlight system using sealed beam headlights.



FIGURE 56–17 A typical composite headlamp assembly. The lens, housing, and bulb sockets are usually included as a complete assembly.



FIGURE 56–18 Handle a halogen bulb by the base to prevent the skin's oil from getting on the glass.

AUTOMATIC HEADLIGHTS

Computer-controlled lights use a light sensor that signals when to have the computer turn on the headlights. The sensor is mounted on the dashboard or mirror. Often these systems have a driver-adjusted sensitivity control that allows for the lights to be turned on at various levels of light. Most systems also have a computer module control over the time that the lights remain on after the ignition has been turned off and the last door has been closed. A scan tool is often needed to change this time delay.

SEALED BEAM HEADLIGHTS

A sealed beam headlight consists of a sealed glass or plastic assembly containing the bulb, reflective surface, and prism lenses to properly focus the light beam. Low-beam headlights contain two filaments and three electrical terminals.

- One for low beam
- One for high beam
- Common ground

High-beam headlights contain only one filament and two terminals. Because low-beam headlights also contain a high-beam filament, the entire headlight assembly must be replaced if either filament is defective. ● **SEE FIGURE 56–16.**

A sealed beam headlight can be tested with an ohmmeter. A good bulb should indicate low ohms between the ground terminal and both power-side (hot) terminals. If either the high-beam or the low-beam filament is burned out, the ohmmeter will indicate infinity (OL).

HALOGEN SEALED BEAM HEADLIGHTS

Halogen sealed beam headlights are brighter and more expensive than normal headlights. Because of their extra brightness, it is common practice to have only two headlights on at any one time, because the candlepower output would exceed the maximum U.S. federal standards if all four halogen headlights were on. Therefore, before trying to repair the problem that only two of the four lamps are on, check the owner or shop manual for proper operation.

CAUTION: Do not attempt to wire all headlights together. The extra current flow could overheat the wiring from the headlight switch through the dimmer switch and to the headlights. The overloaded circuit could cause a fire.

COMPOSITE HEADLIGHTS

Composite headlights are constructed using a replaceable bulb and a fixed lens cover that is part of the vehicle. Composite headlights are the result of changes in the aerodynamic styling of vehicles where sealed beam lamps could no longer be used. ● **SEE FIGURE 56–17.**

TECH TIP

Diagnose Bulb Failure

Halogen bulbs can fail for various reasons. Some causes for halogen bulb failure and their indications are as follows:

- **Gray color.** Low voltage to bulb (check for corroded socket or connector)
- **White (cloudy) color.** Indication of an air leak
- **Broken filament.** Usually caused by excessive vibration
- **Blistered glass.** Indication that someone has touched the glass

NOTE: *Never touch the glass (called the ampoule) of any halogen bulb.* The oils from your fingers can cause unequal heating of the glass during operation, leading to a shorter-than-normal service life. ● **SEE FIGURE 56–18.**

The replaceable bulbs are usually bright halogen bulbs. Halogen bulbs get very hot during operation, between 500°F and 1,300°F (260°C and 700°C). It is important never to touch the glass of any halogen bulb with bare fingers because the natural oils of the skin on the glass bulb can cause the bulb to break when it heats during normal operation.

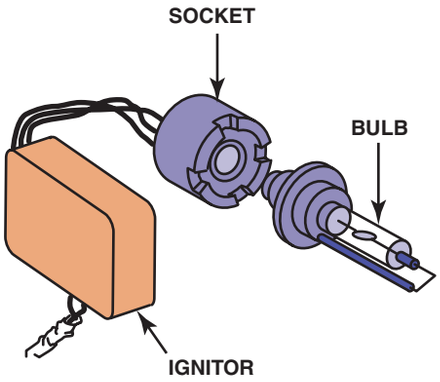


FIGURE 56–19 The igniter contains the ballast and transformer needed to provide high-voltage pulses to the arc tube bulb.

FREQUENTLY ASKED QUESTION

What Is the Difference Between the Temperature of the Light and the Brightness of the Light?

The temperature of the light indicates the color of the light. The brightness of the light is measured in lumens. A standard 100 watt incandescent light bulb emits about 1,700 lumens. A typical halogen headlight bulb produces about 2,000 lumens, and a typical HID bulb produces about 2,800 lumens.

HIGH-INTENSITY DISCHARGE HEADLIGHTS

PARTS AND OPERATION **High-intensity discharge (HID)** headlights produce a distinctive blue-white light that is crisper, clearer, and brighter than light produced by a halogen headlight.

High-intensity discharge lamps do not use a filament like conventional electrical bulbs, but contain two electrodes about 0.2 in. (5 mm) apart. A high-voltage pulse is sent to the bulb which arcs across the tips of electrodes producing light.

It creates light from an electrical discharge between two electrodes in a gas-filled arc tube. It produces twice the light with less electrical input than conventional halogen bulbs.

The HID lighting system consists of the discharge arc source, igniter, ballast, and headlight assembly. ● **SEE FIGURE 56–19.**

The two electrodes are contained in a tiny quartz capsule filled with xenon gas, mercury, and metal halide salts. HID headlights are also called **xenon headlights.** The lights and support electronics are expensive, but they should last the life of the vehicle unless physically damaged.

HID headlights produce a white light giving the lamp a blue-white color. The color of light is expressed in temperature using the Kelvin scale. **Kelvin (K)** temperature is the Celsius temperature plus 273 degrees. Typical color temperatures include:

- Daylight: 5,400°K
- HID: 4,100°K
- Halogen: 3,200°K
- Incandescent (tungsten): 2,800°K

● **SEE FIGURE 56–20.**



FIGURE 56–20 HID (xenon) headlights emit a whiter light than halogen headlights and usually look blue compared to halogen bulbs.

The HID ballast is powered by 12 volts from the headlight switch on the body control module. The HID headlights operate in three stages or states.

1. Start-up or stroke state
2. Run-up state
3. Steady state

START-UP OR STROKE STATE When the headlight switch is turned to the on position, the ballast may draw up to 20 amperes at 12 volts. The ballast sends multiple high-voltage pulses to the arc tube to start the arc inside the bulb. The voltage provided by the ballast during the start-up state ranges from −600 volts to +600 volts, which is increased by a transformer to about 25,000 volts. The increased voltage is used to create an arc between the electrodes in the bulb.

RUN-UP STATE After the arc is established, the ballast provides a higher than steady state voltage to the arc tube to keep the bulb illuminated. On a cold bulb, this state could last as long as 40 seconds. On a hot bulb, the run-up state may last only 15 seconds. The current requirements during the run-up state are about 360 volts from the ballast and a power level of about 75 watts.

STEADY STATE The steady state phase begins when the power requirement of the bulb drops to 35 watts. The ballast provides a minimum of 55 volts to the bulb during steady state operation.

BI-XENON HEADLIGHTS Some vehicles are equipped with bi-xenon headlights, which use a shutter to block some of the light during low-beam operation and then mechanically move to expose more of the light from the bulb for high-beam operation. Because xenon lights are relatively slow to start working, vehicles equipped with bi-xenon headlights use two halogen lights for the “flash-to-pass” feature.

FAILURE SYMPTOMS The following symptoms indicate bulb failure.

- A light flickers
- Lights go out (caused when the ballast assembly detects repeated bulb restrikes)
- Color changes to a dim pink glow

Bulb failures are often intermittent and difficult to repeat. However, bulb failure is likely if the symptoms get worse over time. Always follow the vehicle manufacturer’s recommended testing and service procedures.

DIAGNOSIS AND SERVICE High-intensity discharge headlights will change slightly in color with age. This **color shift** is usually not noticeable unless one headlight arc tube assembly has been replaced due to a collision repair, and then the difference in color may be noticeable. The difference in color will gradually change as

the arc tube ages and should not be too noticeable by most customers. If the arc tube assembly is near the end of its life, it may not light immediately if it is turned off and then back on immediately. This test is called a "hot restrike" and if it fails, a replacement arc tube assembly may be needed or there is another fault, such as a poor electrical connection, that should be checked.

WARNING

Always adhere to all warnings because the high-voltage output of the ballast assembly can cause personal injury or death.

LED HEADLIGHTS

Some vehicles, including several Lexus models, use LED headlights either as standard equipment (Lexus LS600h) or optional. ● **SEE FIGURE 56–21.**

Advantages include:

- Long service life
- Reduced electrical power required

Disadvantages include:

- High cost
- Many small LEDs required to create the necessary light output

HEADLIGHT AIMING

According to U.S. federal law, all headlights, regardless of shape, must be able to be aimed using headlight aiming equipment. Older vehicles equipped with sealed beam headlights used a headlight aiming system that attached to the headlight itself. ● **SEE FIGURES 56–22 AND 56–23**. Also see the photo sequence on headlight aiming at the end of the chapter.



FIGURE 56–21 LED headlights usually require multiple units to provide the needed light as seen on this Lexus LS600h.

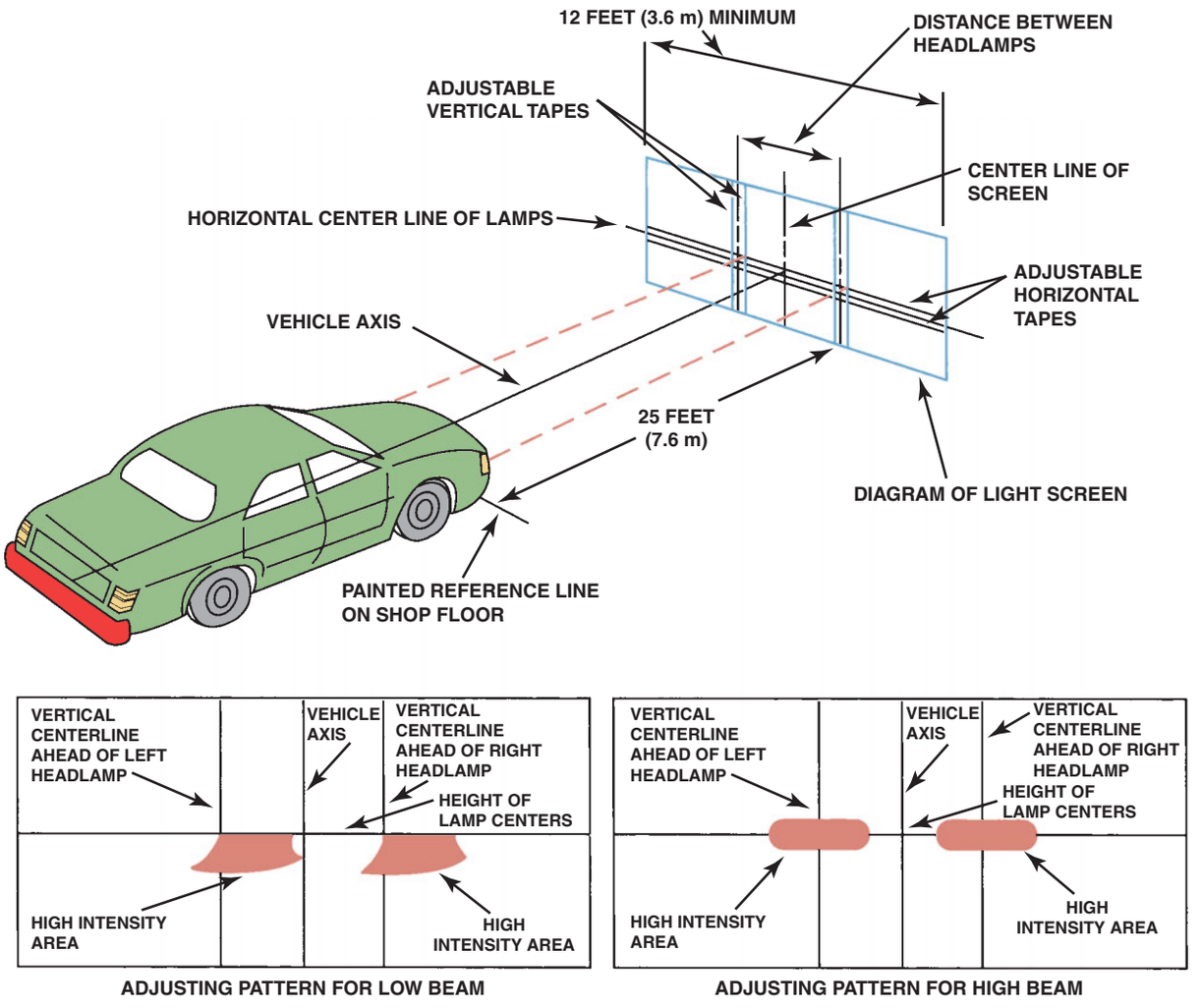


FIGURE 56–22 Typical headlight aiming diagram as found in service information.



FIGURE 56–23 Many composite headlights have a built-in bubble level to make aiming easy and accurate.

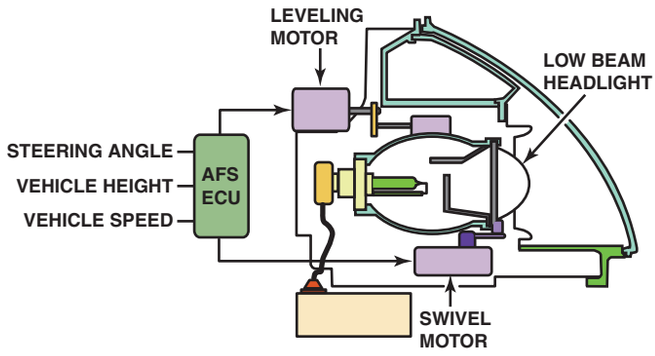


FIGURE 56–25 A typical adaptive front lighting system uses two motors: one for the up and down movement and the other for rotating the low-beam headlight to the left and right.

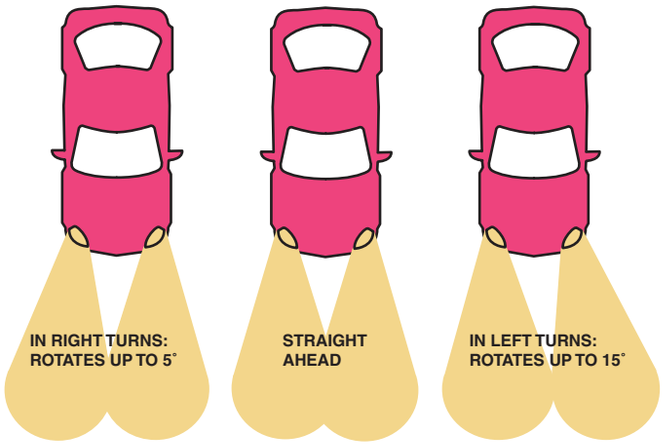


FIGURE 56–24 Adaptive front lighting systems rotate the low-beam headlight in the direction of travel.



FIGURE 56–26 Typical dash-mounted switch that allows the driver to disable the front lighting system.

ADAPTIVE FRONT LIGHTING SYSTEM

PARTS AND OPERATION A system that mechanically moves the headlights to follow the direction of the front wheels is called **adaptive** (or **advanced**) **front light system,** or **AFS.** The AFS provides a wide range of visibility during cornering. The headlights are usually capable of rotating 15 degrees to the left and 5 degrees to the right (some systems rotate 14 degrees and 9 degrees, respectively). Vehicles that use AFS include Lexus, Mercedes, and certain domestic models, usually as an extra cost option. ● **SEE FIGURE 56–24.**

NOTE: These angles are reversed on vehicles sold in countries that drive on the left side of the road, such as Great Britain, Japan, Australia, and New Zealand.

The vehicle has to be moving above a predetermined speed, usually above 20 mph (30 km/h) and the lights stop moving when the speed drops below about 3 mph (5 km/h).

AFS is often used in addition to self-leveling motors so that the headlights remain properly aimed regardless of how the vehicle is loaded. Without self-leveling, headlights would shine higher than normal if the rear of the vehicle is heavily loaded. ● **SEE FIGURE 56–25.**

When a vehicle is equipped with an adaptive front lighting system, the lights are moved by the headlight controller outward, and then inward as well as up and down as a test of the system. This action is quite noticeable to the driver, and is normal operation of the system.

DIAGNOSIS AND SERVICE The first step when diagnosing an AFS fault is to perform the following visual inspection.

- Start by checking that the AFS is switched on. Most AFS headlights are equipped with a switch that allows the driver to turn the system on and off. ● **SEE FIGURE 56–26.**
- Check that the system performs a self-test during start-up.
- Verify that both low-beam and high-beam lights function correctly. The system may be disabled if a fault with one of the headlights is detected.
- Use a scan tool to test for any AFS-related diagnostic trouble codes. Some systems allow the AFS to be checked and operated using a scan tool.

Always follow the recommended testing and service procedures as specified by the vehicle manufacturer in service information.

TECH TIP

Checking a Dome Light Can Be Confusing

If a technician checks a dome light with a test light, both sides of the bulb will "turn on the light" if the bulb is good. This will be true if the system's "ground switched" doors are closed and the bulb is good. This confuses many technicians because they do not realize that the ground will not be sensed unless the door is open.

DAYTIME RUNNING LIGHTS

PURPOSE AND FUNCTION **Daytime running lights (DRLs)** involve operation of the following:

- Front parking lights
- Separate DRL lamps
- Headlights (usually at reduced current and voltage) when the vehicle is running

Canada has required daytime running lights on all new vehicles since 1990. Studies have shown that DRLs have reduced accidents where used.

Daytime running lights primarily use a control module that turns on either the low or high-beam headlights or separate daytime running lights. The lights on some vehicles come on when the engine starts. Other vehicles will turn on the lamps when the engine is running but delay their operation until a signal from the vehicle speed sensor indicates that the vehicle is moving.

To avoid having the lights on during servicing, some systems will turn off the headlights when the parking brake is applied and the ignition switch is cycled off then back on. Others will only light the headlights when the vehicle is in a drive gear. ● **SEE FIGURE 56–27.**

CAUTION: Most factory daytime running lights operate the headlights at reduced intensity. These are *not* designed to be used at night. Normal intensity of the headlights (and operation of the other external lamps) is actuated by turning on the headlights as usual.

DIMMER SWITCHES

The headlight switch controls the power or hot side of the headlight circuit. The current is then sent to the dimmer switch, which allows current to flow to either the high-beam or the low-beam filament of the headlight bulb, as shown in ● **FIGURE 56–28.**

An indicator light illuminates on the dash when the high beams are selected.

The dimmer switch is usually hand operated by a lever on the steering column. Some steering column switches are actually attached to the *outside* of the steering column and are spring loaded. To replace these types of dimmer switches, the steering column needs to be lowered slightly to gain access to the switch itself.

COURTESY LIGHTS

Courtesy light is a generic term primarily used for interior lights, including overhead (dome) and under-the-dash (courtesy) lights. These interior lights are controlled by operating switches located in the doorjambs of the vehicle doors or by a switch on the dash. ● **SEE FIGURE 56–29.**

Many Ford vehicles use the door switches to open and close the power side of the circuit. Many newer vehicles operate the interior lights through the vehicle computer or through an electronic module. Because the exact wiring and operation of these units differ, consult the service information for the exact model of the vehicle being serviced.

ILLUMINATED ENTRY

Some vehicles are equipped with illuminated entry, meaning the interior lights are turned on for a given amount of time when the outside door handle is operated while the doors are locked. Most vehicles equipped with illuminated entry also light the exterior door keyhole. Vehicles equipped with body computers use the input from the key fob remote to "wake up" the power supply for the body computer.

FIBER OPTICS

Fiber optics is the transmission of light through special plastic (polymethyl methacrylate) that keeps the light rays parallel even if the plastic is tied in a knot. These strands of plastic are commonly used in automotive applications as indicators for the driver that certain lights are functioning. For example, some vehicles are equipped with fender-mounted units that light when the lights or turn signals are operating. Plastic fiber-optic strands, which often look like standard electrical wire, transmit the light at the bulb to the indicator on top of the fender so that the driver can determine if a certain light is operating. Fiber-optic strands also can be run like wires to indicate the operation of all lights on the dash or console. Fiber-optic strands are also commonly used to light ashtrays, outside door locks, and other areas where a small amount of light is required. The source of the light can be any normally operating light bulb, which means that one bulb can be used to illuminate many areas. A special bulb clip is normally used to retain the fiber-optic plastic tube near the bulb.

AUTOMATIC DIMMING MIRRORS

PARTS AND OPERATION Automatic dimming mirrors use electrochromic technology to dim the mirror in proportion to the amount of headlight glare from other vehicles at the rear. The electrochromic technology developed by Gentex Corporation uses a gel that changes with light between two pieces of glass. One piece of glass acts as a reflector and the other has a transparent (clear) electrically conductive coating. The inside rearview mirror also has

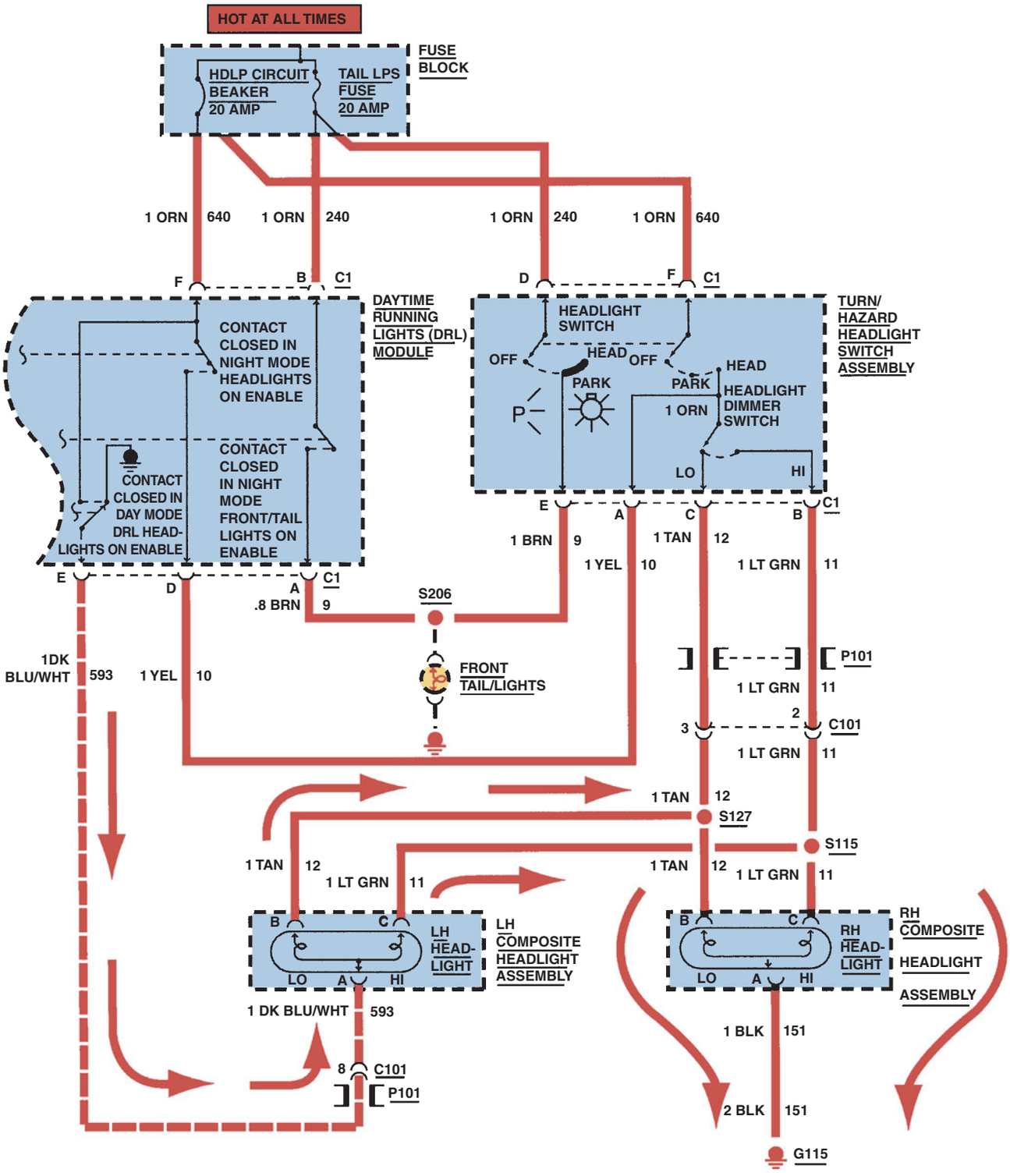


FIGURE 56–27 Typical daytime running light (DRL) circuit. Follow the arrows from the DRL module through both headlights. Notice that the left and right headlights are connected in series, resulting in increased resistance, less current flow, and dimmer than normal lighting. When the normal headlights are turned on, both headlights receive full battery voltage, with the left headlight grounding through the DRL module.

a forward-facing light sensor that is used to detect darkness and signal the rearward-facing sensor to begin to check for excessive glare from headlights behind the vehicle. The rearward-facing sensor sends a voltage to the electrochromic gel in the mirror that is in proportion to the amount of glare detected. The mirror dims in proportion to the glare and then becomes like a standard rearview mirror when the glare is no longer detected. If automatic dimming mirrors are used on the exterior, the sensors in the interior mirror and electronics are used to control both the interior and exterior mirrors. ● **SEE FIGURE 56–30.**

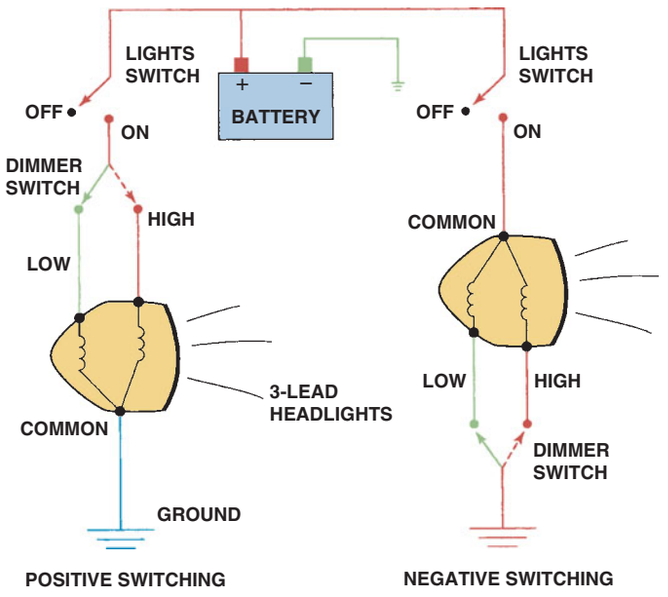


FIGURE 56–28 Most vehicles use positive switching of the high- and low-beam headlights. Notice that both filaments share the same ground connection. Some vehicles use negative switching and place the dimmer switch between the filaments and the ground.



FIGURE 56–29 A typical courtesy light doorjamb switch. Newer vehicles use the door switch as an input to the vehicle computer and the computer turns the interior lights on or off. By placing the lights under the control of the computer, the vehicle engineers have the opportunity to delay the lights after the door is closed and to shut them off after a period of time to avoid draining the battery.

DIAGNOSIS AND SERVICE

If a customer concern states that the mirrors do not dim when exposed to bright headlights from the vehicle behind, the cause could be sensors or the mirror itself. Be sure that the mirror is getting electrical power. Most automotive dimming mirrors have a green light to indicate the presence of electrical power. If no voltage is found at the mirror, follow standard troubleshooting procedures to find the cause. If the mirror is getting voltage, start the diagnosis by placing a strip of tape over the forward-facing light sensor. Turn the ignition key on, engine off (KOEO), and observe the operation of the mirror when a flashlight or trouble light is directed onto the mirror. If the mirror reacts and dims, the forward-facing sensor is defective. Most often, the entire mirror assembly has to be replaced if any sensor or mirror faults are found.

One typical fault with automatic dimming mirrors is a crack can occur in the mirror assembly, allowing the gel to escape from between the two layers of glass. This gel can drip onto the dash or center console and harm these surfaces. The mirror should be replaced at the first sign of any gel leakage.

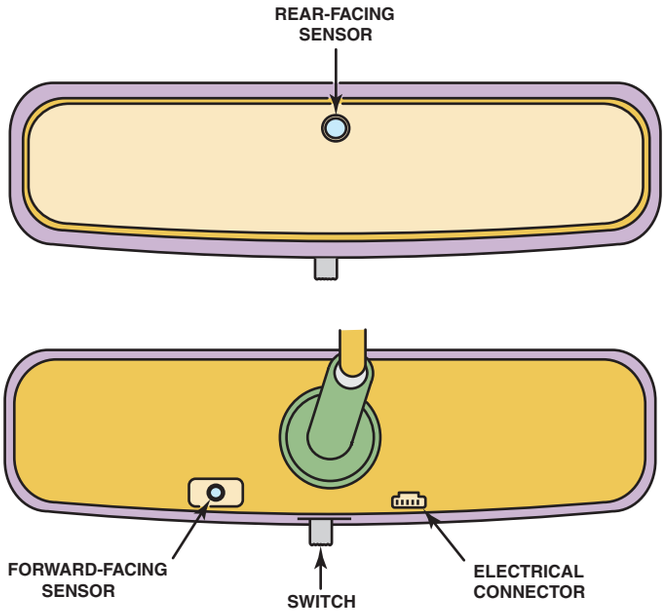


FIGURE 56–30 An automatic dimming mirror compares the amount of light toward the front of the vehicle to the rear of the vehicle and allies a voltage to cause the gel to darken the mirror.

FREQUENTLY ASKED QUESTION

What Is the Troxler Effect?

The **Troxler effect,** also called *Troxler fading,* is a visual effect where an image remains on the retina of the eye for a short time after the image has been removed. The effect was discovered in 1804 by Igney Paul Vital Troxler (1780–1866), a Swiss physician. Because of the Troxler effect, headlight glare can remain on the retina of the eye and create a blind spot. At night, this fading away of the bright lights from the vehicle in the rear reflected by the rearview mirror can cause a hazard.

TECH TIP

The Weirder the Problem, the More Likely It Is a Poor Ground Connection

Bad grounds are often the cause for feedback or lamps operating at full or partial brilliance. At first the problem looks weird because often the switch for the lights that are on dimly is not even turned on. When an electrical device is operating and it lacks a proper ground connection, the current will try to find ground and will often cause other circuits to work. Check all grounds before replacing parts.

FEEDBACK

DEFINITION When current that lacks a good ground goes backward along the power side of the circuit in search of a return path (ground) to the battery, this reverse flow is called **feedback,** or *reverse-bias* current flow. Feedback can cause other lights or gauges that should not be working to actually turn on.

FEEDBACK EXAMPLE A customer complained that when the headlights were on, the left turn signal indicator light on the dash remained on. The cause was found to be a poor ground connection for the left front parking light socket. The front parking light bulb is a dual filament: one filament for the parking light (dim) and one filament for the turn signal operation (bright). A corroded socket did not provide a good enough ground to conduct all current required to light the dim filament of the bulb.

The two filaments of the bulb share the same ground connection and are electrically connected. When all the current could not flow through the bulb's ground in the socket, it caused a feedback or reversed its flow through the other filament, looking for ground. The turn signal filament is electrically connected to the dash indicator light; therefore, the reversed current on its path toward ground could light the turn signal indicator light. Cleaning or replacing the socket usually solves the problem if the ground wire for the socket is making a secure chassis ground connection.

LIGHTING SYSTEM DIAGNOSIS

Diagnosing any faults in the lighting and signaling systems usually includes the following steps.

STEP 1 Verify the customer concern.

STEP 2 Perform a visual inspection, checking for collision damage or other possible causes that would affect the operation of the lighting circuit.

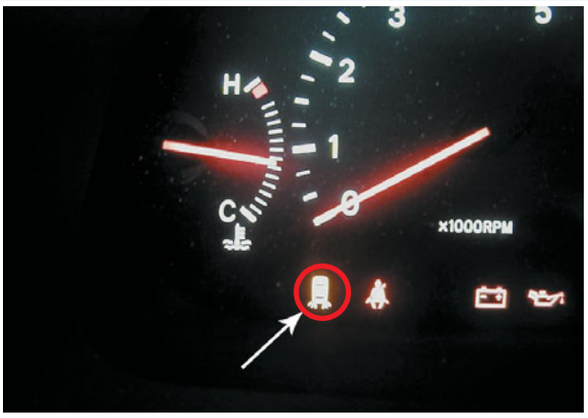
STEP 3 Connect a factory or enhanced scan tool with bidirectional control of the computer modules to check for proper operation of the affected lighting circuit.

STEP 4 Follow the diagnostic procedure as found in service information to determine the root cause of the problem.

LIGHTING SYSTEM SYMPTOM GUIDE

The following list will assist technicians in troubleshooting lighting systems.

Problem	Possible Causes and/or Solutions
One headlight dim	1. Poor ground connection on body 2. Corroded connector
One headlight out (low or high beam)	1. Burned out headlight filament (Check the headlight with an ohmmeter. There should be a low-ohm reading between the power-side connection and the ground terminal of the bulb.) 2. Open circuit (no 12 volts to the bulb)
Both high and low-beam headlights out	1. Burned out bulbs (Check for voltage at the wiring connector to the headlights for a possible open circuit to the headlights or open [defective] dimmer switch.) 2. Open circuit (no 12 volts to the bulb)
All headlights inoperative	1. Burned out filaments in all headlights (Check for excessive charging system voltage.) 2. Defective dimmer switch 3. Defective headlight switch
Slow turn signal operation	1. Defective flasher unit 2. High resistance in sockets or ground wire connections 3. Incorrect bulb numbers
Turn signals operating on one side only	1. Burned out bulb on affected side 2. Poor ground connection or defective socket on affected side 3. Incorrect bulb number on affected side 4. Defective turn signal switch
Interior light(s) inoperative	1. Burned out bulb(s) 2. Open in the power-side circuit (blown fuse) 3. Open in doorjamb switch(es)
Interior lights on all the time	1. Shorted doorjamb switch 2. Shorted control switch
Brake lights inoperative	1. Defective brake switch 2. Defective turn signal switch 3. Burned out brake light bulbs 4. Open circuit or poor ground connection 5. Blown fuse
Hazard warning lights inoperative	1. Defective hazard flasher unit 2. Open in hazard circuit 3. Blown fuse 4. Defective hazard switch
Hazard warning lights blinking too rapidly	1. Incorrect flasher unit 2. Shorted wiring to front or rear lights 3. Incorrect bulb numbers



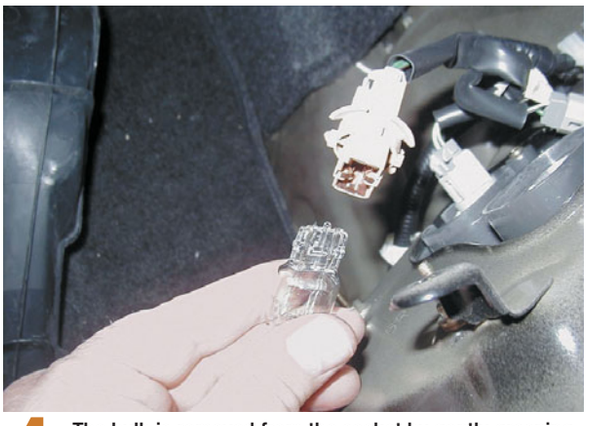
1 The driver noticed that the taillight fault indicator (icon) on the dash was on any time the lights were on.



2 A visual inspection at the rear of the vehicle indicated that the right rear taillight bulb did not light. Removing a few screws from the plastic cover revealed the taillight assembly.



3 The bulb socket is removed from the taillight assembly by gently twisting the base of the bulb counterclockwise.



4 The bulb is removed from the socket by gently grasping the bulb and pulling the bulb straight out of the socket. Many bulbs required that you rotate the bulb 90° (1/4 turn) to release the retaining bulbs.



5 The new 7443 replacement bulb is being checked with an ohmmeter to be sure that it is okay before it is installed in the vehicle.



6 The replacement bulb in inserted into the taillight socket and the lights are turned on to verify proper operation before putting the components back together.

CONTINUED ▶

OPTICAL HEADLIGHT AIMING



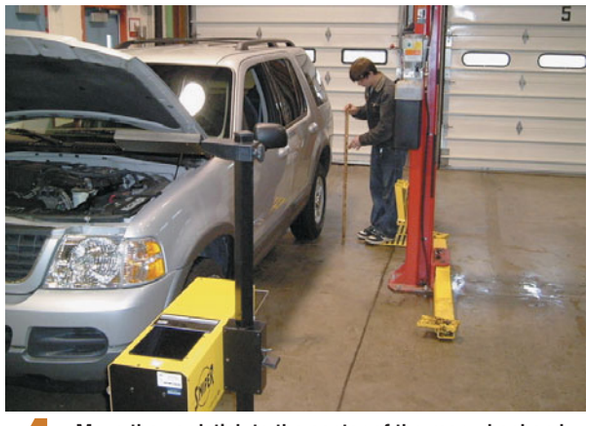
1 Before checking the vehicle for headlight aim, be sure that all the tires are at the correct inflation pressure, and that the suspension is in good working condition.



2 The headlight aim equipment will have to be adjusted for the slope of the floor in the service bay. Start the process by turning on the laser light generator on the side of the aimer body.



3 Place a yardstick or measuring tape vertically in front of the center of the front wheel, noting the height of the laser beam.



4 Move the yardstick to the center of the rear wheel and measure the height of the laser beam at this point. The height at the front and rear wheels should be the same.



5 If the laser beam height measurements are not the same, the floor slope of the aiming equipment must be adjusted. Turn the floor slope knob until the measurements are equal.



6 Place the aimer in front of the headlight to be checked, at a distance of 10 to 14 inches (25 to 35 cm). Use the aiming pointer to adjust the height of the aimer to the middle of the headlight.



7 Align the aimer horizontally, using the pointer to place the aimer at the center of the headlight.



8 Lateral alignment (aligning the body of the aimer with the body of the vehicle) is done by looking through the upper visor. The line in the upper visor is aligned with symmetrical points on the vehicle body.



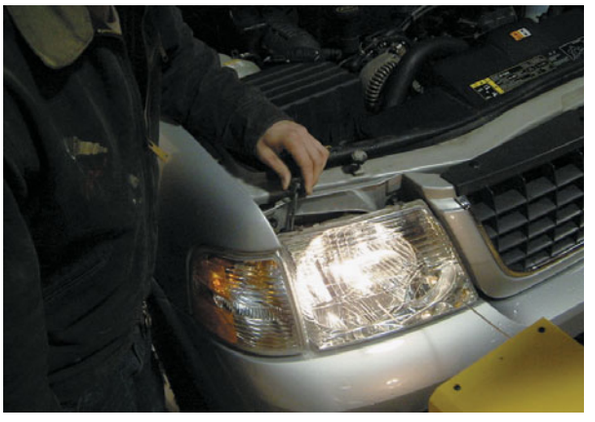
9 Turn on the vehicle headlights, being sure to select the correct beam position for the headlight to be aimed.



10 View the light beam through the aimer window. The position of the light pattern will be different for high and low beams.



11 If the first headlight is aimed adequately, move the aimer to the headlight on the opposite side of the vehicle. Follow the previous steps to position the aimer accurately.



12 If adjustment is required, move the headlight adjusting screws using a special tool or a 1/4-in. drive ratchet/socket combination. Watch the light beam through the aimer window to verify the adjustment.

CONTINUED ▶

REVIEW QUESTIONS

1. Why should the exact same trade number of bulb be used as a replacement?
2. Why is it important to avoid touching a halogen bulb with your fingers?
3. How do you diagnose a turn signal operating problem?
4. How do you aim headlights on a vehicle equipped with aerodynamic-style headlights?

CHAPTER QUIZ

1. Technician A says that the bulb trade number is the same for all bulbs of the same size. Technician B says that a dual-filament bulb has different candlepower ratings for each filament. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. Two technicians are discussing flasher units. Technician A says that only a DOT-approved flasher unit should be used for turn signals. Technician B says that a parallel (variable-load) flasher will function for turn signal usage, although it will not warn the driver if a bulb burns out. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. Interior overhead lights (dome lights) are operated by doorjamb switches that _____.
   a. Complete the power side of the circuit
   b. Complete the ground side of the circuit
   c. Move the bulb(s) into contact with the power and ground
   d. Either a or b depending on application
4. Electrical feedback is usually a result of _____.
   a. Too high a voltage in a circuit
   b. Too much current (in amperes) in a circuit
   c. Lack of a proper ground
   d. Both a and b
5. According to Chart 56–1, which bulb is brightest?
   a. 194 **c.** 194NA
   b. 168 **d.** 1157
6. If a 1157 bulb were to be installed in a left front parking light socket instead of a 2057 bulb, what would be the most likely result?
   a. The left turn signal would flash faster.
   b. The left turn signal would flash slower.
   c. The left parking light would be slightly brighter.
   d. The left parking light would be slightly dimmer.
7. A technician replaced a 1157NA with a 1157A bulb. Which is the most likely result?
   a. The bulb is brighter because the 1157A candlepower is higher.
   b. The amber color of the bulb is a different shade.
   c. The bulb is dimmer because the 1157A candlepower is lower.
   d. Both b and c
8. A customer complained that every time he turned on his vehicle's lights, the left-side turn signal indicator light on the dash remained on. The most likely cause is a _____.
   a. Poor ground to the parking light (or taillight) bulb on the *left side*
   b. Poor ground to the parking light (or taillight) bulb on the *right* side, causing current to flow to the left-side lights
   c. Defective (open) parking light (or taillight) bulb on the left side
   d. Both a and c
9. A defective taillight or front park light bulb could cause the _____.
   a. Turn signal indicator on the dash to light when the lights are turned on
   b. Dash lights to come on when the brake lights are on
   c. Lights-on warning chime to sound if the brake pedal is depressed
   d. All of the above
10. A defective brake switch could prevent proper operation of the _____.
    a. Cruise control **c.** Shift interlock
    b. ABS brakes **d.** All of the above

chapter 57

DRIVER INFORMATION AND NAVIGATION SYSTEMS

OBJECTIVES: **After studying Chapter 57, the reader will be able to:** • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "F" (Gauges, Warning Devices, and Driver Information System Diagnosis and Repair). • Be able to identify the meaning of dash warning symbols. • Discuss how a fuel gauge works. • Explain how to use a service manual to troubleshoot a malfunctioning dash instrument. • Describe how a navigation system works. • List the various types of dash instrument displays.

KEY TERMS: Backup camera 640 • CFL 634 • Combination valve 628 • CRT 634 • EEPROM 637 • GPS 637 • HUD 630 • IP 629 • LCD 633 • LDWS 641 • LED 633 • NVRAM 637 • Phosphor 633 • PM generator 635 • Pressure differential switch 628 • RPA 641 • Stepper motor 629 • VTF 633 • WOW display 634

DASH WARNING SYMBOLS

PURPOSE AND FUNCTION All vehicles are equipped with warning lights that are often confusing to drivers. Because many vehicles are sold throughout the world, symbols instead of words are being used as warning lights. The dash warning lights are often called *telltale* lights as they are used to notify the driver of a situation or fault.

BULB TEST When the ignition is first turned on, all of the warning lights come on as part of a self-test and to help the driver or technician spot any warning light that may be burned out. Technicians or drivers who are familiar with what lights should light may be able to determine if one or more warning lights are not on when the ignition is first turned on. Most factory scan tools can be used to command all of the warning lights on to help determine if one is not working.

ENGINE FAULT WARNING Engine fault warning lights include the following:

- **Engine coolant temperature.** This warning lamp should come on when the ignition is first turned on as a bulb check and if the coolant temperature reaches 248°F to 258°F (120°C to 126°C), depending on the make and model of the vehicle. **SEE FIGURE 57–1.**

  If the engine coolant temperature warning lamp comes on while driving, perform the following in an attempt to reduce the temperature.

  1. Turn off the air conditioning.
  2. Turn on the heater.
  3. If the hot light remains on, drive to a safe location and shut off the engine and allow it to cool to help avoid serious engine damage.

- **Engine oil pressure.** This warning lamp should light when the ignition is first turned on as a bulb check; or if the engine oil pressure light comes on when driving, perform the following:

  1. Pull off the road as soon as possible.
  2. Shut off the engine.
  3. Check the oil level.
  4. Do not drive the vehicle with the engine oil light on or severe engine damage can occur.

  SEE FIGURE 57–2.

- **Water in diesel fuel warning.** This warning lamp will light when the ignition is first turned on as a bulb check and if water is detected in the diesel fuel. This lamp is only used or operational in vehicles equipped with a diesel engine. If the water in diesel fuel warning lamp comes on, do the following:

  1. Remove the water using the built-in drain, usually part of the fuel filter.
  2. Check service information for the exact procedure to follow.

  SEE FIGURE 57–3.

- **Maintenance required warning.** The maintenance required lamp comes on when the ignition is first turned on as a bulb check and if the vehicle requires service. The service required could include:

  1. Oil and oil filter change
  2. Tire rotation
  3. Inspection



FIGURE 57–1 Engine coolant temperature is too high.



FIGURE 57–2 Engine oil pressure too low.



FIGURE 57–3 Water detected in fuel. Notice to drain the water from the fuel filter assembly on a vehicle equipped with a diesel engine.



FIGURE 57–4 Maintenance required. This usually means that the engine oil is scheduled to be changed or other routine service items replaced or checked.



FIGURE 57–5 Malfunction indicator lamp (MIL), also called a check engine light. The light means the engine control computer has detected a fault.



FIGURE 57–6 Charging system fault detected.

Check service information for the exact service required. ● **SEE FIGURE 57–4.**

- **Malfunction indicator lamp (MIL), also called a check engine or service engine soon (SES) light.** This warning lamp comes on when the ignition is first turned on as a bulb test and then only if a fault in the powertrain control module (PCM) has been detected. If the MIL comes on when driving, it is not necessary to stop the vehicle, but the cause for why the warning lamp came on should be determined as soon as possible to avoid harming the engine or engine control systems. The MIL could come on if any of the following has been detected.
  1. A sensor or actuator is electrically open or shorted.
  2. A sensor is out of range for expected values.
  3. An emission control system failure occurs, such as a loose gas cap.

  If the MIL is on, a diagnostic trouble code has been set. Use a scan tool to retrieve the code(s) and follow service information for the exact procedure to follow. ● **SEE FIGURE 57–5.**

ELECTRICAL SYSTEM–RELATED WARNING LIGHTS

- **Charging system fault.** This warning lamp will come on when the ignition is first turned on as a bulb check and if a fault in the charging system has been detected. The lamp could include a fault with any of the following:
  1. Battery state of charge (SOC), electrical connections, or the battery itself
  2. Alternator or related wiring

  ● **SEE FIGURE 57–6.**

  If the charge system warning lamp comes on, continue to drive until it is safe to pull over. The vehicle can usually be driven for several miles using battery power alone.

  Check the following by visible inspection.
  1. Alternator drive belt
  2. Loose or corroded electrical connections at the battery
  3. Loose or corroded wiring to the alternator
  4. Defective alternator

SAFETY-RELATED WARNING LAMPS

Safety-related warning lamps include the following:

- **Safety belt warning lamp.** The safety belt warning lamp will light and sound an alarm to notify the driver if the driver's side or passenger's side safety belt is not fastened. It is also used to indicate a fault in the safety belt circuit. Check service information for the exact procedure to follow if the safety belt warning light remains on even when the belts are fastened. ● **SEE FIGURE 57–7.**



FIGURE 57–7 Fasten safety belt warning light.



FIGURE 57–8 Fault detected in the supplemental restraint (airbag) system.



FIGURE 57–9 Fault detected in base brake system.



FIGURE 57–10 Brake light bulb failure detected.



FIGURE 57–11 Exterior light bulb failure detected.

- **Airbag warning lamp.** The airbag warning lamp comes on and flashes when the ignition is first turned on as part of a self-test of the system. If the airbag warning lamp remains on after the self-test, then the airbag controller has detected a fault. Check service information for the exact procedure to follow if the airbag warning lamp is on. ● **SEE FIGURE 57–8.**

  NOTE: The passenger side airbag light may indicate that it is on or off, depending if there is a passenger or an object heavy enough to trigger the seat sensor.

- **Red brake fault warning light.** All vehicles are equipped with a red brake warning (RBW) lamp that lights if a fault in the base (hydraulic) brake system is detected. Three types of sensors are used to light this warning light.
  1. A brake fluid level sensor located in the master cylinder brake fluid reservoir
  2. A pressure switch located in the pressure differential switch, which detects a difference in pressure between the front and rear or diagonal brake systems
  3. The parking brake could be applied. ● **SEE FIGURE 57–9.**

  If the red brake warning light comes on, do not drive the vehicle until the cause is determined and corrected.
- **Brake light bulb failure.** Some vehicles are able to detect if a brake light is burned out. The warning lamp will warn the driver when a situation like this occurs. ● **SEE FIGURE 57–10.**
- **Exterior light bulb failure.** Many vehicles use the body control module (BCM) to monitor current flow through all of the exterior lights and therefore can detect if a bulb is not working. ● **SEE FIGURE 57–11.**



FIGURE 57–12 Worn brake pads or linings detected.



FIGURE 57–13 Fault detected in antilock brake system.



FIGURE 57–14 Low tire pressure detected.



FIGURE 57–15 Door open or ajar.

TECH TIP

Check the Spare

Some vehicles that are equipped with a full-size spare tire also have a sensor in the spare. If the warning lamp is on and all four tires are properly inflated, check the spare.

- **Worn brake pads.** Some vehicles are equipped with sensors built into the disc brake pads that are used to trigger a dash warning light. The warning light often comes on when the ignition is first turned on as a bulb check and then goes out. If the brake pad warning lamp is on, check service information for the exact service procedure to follow. ● **SEE FIGURE 57–12.**
- **Antilock brake system (ABS) fault.** The amber antilock brake system warning light comes on if the ABS controller detects a fault in the antilock braking system. Examples of what could trigger the warning light include:
  1. Defective wheel speed sensor
  2. Low brake fluid level in the hydraulic control unit assembly
  3. Electrical fault detected anywhere in the system

  ● **SEE FIGURE 57–13.**

  If the amber ABS warning lamp is on, it is safe to drive the vehicle, but the antilock portion may not function.
- **Low tire pressure warning.** A tire pressure monitoring system (TPMS) warns if the inflation pressure of a tire has decreased by 25% (about 8 psi). If the warning lamp or message of a low tire is displayed, check the tire pressures before driving. If the inflation pressure is low, repair or replace the tire. ● **SEE FIGURE 57–14.**

DRIVER INFORMATION SYSTEM

- **Door open or ajar warning light.** If a door is open or ajar, a warning light is used to notify the driver. Check and close all doors and tailgates before driving. ● **SEE FIGURE 57–15.**
- **Windshield washer fluid low.** A sensor in the windshield washer fluid reservoir is used to turn on the low washer fluid warning lamp. ● **SEE FIGURE 57–16.**



FIGURE 57–16 Windshield washer fluid low.

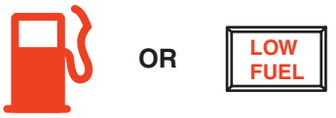


FIGURE 57–17 Low fuel level.



FIGURE 57–18 Headlights on.

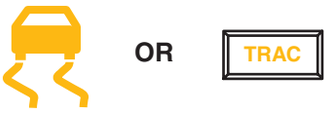


FIGURE 57–19 Low traction detected. Traction control system is functioning to restore traction (usually flashes when actively working to restore traction).



FIGURE 57–20 Vehicle stability control system either off or working if flashing.



FIGURE 57–21 Traction control system has been turned off.

- **Low fuel warning.** A low fuel indicator light is used to warn the driver that the fuel level is low. In most vehicles, the light comes on when there is between 1 and 3 gallons (3.8 and 11 liters) of fuel remaining. ● **SEE FIGURE 57–17.**
- **Headlights on light.** This dash indicator lights whenever the headlights are on. ● **SEE FIGURE 57–18.**

  NOTE: This light may or may not indicate that the headlights are on if the headlight switch is set to the automatic position.
- **Low traction detected.** On a vehicle equipped with a traction control system (TCS), a dash indicator light is flashed whenever the system is working to restore traction. If the low traction warning light is flashing, reduce the rate of acceleration to help the system restore traction of the drive wheels with the road surface. ● **SEE FIGURE 57–19.**
- **Electronic stability control.** If a vehicle is equipped with electronic stability control (ESC), also called vehicle stability control (VSC), the dash indicator lamp will flash if the system is trying to restore vehicle stability. ● **SEE FIGURE 57–20.**
- **Traction off.** If the traction control system (TCS) is turned off by the driver, an indicator lamp lights to help remind the driver that this system has been turned off and will not be able to restore traction when lost. The system reverts to on, when the ignition is turned off, and then back on as the traction off button is depressed. ● **SEE FIGURE 57–21.**

CRUISE

FIGURE 57–22 Indicates that the cruise control is on and able to maintain vehicle speed if set. Some vehicles use a symbol that looks like a small speedometer to indicate that the cruise control is on.

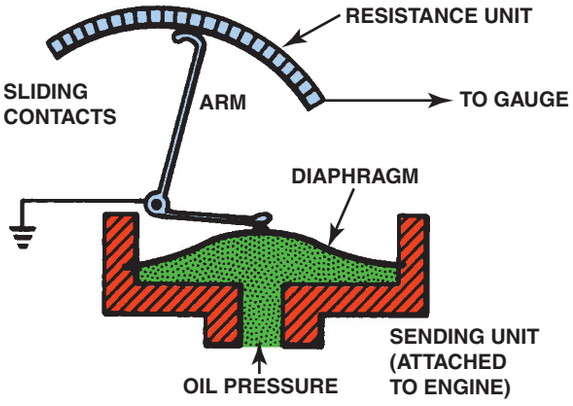


FIGURE 57–23 A typical oil pressure sending unit provides a varying amount of resistance as engine oil pressure changes. The output from the sensor is a variable voltage.

- **Cruise indicator lamp.** Most vehicles are equipped with a switch that turns on the cruise control. The cruise (speed) control system does not work unless it has been turned on to help prevent accidental engagement. When the cruise control has been turned on, the cruise indicator light is on. ● **SEE FIGURE 57–22.**

OIL PRESSURE WARNING DEVICES

OPERATION The oil pressure lamp operates through use of an oil pressure sensor unit, which is screwed into the engine block, and grounds the electrical circuit and lights the dash warning lamp in the event of low oil pressure, that is, 3 to 7 psi (20 to 50 kilopascals [kPa]). Normal oil pressure is generally between 10 and 60 psi (70 and 400 kPa). Some vehicles are equipped with a variable voltage oil pressure sensors rather than a simple pressure switch. ● **SEE FIGURE 57–23.**

OIL PRESSURE LAMP DIAGNOSIS To test the operation of the oil pressure warning circuit, unplug the wire from the oil pressure sending unit, usually located near the oil filter, with the ignition switch on. With the wire disconnected from the sending unit, the warning lamp should be off. If the wire is touched to a ground, the warning lamp should be on. If there is *any* doubt of the operation of the oil pressure warning lamp, always check the actual engine oil pressure using a gauge that can be screwed into the opening that is left after unscrewing the oil pressure sending unit. For removing the sending unit, special sockets are available at most auto parts stores, or a 1 in. or 1 1/16 in. 6-point socket may be used for most units.

TEMPERATURE LAMP DIAGNOSIS

The "hot" lamp, or engine coolant overheat warning lamp, warns the driver whenever the engine coolant temperature is between 248°F and 258°F (120°C and 126°C). This temperature is slightly below the boiling point of the coolant in a properly operating cooling system. The temperature sensor on older models was separate from the sensor used by the engine computer. However, most vehicles now use the engine coolant temperature (ECT) sensor for engine temperature gauge operation. To test this sensor, use a scan tool to verify proper engine temperature and follow the vehicle manufacturer's recommended testing procedures. ● **SEE FIGURE 57–24.**



FIGURE 57–24 A temperature gauge showing normal operating temperature between 180°F and 215°F, depending on the specific vehicle and engine.

REAL WORLD FIX

The Low Oil Pressure Story

After replacing valve cover gaskets on a Chevrolet V-8, the technician discovered that the oil pressure warning lamp was on. After checking the oil level and finding everything else okay, the technician discovered a wire pinched under the valve cover.

The wire went to the oil pressure sending unit. The edge of the valve cover had cut through the insulation and caused the current from the oil lamp to go to ground through the engine. Normally the oil lamp comes on when the sending unit grounds the wire from the lamp.

The technician freed the pinched wire and covered the cut with silicone sealant to prevent corrosion damage.

BRAKE WARNING LAMP

All vehicles sold in the United States after 1967 must be equipped with a dual braking system and a dash-mounted warning lamp to signal the driver of a failure in one part of the hydraulic brake system. The switch that operates the warning lamp is called a **pressure differential switch.** This switch is usually the center portion of a multipurpose brake part called a **combination valve.** If there is unequal hydraulic pressure in the braking system, the switch usually provides a ground path for the brake warning lamp, and the lamp comes on. ● **SEE FIGURE 57–25.**

Unfortunately, the dash warning lamp is often the same lamp as that used to warn the driver that the parking brake is on. The warning lamp is usually operated by using the parking brake lever

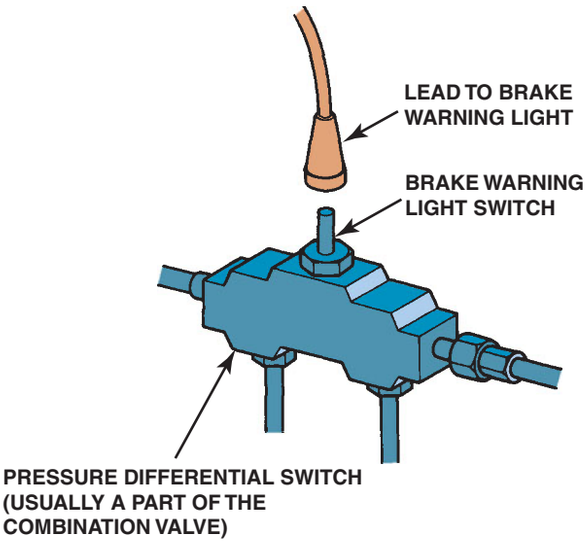


FIGURE 57–25 Typical brake warning light switch located on or near the master brake cylinder.

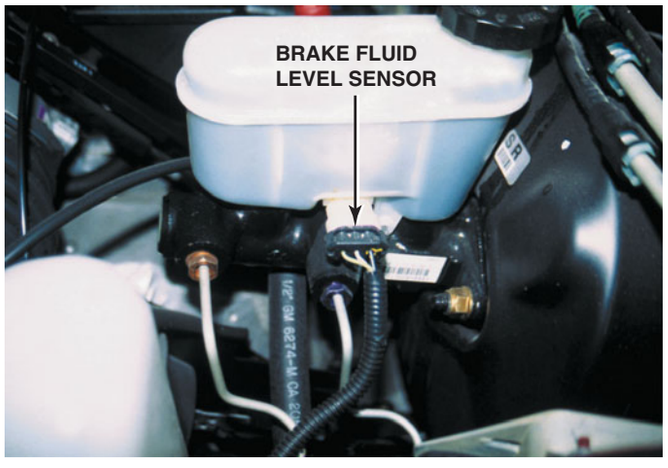


FIGURE 57–26 The red brake warning lamp can be turned on if the brake fluid level is low.

or brake hydraulic pressure switch to complete the ground for the warning lamp circuit. If the warning lamp is on, first check if the parking brake is fully released. If the parking brake is fully released, the problem could be a defective parking brake switch or a hydraulic brake problem. To test for which system is causing the lamp to remain on, simply unplug the wire from the valve or switch. If the wire on the pressure differential switch is disconnected and the warning lamp remains on, then the problem is due to a defective or misadjusted parking brake switch. If, however, the warning lamp goes out when the wire is removed from the brake switch, then the problem is due to a hydraulic brake fault that caused the pressure differential switch to complete the warning lamp circuit. The red brake warning lamp also can be turned on if the brake fluid is low. ● **SEE FIGURE 57–26** for an example of a brake fluid level sensor.

ANALOG DASH INSTRUMENTS

An analog display uses a needle to show the value, whereas a digital display uses numbers. Analog electromagnetic dash instruments use small electromagnetic coils that are connected to a sending unit for such things as fuel level, water temperature, and oil pressure. The sensors are the same regardless of the type of display used. The resistance of the sensor varies with what is being measured. ● **SEE FIGURE 57–27** for typical electromagnetic fuel gauge operation.

NETWORK COMMUNICATION

DESCRIPTION Many instrument panels are operated by electronic control units that communicate with the engine control computer for engine data such as revolutions per minute (rpm) and engine temperature. These electronic **instrument panels (IPs)** use the voltage changes from variable-resistance sensors, such as that of the fuel gauge, to determine fuel level. Therefore, even though the sensor in the fuel tank is the same, the display itself may be computer controlled. The data is transmitted to the instrument cluster as well as to the powertrain control module through serial data lines. Because all sensor inputs are interconnected, the technician should always follow the factory recommended diagnostic procedures. ● **SEE FIGURE 57–28.**

STEPPER MOTOR ANALOG GAUGES

DESCRIPTION Most analog dash displays use a stepper motor to move the needle. A **stepper motor** is a type of electric motor that is designed to rotate in small steps based on the signal from a computer. This type of gauge is very accurate.

OPERATION A digital output is used to control stepper motors. Stepper motors are direct current motors that move in fixed steps or increments from de-energized (no voltage) to fully energized (full voltage). A stepper motor often has as many as 120 steps of motion. When using a stepper motor that is controlled by the PCM, it is very easy for the PCM to keep track of the stepper motor's position. By counting the number of steps that have been sent to the stepper motor, the PCM can determine its relative position. While the PCM does not actually receive a feedback signal from the stepper motor, it knows how many steps forward or backward the motor should have moved.

A typical stepper motor uses a permanent magnet and two electromagnets. Each of the two electromagnetic windings is controlled by the computer. The computer pulses the windings and changes the polarity of the windings to cause the armature of the stepper motor to rotate 90 degrees at a time. Each 90-degree pulse is recorded by the computer as a "count" or "step," which explains the name given to this type of motor. ● **SEE FIGURE 57–29.**

NOTE: Many electronic gauge clusters are checked at key on where the dash display needles will be commanded to 1/4, 1/2, 3/4, and full positions before returning to their normal readings. This self-test allows the service technician to check the operation of each individual gauge, even though replacing the entire instrument panel cluster is usually necessary to repair an inoperative gauge.

DIAGNOSIS The dash electronic circuits are often too complex to show on a wiring diagram. Instead, all related electronic circuits are simply indicated as a solid box with "electronic module" printed

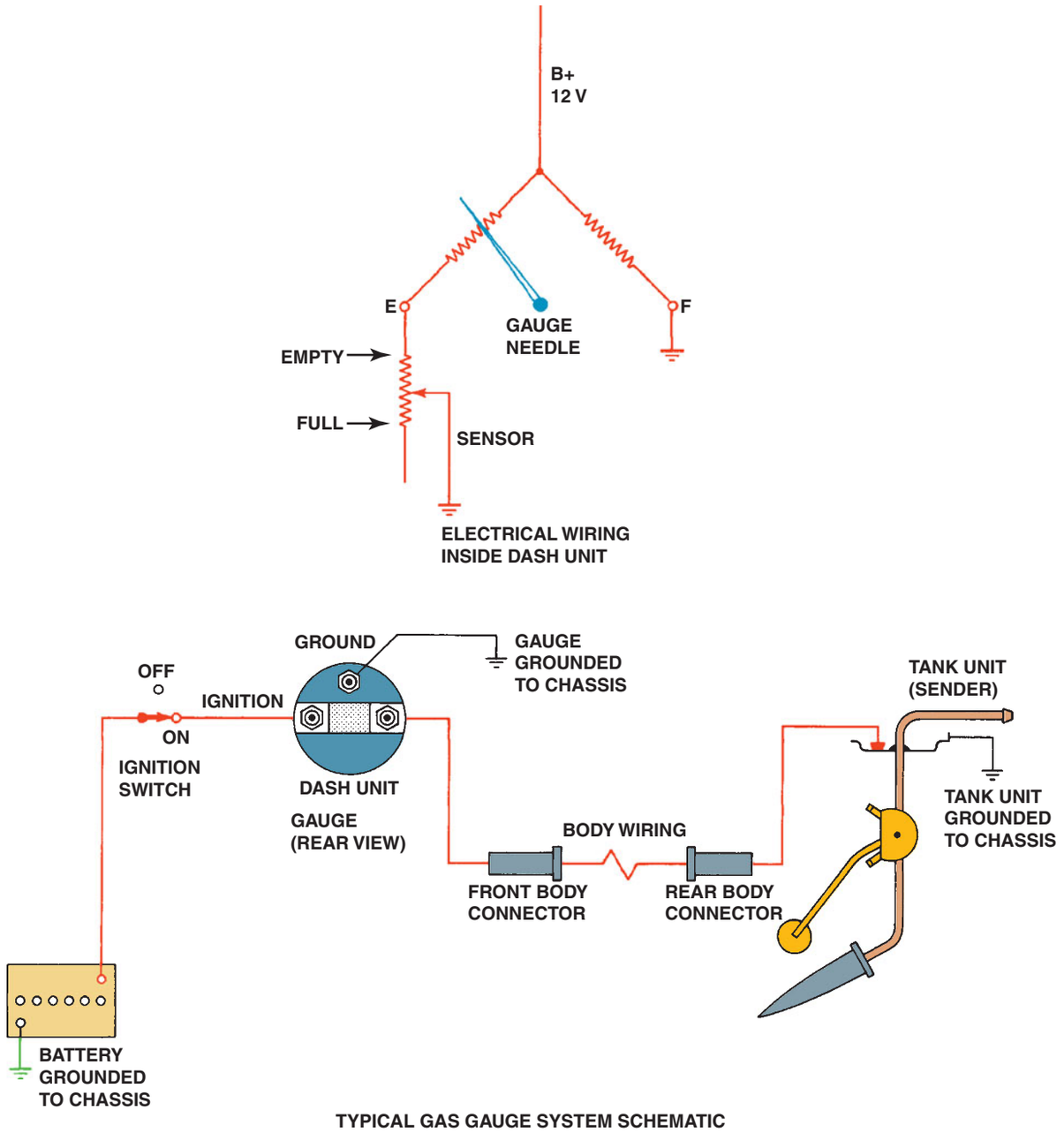


FIGURE 57–27 Electromagnetic fuel gauge wiring. If the sensor wire is unplugged and grounded, the needle should point to "E" (empty). If the sensor wire is unplugged and held away from ground, the needle should point to "F" (full).

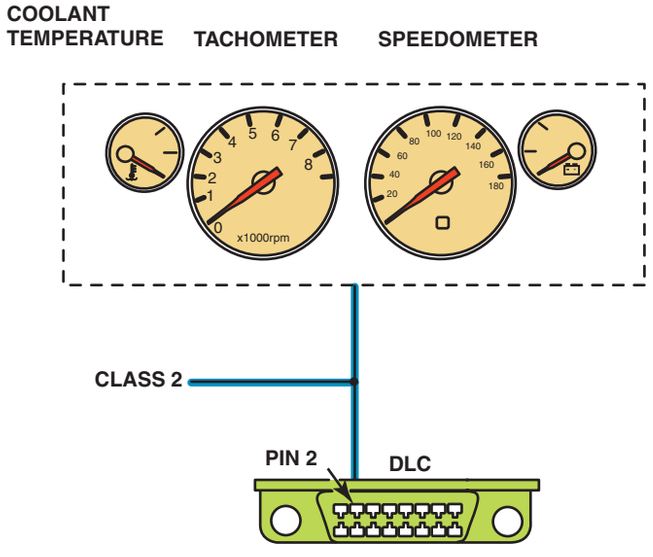


FIGURE 57–28 A typical instrument display uses data from the sensors over serial data lines to the individual gauges.

on the diagram. Even if all the electronic circuits were shown on the wiring diagram, it would require the skill of an electronics engineer to determine exactly how the circuit was designed to work. ● **SEE FIGURE 57–30.**

Note that the grounding for the "check oil" dash indicator lamp is accomplished through an electronic buffer. The exact conditions, such as amount of time since the ignition was shut off, are unknown to the technician. To correctly diagnose problems with this type of circuit, technicians must read, understand, and follow the written diagnostic procedures specified by the vehicle manufacturer.

HEAD-UP DISPLAY

The **head-up display (HUD)** is a supplemental display that projects the vehicle speed and sometimes other data, such as turn signal information, onto the windshield. The projected image looks as if it

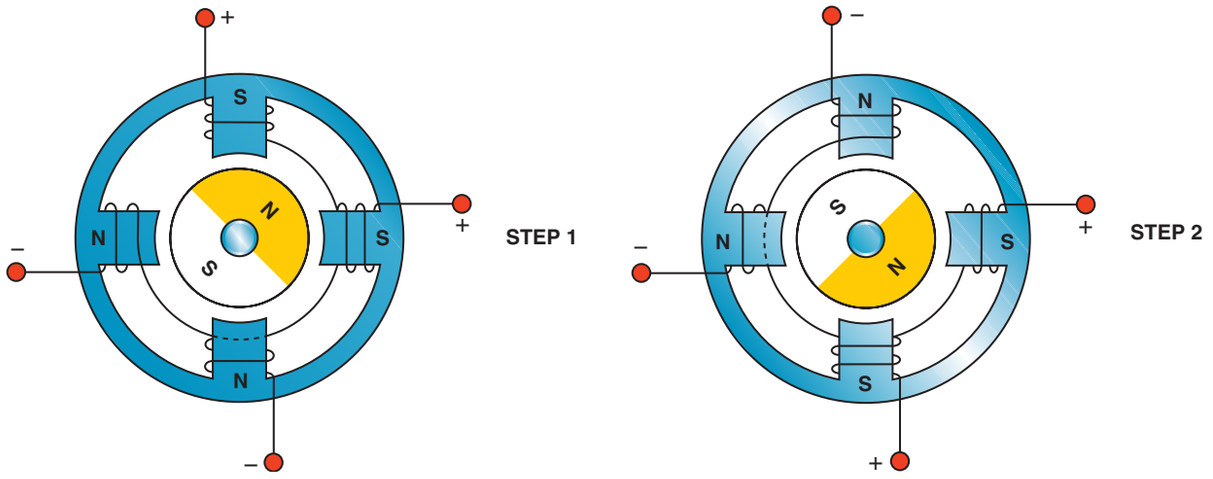


FIGURE 57–29 Most stepper motors use four wires which are pulsed by the computer to rotate the armature in steps.

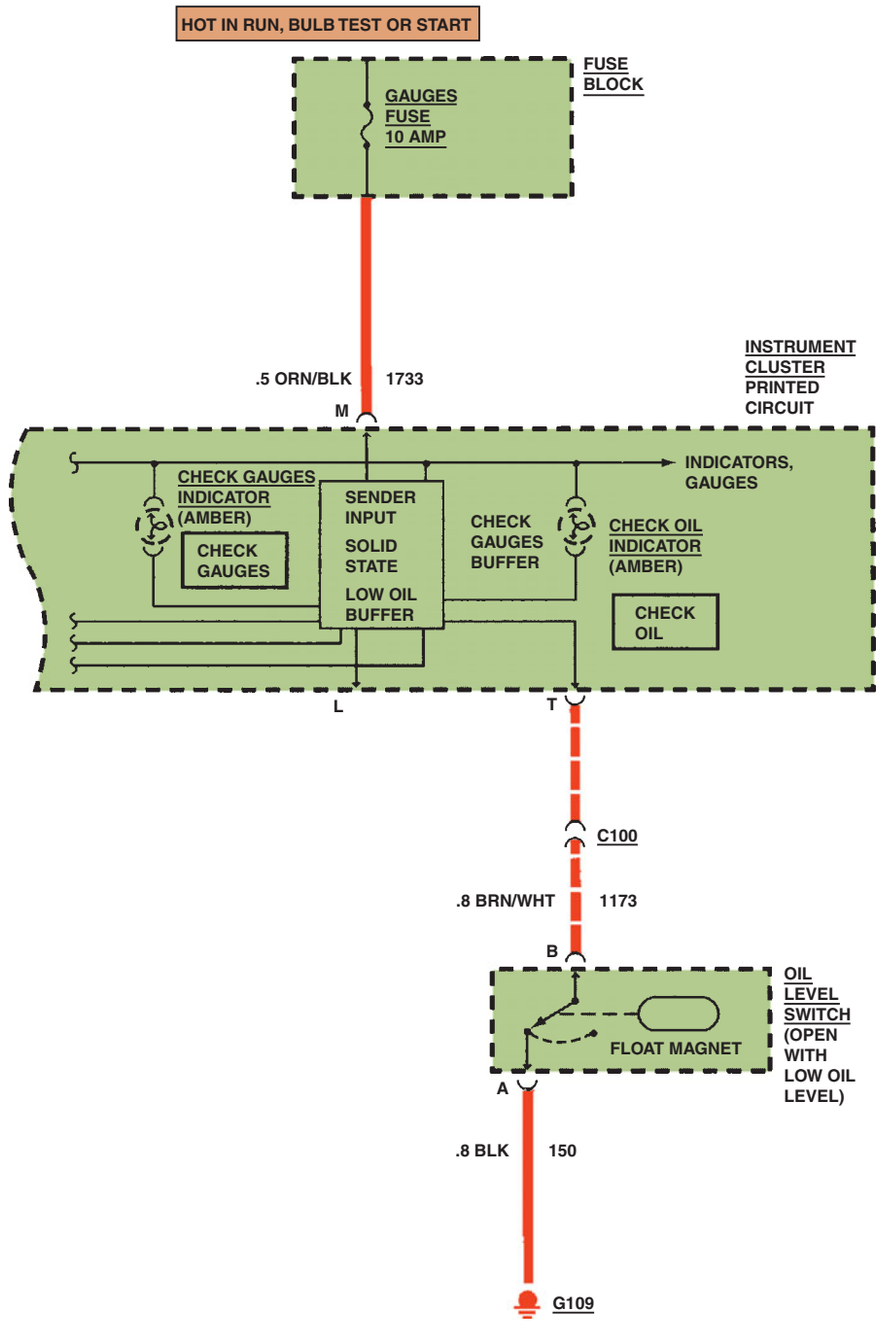


FIGURE 57–30 The ground for the "check oil" indicator lamp is controlled by the electronic low-oil buffer. Even though this buffer is connected to an oil level sensor, the buffer also takes into consideration the amount of time the engine has been stopped and the temperature of the engine. The only way to properly diagnose a problem with this circuit is to use the procedures specified by the vehicle manufacturer. Besides, only the engineer who designed the circuit knows for sure how it is supposed to work.

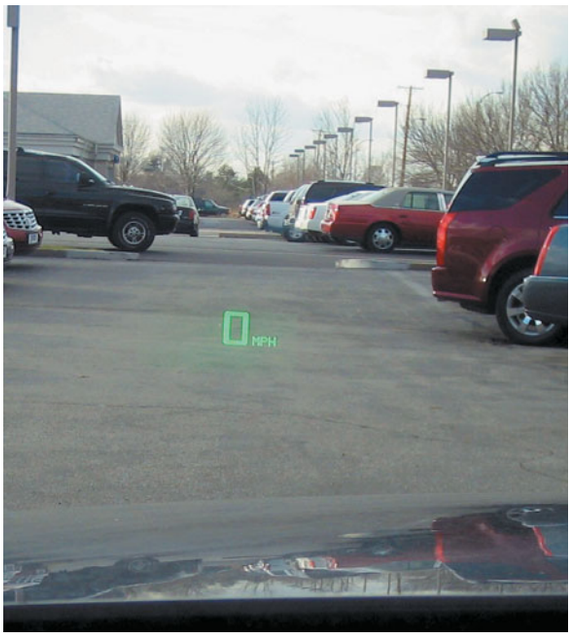


FIGURE 57–31 A typical head-up display showing zero miles per hour, which is actually projected on the windshield from the head-up display in the dash.



FIGURE 57–32 The dash-mounted control for the head-up display on this Cadillac allows the driver to move the image up and down on the windshield for best viewing.

is some distance ahead, making it easy for the driver to see without having to refocus on a closer dash display. ● **SEE FIGURES 57–31 AND 57–32.**

The head-up display can also have the brightness controlled on most vehicles that use this type of display. The HUD unit is installed in the instrument panel (IP) and uses a mirror to project vehicle information onto the inside surface of the windshield. ● **SEE FIGURE 57–33.**

Follow the vehicle manufacturer's recommended diagnostic and testing procedures if any faults are found with the head-up display.

NIGHT VISION

PARTS AND OPERATION Night vision systems use a camera that is capable of observing objects in the dark to assist the driver while driving at night. The primary night viewing illumination devices

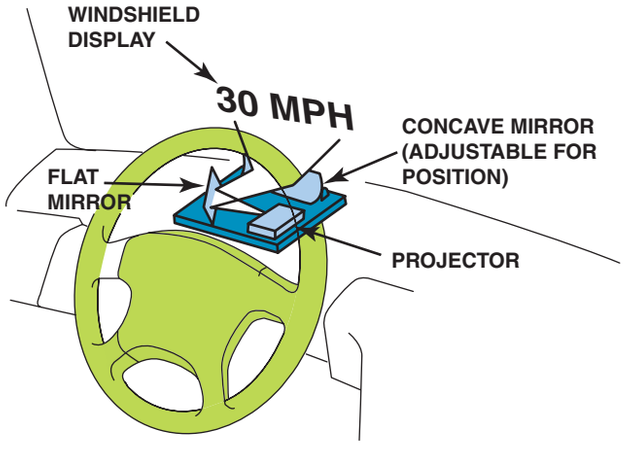


FIGURE 57–33 A typical head-up display (HUD) unit.

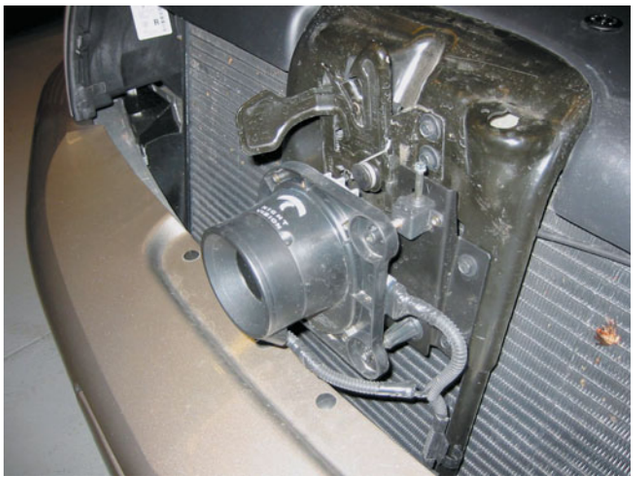


FIGURE 57–34 A night vision camera behind the grille of a Cadillac.

are the headlights. The night vision option uses a head-up display (HUD) to improve the vision of the driver beyond the scope of the headlights. Using a HUD display allows the driver to keep eyes on the road and hands on the wheel for maximum safety.

Besides the head-up display, the night vision camera uses a special thermal imaging or infrared technology. The camera is mounted behind the grille in the front of the vehicle. ● **SEE FIGURE 57–34.**

The camera creates pictures based on the heat energy emitted by objects rather than from light reflected on an object as in a normal optical camera. The image looks like a black and white photo negative when hot objects (higher thermal energy) appear light or white, and cool objects appear dark or black. Other parts of the night vision system include:

- **On/off and dimming switch.** This allows the driver to adjust the brightness of the display and to turn it on or off as needed.
- **Up/down switch.** The night vision HUD system has an electric tilt adjust motor that allows the driver to adjust the image up or down on the windshield within a certain image.

CAUTION: Becoming accustomed to night vision can be difficult and may take several nights to get used to looking at the head-up display.

DIAGNOSIS AND SERVICE The first step when diagnosing a fault with the night vision system is to verify the concern. Check the owner manual or service information for proper operation. For

example, the Cadillac night vision system requires the following actions to function.

1. The ignition has to be in the on (run) position.
2. The Twilight Sentinel photo cell must indicate that it is dark.
3. The headlights must be on.
4. The switch for the night vision system must be on and the brightness adjusted so the image is properly displayed.

The night vision system uses a camera in the front of the vehicle that is protected from road debris by a grille. However, small stones or other debris can get past the grille and damage the lens of the camera. If the camera is damaged, it must be replaced as an assembly because no separate parts are available. Always follow the vehicle manufacturer's recommended testing and servicing procedures.

DIGITAL ELECTRONIC DISPLAY OPERATION

TYPES

- Mechanical or electromechanical dash instruments use cables, mechanical transducers, and sensors to operate a particular dash instrument.
- Digital dash instruments use various electric and electronic sensors that activate segments or sections of an electronic display. Most electronic dash clusters use a computer chip and various electronic circuits to operate and control the internal power supply, sensor voltages, and display voltages.
- Electronic dash display systems may use one or more of several types of displays: light-emitting diode (LED), liquid crystal display (LCD), vacuum tube fluorescent (VTF), and cathode ray tube (CRT).

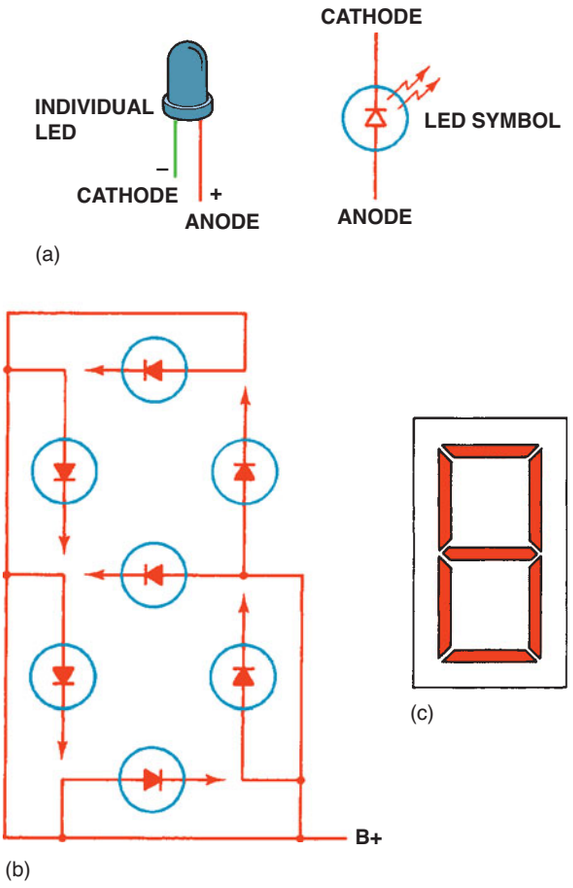


FIGURE 57–35 (a) Symbol and line drawing of a typical light-emitting diode (LED). (b) Grouped in seven segments, this array is called a seven-segment LED display with a common anode (positive connection). The dash computer toggles the cathode (negative) side of each individual segment to display numbers and letters. (c) When all segments are turned on, the number 8 is displayed.

LED DIGITAL DISPLAYS All diodes emit some form of energy during operation; the **light-emitting diode (LED)** is a semiconductor that is constructed to release energy in the form of light. Many colors of LEDs can be constructed, but the most popular are red, green, and yellow. Red is difficult to see in direct sunlight; therefore, if an LED is used, most vehicle manufacturers use yellow. Light-emitting diodes can be arranged in a group of seven, which then can be used to display both numbers and letters. ● **SEE FIGURE 57–35.**

An LED display requires more electrical power than other types of electronic displays. A typical LED display requires 30 mA for each *segment;* therefore, each number or letter displayed could require 210 mA (0.210 A).

LIQUID CRYSTAL DISPLAYS **Liquid crystal displays (LCDs)** can be arranged into a variety of forms, letters, numbers, and bar graph displays.

- LCD construction consists of a special fluid sandwiched between two sheets of polarized glass. The special fluid between the glass plates will permit light to pass if a small voltage is applied to the fluid through a conductive film laminated to the glass plates.
- The light from a very bright halogen bulb behind the LCD shines through those segments of the LCD that have been polarized to let the light through, which then show numbers or letters. Color filters can be placed in front of the display to change the color of certain segments of the display, such as the maximum engine speed on a digital tachometer.

CAUTION: Be careful, when cleaning an LCD, not to push on the glass plate covering the special fluid. If excessive pressure is exerted on the glass, the display may be permanently distorted. If the glass breaks, the fluid will escape and could damage other components in the vehicle as a result of its strong alkaline nature. Use only a soft, damp cloth to clean these displays.

- The major disadvantage of an LCD digital dash is that the numbers or letters are slow to react or change at low temperatures. ● **SEE FIGURE 57–36.**

VACUUM TUBE FLUORESCENT DISPLAYS The **vacuum tube fluorescent (VTF)** display is a popular automotive and household appliance display because it is very bright and can easily be viewed in strong sunlight. The usual VTF display is green, but white is often used for home appliances.

- The VTF display generates its bright light in a manner similar to that of a TV screen, where a chemical-coated light-emitting element called a **phosphor** is hit with high-speed electrons.



FIGURE 57–36 A typical navigation system. This Honda/Acura system uses some of the climate control functions as well as the trip information on the display. This particular unit uses a DVD unit in the trunk along with a global positioning satellite (GPS) to display a map and your exact location for the entire country.

- VTF displays are very bright and must be dimmed by use of dense filters or by controlling the voltage applied to the display. A typical VTF dash is dimmed to 75% brightness whenever the parking lights or headlights are turned on. Some displays use a photocell to monitor and adjust the intensity of the display during daylight viewing. Most VTF displays are green for best viewing under most lighting conditions.

CATHODE RAY TUBE

A **cathode ray tube (CRT)** dash display, which is similar to a television tube or LCD display, permits the display of hundreds of controls and diagnostic messages in one convenient location.

Using the touch-sensitive cathode ray tube, the driver or technician can select from many different displays, including those of radio, climate, trip, and dash instrument information. The driver can readily access all of these functions. Further diagnostic information can be displayed on the CRT if the proper combination of air-conditioning controls is touched. The diagnostic procedures for these displays involve pushing two or more buttons at the same time to access the diagnostic menu. Always follow the factory service manual recommendations.

COLD CATHODE FLUORESCENT DISPLAYS

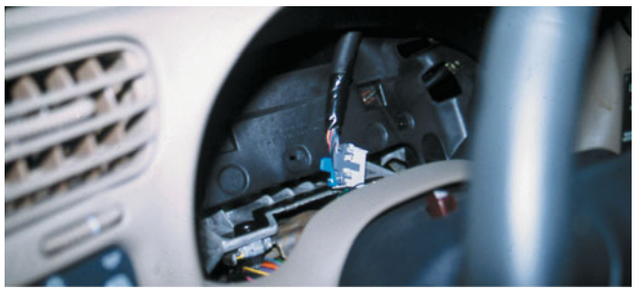
Cold **cathode fluorescent lighting (CFL)** models are used by many vehicle manufacturers for backlighting. Current consumption ranges from 3 to 5 mA (0.003 to 0.005 A) with an average life of 40,000 hours. CFL is replacing conventional incandescent light bulbs.

ELECTRONIC ANALOG DISPLAYS

Most analog dash displays since the early 1990s are electronically or computer controlled. The sensors may be the same, but the sensor information is sent to the body or vehicle computer through a data BUS, and then the computer controls current through small electromagnets that move the needle of the gauge. ● **SEE FIGURE 57–37.** A scan tool often is needed to diagnosis the operation of a computer-controlled analog dash instrument display.

WOW DISPLAY

When a vehicle equipped with a digital dash is started, all segments of the electronic display are turned on at full brilliance for 1 or 2 seconds. This is commonly called the **WOW display,** and is used to show off the brilliance of the display. If numbers are part of the display, the number 8 is shown, because this number uses all segments of a number display. Technicians can also use the WOW display to determine if all segments of the electronic display are functioning correctly.



(a)



(b)



(c)

FIGURE 57–37 (a) View of the vehicle dash with the instrument cluster removed. Sometimes the dash instruments can be serviced by removing the padded dash cover (crash pad) to gain access to the rear of the dash. (b) The front view of the electronic analog dash display. (c) The rear view of the dash display showing that there are a few bulbs that can be serviced, but otherwise the unit is serviced as an assembly.

TECH TIP

The Bulb Test

Many ignition switches have six positions. Notice the *bulb test* position (between "on" and "start"). When the ignition is turned to "on" (run), some dash warning lamps are illuminated. When the bulb test position is reached, additional dash warning lamps often are lighted. Technicians use this ignition switch position to check the operation of fuses that protect various circuits. Dash warning lamps are not all powered by the same fuses. If an electrical component or circuit does not work, the power side (fuse) can be quickly checked by observing the operation of the dash lamps that have a common fuse with the problem circuit. Consult a wiring diagram for fuse information on the exact circuit being tested. ● **SEE FIGURES 57–38 AND 57–39.**

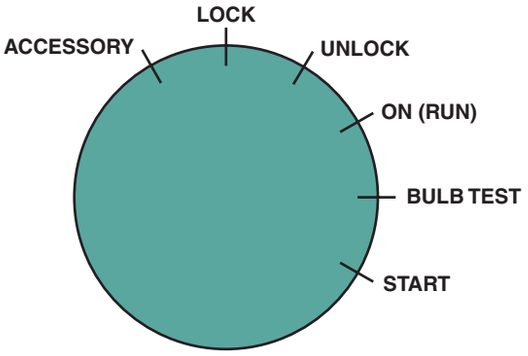


FIGURE 57–38 Typical ignition switch positions. Notice the bulb check position between "on" (run) and "start." These inputs are often just voltage signal to the body control module and can be checked using a scan tool.



FIGURE 57–39 Many newer vehicles place the ignition switch on the dash and incorporate antitheft controls. Note the location of the accessory position.



REAL WORLD FIX

The Speedometer Works as if It Is a Tachometer

The owner of a Lincoln Town Car complained that all of a sudden the speedometer needle went up and down with engine speed rather than vehicle speed. In fact, the speedometer needle went up and down with engine speed even though the gear selector was in "park" and the vehicle was not moving. After hours of troubleshooting, the service technician went back and started checking the basics and discovered that the alternator had a bad diode. The technician measured over 1 volt AC and over 10 amperes AC ripple current using a clamp-on AC/DC ammeter. Replacing the alternator restored the proper operation of the speedometer.

ELECTRONIC SPEEDOMETERS

OPERATION Electronic dash displays ordinarily use an electric vehicle speed sensor driven by a small gear on the output shaft of the transmission. These speed sensors contain a permanent magnet and generate a voltage in proportion to the vehicle speed. These speed sensors are commonly called **permanent magnet (PM) generators.** ● **SEE FIGURE 57–40.**

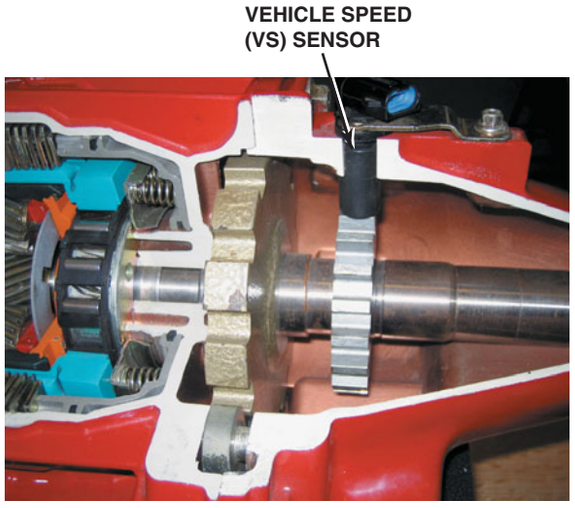


FIGURE 57–40 A vehicle speed sensor located in the extension housing of the transmission. Some vehicles use the wheel speed sensors for vehicle speed information.



TECH TIP

The Soldering Gun Trick

Diagnosing problems with digital or electronic dash instruments can be difficult. Replacement parts generally are expensive and usually not returnable if installed in the vehicle. A popular trick that helps isolate the problem is to use a soldering gun near the PM generator.

A PM generator contains a coil of wire. As the magnet inside revolves, a voltage is produced. It is the *frequency* of this voltage that the dash (or engine) computer uses to calculate vehicle speed.

A soldering gun plugged into 110 volts AC will provide a strong *varying* magnetic field around the soldering gun. This magnetic field is constantly changing at the rate of 60 cycles per second. This frequency of the magnetic field induces a voltage in the windings of the PM generator. This induced voltage at 60 hertz (Hz) is converted by the computer circuits to a miles per hour (mph) reading on the dash.

To test the electronic speedometer, turn the ignition to "on" (engine off) and hold a soldering gun near the PM generator.

CAUTION: The soldering gun tip can get hot, so hold it away from wiring or other components that may be damaged by the hot tip.

If the PM generator, wiring, computer, and dash are okay, the speedometer should register a speed, usually 54 mph (87 km/h). If the speedometer does not work when the vehicle is driven, the problem is in the PM generator drive.

If the speedometer does not register a speed when the soldering gun is used, the problem could be caused by the following:

1. Defective PM generator (check the windings with an ohmmeter)
2. Defective (open or shorted) wiring from the PM generator to the computer
3. Defective computer or dash circuit

REAL WORLD FIX

The Toyota Truck Story

The owner of a Toyota truck complained that several electrical problems plagued the truck, including the following:

1. The cruise (speed) control would kick out intermittently.
2. The red brake warning lamp would come on, especially during cold weather.

The owner had replaced the parking brake switch, thinking that was the cause of the red brake warning lamp coming on.

An experienced technician checked the wiring diagram in service information. Checking the warning lamp circuit, the technician noticed that the same wire went to the brake fluid level sensor. The brake fluid was at the minimum level. Filling the master cylinder to the maximum level with clean brake fluid solved both problems. The electronics of the cruise control stopped operation when the red brake warning lamp was on as a safety measure.

REAL WORLD FIX

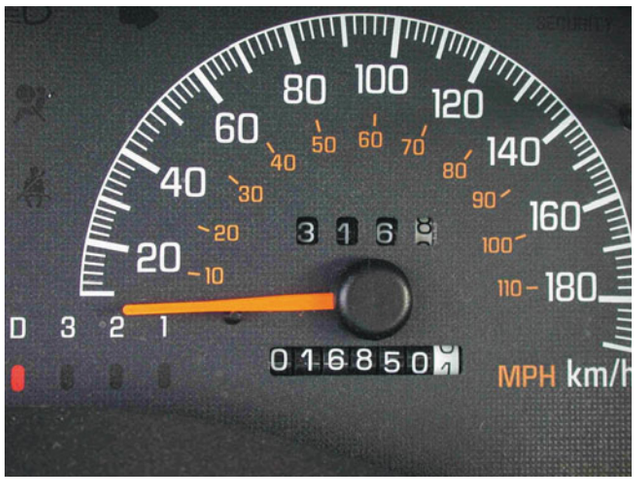
Look for Previous Repairs

A technician was asked to fix the speedometer on a Pontiac Grand Am that showed approximately double the actual speed. Previous repairs had included a new vehicle speed (VS) sensor and computer. Nothing made any difference. The customer stated that the problem happened all of a sudden. After hours of troubleshooting, the customer just happened to mention that the automatic transaxle had been repaired shortly before the speedometer problem. The root cause of the problem was discovered when the technician learned that a final drive assembly from a 4T60-E transaxle had been installed on the 3T-40 transaxle. The 4T60-E final drive assembly has 13 reluctor teeth whereas the 3T-40 has 7 teeth. This difference in the number of teeth caused the speedometer to read almost double the actual vehicle speed. After the correct part was installed, the speedometer worked correctly. The technician now always asks if there has been any recent work performed in the vehicle prior to any diagnosis.

The output of a PM generator speed sensor is an AC voltage that varies in frequency and amplitude with increasing vehicle speed. The PM generator speed signal is sent to the instrument cluster electronic circuits. These specialized electronic circuits include a buffer amplifier circuit that converts the variable sine wave voltage from the speed sensor to an on/off signal that can be used by other electronic circuits to indicate a vehicle's speed. The vehicle speed is then displayed by either an electronic needle-type speedometer or by numbers on a digital display.

ELECTRONIC ODOMETERS

PURPOSE AND FUNCTION An odometer is a dash display that indicates the total miles traveled by the vehicle. Some dash displays also include a trip odometer that can be reset and used to record total miles traveled on a trip or the distance traveled between fuel stops. Electronic dash displays can use either an electrically driven mechanical odometer or a digital display odometer to indicate miles traveled. On mechanical type odometers, a small electric motor, called a stepper motor, is used to turn the number wheels of a mechanical-style odometer. A pulsed voltage is fed to this stepper motor, which moves in relation to the miles traveled. ● **SEE FIGURE 57–41.**



(a)



(b)

FIGURE 57–41 (a) Some odometers are mechanical and are operated by a stepper motor. (b) Many vehicles are equipped with an electronic odometer.

REAL WORLD FIX

Electronic Devices Cannot Swim

The owner of a Dodge minivan complained that after the vehicle was cleaned inside and outside, the temperature gauge, fuel gauge, and speedometer stopped working. The vehicle speed sensor was checked and found to be supplying a square wave signal that changed with vehicle speed. A scan tool indicated a speed, yet the speedometer displayed zero all the time. Finally, the service technician checked the body computer to the right of the accelerator pedal and noticed that it had been wet, from the interior cleaning. Drying the computer did not fix the problem, but a replacement body computer fixed all the problems. The owner discovered that electronic devices do not like water and that computers cannot swim.

Digital odometers use LED, LCD, or VTF displays to indicate miles traveled. Because total miles must be retained when the ignition is turned off or the battery is disconnected, a special electronic chip must be used that will retain the miles traveled.

These special chips are called **nonvolatile random-access memory (NVRAM).** *Nonvolatile* means that the information stored in the electronic chip is not lost when electrical power is removed. Some vehicles use a chip called **electronically erasable programmable read-only memory (EEPROM).** Most digital odometers can read up to 999,999.9 miles or kilometers (km), and then the display indicates error. If the chip is damaged or exposed to static electricity, it may fail to operate and "error" may appear.

SPEEDOMETER/ODOMETER SERVICE If the speedometer and odometer fail to operate, check the following:

- The speed sensor should be the first item checked. With the vehicle safely raised off the ground and supported, check vehicle speed using a scan tool. If a scan tool is not available, disconnect the wires from the speed sensor near the output shaft of the transmission. Connect a multimeter set on AC volts to the terminals of the speed sensor and rotate the drive wheels with the transmission in neutral. A good speed sensor should indicate approximately 2 volts AC if the drive wheels are rotated by hand.
- If the speed sensor is working, check the wiring from the speed sensor to the dash cluster. If the wiring is good, the instrument panel (IP) should be sent to a specialty repair facility.
- If the speedometer operates correctly but the mechanical odometer does not work, the odometer stepper motor, the number wheel assembly, or the circuit controlling the stepper motor is defective. If the digital odometer does not operate but the speedometer operates correctly, then the dash cluster must be removed and sent to a specialized repair facility. A replacement chip is available only through authorized sources; if the odometer chip is defective, the original number of miles must be programmed into the replacement chip.

ELECTRONIC FUEL LEVEL GAUGES

OPERATION Electronic fuel level gauges ordinarily use the same fuel tank sending unit as that used on conventional fuel gauges. The tank unit consists of a float attached to a variable resistor. As the fuel level changes, the resistance of the sending unit changes. As the resistance of the tank unit changes, the dash-mounted gauge also changes. The only difference between a digital fuel level gauge and a conventional needle type is in the display. Digital fuel level gauges can be either numerical (indicating gallons or liters remaining in the tank) or a bar graph display. ● **SEE FIGURE 57–42.**

The diagnosis of a problem is the same as that described earlier for conventional fuel gauges. If the tests indicate that the dash unit is defective, usually the *entire* dash gauge assembly must be replaced.

NAVIGATION AND GPS

PURPOSE AND FUNCTION The **global positioning system (GPS)** uses 24 satellites in orbit around the earth to provide signals for navigation devices. GPS is funded and controlled by the U.S. Department of Defense (DOD). While the system can be used by anyone with a GPS receiver, it was designed for and is operated by the U.S. military. ● **SEE FIGURE 57–43.**

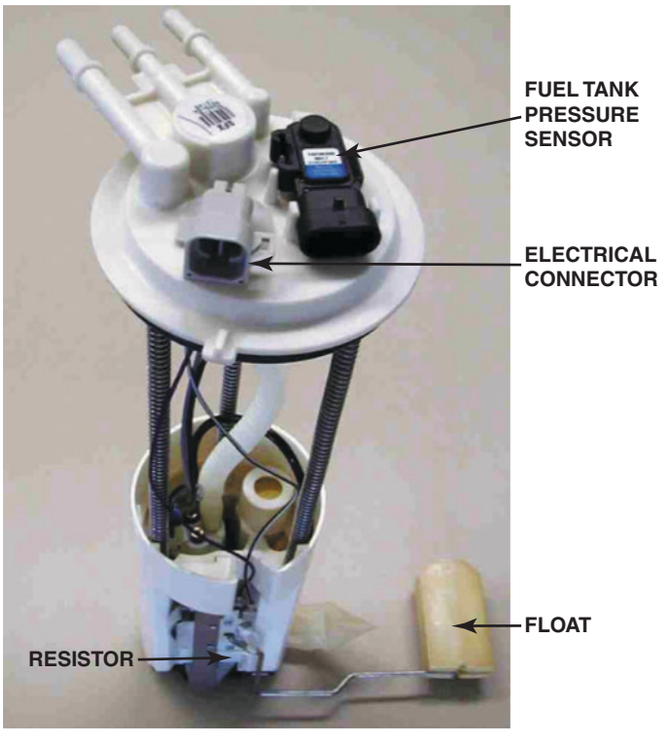


FIGURE 57–42 A fuel tank module assembly that contains the fuel pump and fuel level sensor in one assembly.

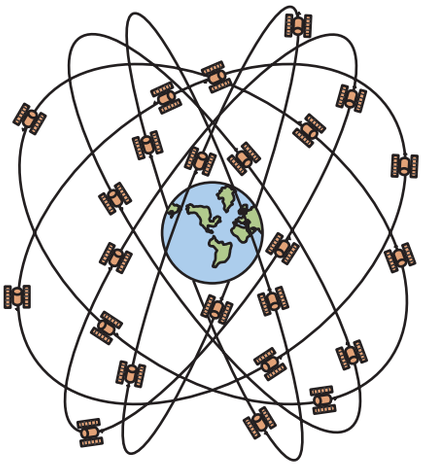


FIGURE 57–43 Global positioning systems use 24 satellites in high earth orbit whose signals are picked up by navigation systems. The navigation system computer then calculates the location based on the position of the satellite overhead.

BACKGROUND The current global positioning system was developed after a civilian airplane from Korean Airlines, Flight 007, was shot down as it flew over Soviet territory in 1983. The system became fully operational in 1991. Civilians were granted use of GPS that same year, but with less accuracy than the system used by the military.

Until 2000, the nonmilitary use of GPS was purposely degraded by a computer program called selection availability (S/A) built into the satellite transmission signals. After 2000, the S/A has been officially turned off, allowing nonmilitary users more accurate position information from the GPS receivers.

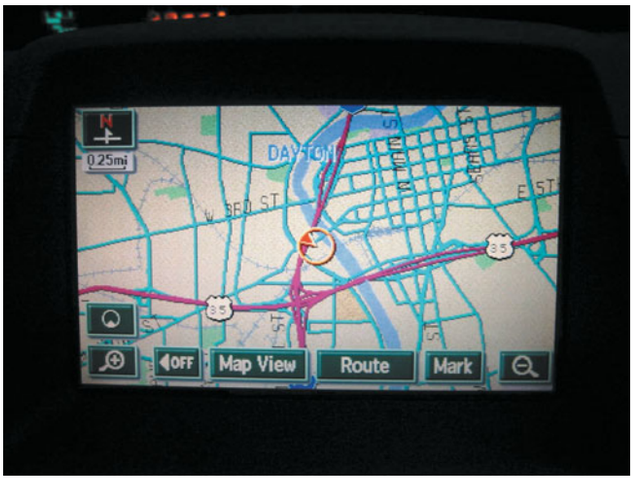


FIGURE 57–44 A typical GPS display screen showing the location of the vehicle.

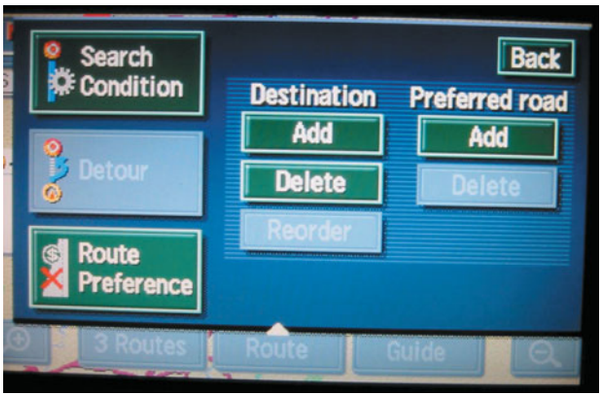


FIGURE 57–45 A typical navigation display showing various options. Some systems do not allow access to these functions if the vehicle is in gear and/or moving.

FREQUENTLY ASKED QUESTION

Does the Government Know Where I Am?

No. The navigation system uses signals from the satellites and uses the signals from three or more to determine position. If the vehicle is equipped with OnStar, then the vehicle position can be monitored by the use of the cellular telephone link to OnStar call centers. Unless the vehicle has a cellular phone connection to the outside world, the only people who will know the location of the vehicle are the persons inside the vehicle viewing the navigation screen.

TECH TIP

Window Tinting Can Hurt GPS Reception

Most factory-installed navigation systems use a GPS antenna inside the rear back glass or under the rear package shelf. If a metalized window tint is applied to the rear glass, the signal strength from the GPS satellites can be reduced. If the customer concern includes inaccurate or nonfunctioning navigation, check for window tint.

TECH TIP

Touch Screen Tip

Most vehicle navigation systems use a touch screen for use by the driver (or passenger) to input information or other on-screen prompts. Most touch screens use infrared beams projected from the top and bottom plus across the screen to form a grid. The system detects where on the screen a finger is located by the location of the beams that are cut. Do not push harder on the display if the unit does not respond, or damage to the display unit may occur. If no response is detected when lightly depressing the screen, rotate the finger to cause the infrared beams to be cut.

NAVIGATION SYSTEM PARTS AND OPERATION

Navigation systems use the GPS satellites for basic location information. The navigation controller located in the rear of the vehicle uses other sensors, including a digitized map to display the location of the vehicle.

- **GPS satellite signals.** These signals from at least three satellites are needed to locate the vehicle.
- **Yaw sensor.** This sensor is often used inside the navigation unit to detect movement of the vehicle during cornering. This sensor is also called a "g" sensor because it measures force; 1 g is the force of gravity.
- **Vehicle speed sensor.** This sensor input is used by the navigation controller to determine the speed and distance the vehicle travels. This information is compiled and compared to the digital map and GPS satellite inputs to locate the vehicle.
- **Audio output/input.** Voice-activated factory units use a built-in microphone at the center top of the windshield and the audio speakers speech output.

Navigation systems include the following components.

1. Screen display ● **SEE FIGURE 57–44.**
2. GPS antenna
3. Navigation control unit, usually with map information on a DVD

The DVD includes street names and the following information.

1. Points of interest (POI), including automated teller machines (ATMs), restaurants, schools, colleges, museums, shopping, and airports, as well as vehicle dealer locations.
2. Business addresses and telephone numbers, including hotels and restaurants (If the telephone number is listed in the business telephone book, it can usually be displayed on the navigation screen. If the telephone number of the business is known, the location can be displayed.)

NOTE: Private residences or cellular telephone numbers are not included in the database of telephone numbers stored on the navigation system DVD.

3. Turn-by-turn directions to addresses that are selected by:
   - Points of interest (POI)
   - Typed in using a keyboard shown on the display

The navigation unit then often allows the user to select the fastest way to the destination, as well as the shortest way, or how to avoid toll roads. ● **SEE FIGURE 57–45.**

DIAGNOSIS AND SERVICE

For the correct functioning of the navigation system, three inputs are needed.

- Location
- Direction
- Speed

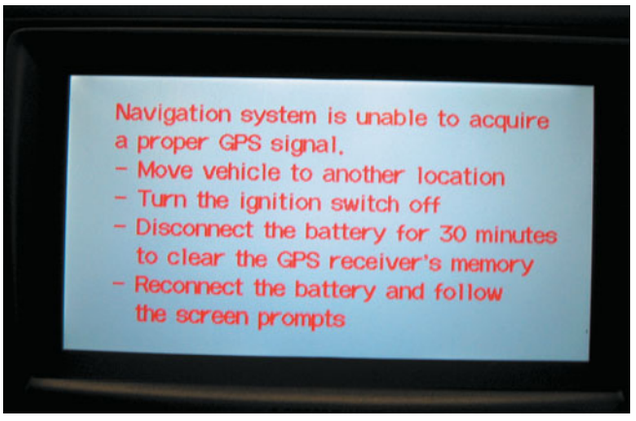


FIGURE 57–46 A screen display of a navigation system that is unable to acquire usable signals from GPS satellites.

The navigation system uses the GPS satellite and map data to determine a location. Direction and speed are determined by the navigation computer from inputs from the satellite, plus the yaw sensor and vehicle speed sensor. The following symptoms may occur and be a customer complaint. Knowing how the system malfunctions helps to determine the most likely cause.

- If the vehicle icon jumps down the road, a fault with the vehicle speed (VS) sensor input is usually indicated.
- If the icon rotates on the screen, but the vehicle is not being driven in circles, a fault with the yaw sensor or yaw sensor input to the navigation controller is likely.
- If the icon goes off course and shows the vehicle on a road that it is not on, a fault with the GPS antenna is the most common reason for this situation.

Sometimes the navigation system itself will display a warning that views from the satellite are not being received. Always follow the displayed instructions. ● **SEE FIGURE 57–46.**

ONSTAR

PARTS AND OPERATION

OnStar is a system that includes the following functions.

1. Cellular telephone
2. Global positioning antenna and computer

OnStar is standard or optional on most General Motors vehicles and selected other brands and models, to help the driver in an emergency or to provide other services. The cellular telephone is used to communicate with the driver from advisors at service centers. The advisor at the service center is able to see the location of the vehicle as transmitted from the GPS antenna and computer system in the vehicle on a display. OnStar does not display the location of the vehicle to the driver unless the vehicle is also equipped with a navigation system.

Unlike most navigation systems, the OnStar system requires a monthly fee. OnStar was first introduced in 1996 as an option on some Cadillac models. Early versions used a handheld cellular telephone while later units used a group of three buttons mounted on the inside rearview mirror and a hands-free cellular telephone. ● **SEE FIGURE 57–47.**

The first version used analog cellular service while later versions used a dual mode (analog and digital) service until 2007. Since 2007, all OnStar systems use digital cellular service, which means that older systems that were analog only need to be upgraded.



FIGURE 57–47 The three-button OnStar control is located on the inside rearview mirror. The left button (telephone handset icon) is pushed if a hands-free cellular call is to be made. The center button is depressed to contact an OnStar advisor and the right emergency button is used to request that help be sent to the vehicle's location.

? FREQUENTLY ASKED QUESTION

What Is Navigation Enhanced Climate Control?

Some vehicles, such as the Acura RL, use data from the navigation system to help control the automatic climate control system. Data about the location of the vehicle includes:

- **Time and date.** This information allows the automatic climate control system to determine where the sun is located.
- **Direction of travel.** The navigation system can also help the climate control system determine the direction of travel.

As a result of the input from the navigation system, the automatic climate control system can control cabin temperature in addition to various other sensors in the vehicle. For example, if the vehicle was traveling south in the late afternoon in July, the climate control system could assume that the passenger side of the vehicle would be warmed more by the sun than the driver's side and could increase the airflow to the passenger side to help compensate for the additional solar heating.

The OnStar system includes the following features, which can vary depending on the level of service desired and cost per month.

- **Automatic notification of airbag deployment.** If the airbag is deployed, the advisor is notified immediately and attempts to call the vehicle. If there is no reply, or if the occupants report an emergency, the advisor will contact emergency services and give them the location of the vehicle.
- **Emergency services.** If the red button is pushed, OnStar immediately locates the vehicle and contacts the nearest emergency service agency.
- **Stolen vehicle location assistance.** If a vehicle is reported stolen, a call center advisor can track the vehicle.
- **Remote door unlock.** An OnStar advisor can send a cellular telephone message to the vehicle to unlock the vehicle if needed.
- **Roadside assistance.** When called, an OnStar advisor can locate a towing company or locate a provider who can bring gasoline or change a flat tire.

- **Accident assistance.** An OnStar advisor is able to help with the best way to handle an accident. The advisor can supply a step-by-step checklist of the things that should be done plus call the insurance company, if desired.
- **Remote horn and lights.** The OnStar system is tied into the lights and horn circuits so an advisor can activate them if requested to help the owner locate the vehicle in a parking lot or garage.
- **Vehicle diagnosis.** Because the OnStar system is tied to the PCM, an OnStar advisor can help with diagnosis if there is a fault detected. The system works as follows:
  - The malfunction indicator light (MIL) (check engine) comes on to warn the driver that a fault has been detected.
  - The driver can depress the OnStar button to talk to an advisor and ask for a diagnosis.
  - The OnStar advisor will send a signal to the vehicle requesting the status from the powertrain control module (PCM), as well as the controller for the antilock brakes and the airbag module.
  - The vehicle then sends any diagnostic trouble codes to the advisor. The advisor can then inform the driver about the importance of the problem and give advice as to how to resolve the problem.

DIAGNOSIS AND SERVICE The OnStar system can fail to meet the needs of the customer if any of the following conditions occur.

1. Lack of cellular telephone service in the area
2. Poor global positioning system (GPS) signals, which can prevent an OnStar advisor from determining the position of the vehicle
3. Transport of the vehicle by truck or ferry so that it is out of contact with the GPS satellite in order for an advisor to properly track the vehicle

If all of the above are okay and the problem still exists, follow service information diagnostic and repair procedures. If a new vehicle communication interface module (VCIM) is installed in the vehicle, the electronic serial number (ESN) must be tied to the vehicle. Follow service information instructions for the exact procedures to follow.

BACKUP CAMERA

PARTS AND OPERATION A **backup camera** is used to display the area at the rear of the vehicle in a screen display on the dash when the gear selector is placed in reverse. Backup cameras are also called *reversing cameras* or *rearview cameras.*

Backup cameras are different from normal cameras because the image displayed on the dash is flipped so it is a mirror image of the scene at the rear of the vehicle. This reversing of the image is needed because the driver and the camera are facing in opposite directions. Backup cameras were first used in large vehicles with limited rearward visibility, such as motor homes. Many vehicles equipped with navigation systems today include a backup camera for added safety while backing. ● **SEE FIGURE 57–48.**

The backup camera contains a wide-angle or fisheye lens to give the largest viewing area. Most backup cameras are pointed downward so that objects on the ground, as well as walls, are displayed. ● **SEE FIGURE 57–49.**

DIAGNOSIS AND SERVICE Faults in the backup camera system can be related to the camera itself, the display, or the connecting wiring. The main input to the display unit comes from the transmission range switch which signals the backup camera when the transmission is shifted into reverse.



FIGURE 57–48 A typical view displayed on the navigation screen from the backup camera.



FIGURE 57–49 A typical fisheye-type backup camera usually located near the center on the rear of the vehicle near the license plate.

TECH TIP

Check for Repainted Bumper

The ultrasonic sensors embedded in the bumper are sensitive to paint thickness because the paint covers the sensors. If the system does not seem to be responding to objects, and if the bumper has been repainted, measure the paint thickness using a nonferrous paint thickness gauge. The maximum allowable paint thickness is 6 mils (0.006 inch or 0.15 mm).

To check the transmission range switch, perform the following:

1. Check if the backup (reverse) lights function when the gear selector is placed in reverse with the key on, engine off (KOEO).
2. Check that the transmission/transaxle is fully engaged in reverse when the selector is placed in reverse.

Most of the other diagnosis involves visual inspection, including:

1. Check the backup camera for damage.
2. Check the screen display for proper operation.
3. Check that the wiring from the rear camera to the body is not cut or damaged.

Always follow the vehicle manufacturer's recommended diagnosis and repair procedures.



FIGURE 57–50 A typical backup sensor display located above the rear window inside the vehicle. The warning lights are visible in the inside rearview mirror.



FIGURE 57–51 The small round buttons in the rear bumper are ultrasonic sensors used to sense distance to an object.

BACKUP SENSORS

COMPONENTS Backup sensors are used to warn the driver if there is an object behind the vehicle while backing. The system used in General Motors vehicles is called **rear park assist (RPA),** and includes the following components.

- Ultrasonic object sensors built into the rear bumper assembly
- A display with three lights usually located inside the vehicle above the rear window and visible to the driver in the rearview mirror
- An electronic control module that uses an input from the transmission range switch and lights the warning lamps needed when the vehicle gear selector is in reverse

OPERATION The three-light display includes two amber lights and one red light. The following lights are displayed depending on the distance from the rear bumper.

- One amber lamp will light when the vehicle is in reverse and traveling at less than 3 mph (5 km/h) and the sensors detect an object 40 to 60 in. (102 to 152 cm) from the rear bumper. A chime also sounds once when an object is detected, to warn the driver to look at the rear parking assist display. ● **SEE FIGURE 57–50.**
- Two amber lamps light when the distance between the rear bumper and an object is between 20 and 40 in. (50 and 100 cm) and the chime will sound again.
- Two amber lamps and the red lamp light and the chime sounds continuously when the distance between the rear bumper and the object is between 11 and 20 in. (28 and 50 cm).

If the distance between the rear bumper and the object is less than 11 in. (28 cm), all indicator lamps flash and the chime will sound continuously.

The ultrasonic sensors embedded in the rear bumper "fire" individually every 150 milliseconds (27 times per second). ● **SEE FIGURE 57–51.**

The sensors fire and then receive a return signal and arm to fire again in sequence from the left sensor to the right sensor.

Each sensor has the following three wires.

1. An 8 volt supply wire from the RPA module, used to power the sensor
2. A reference low or ground wire
3. A signal line, used to send and receive commands to and from the RPA module

DIAGNOSIS The rear parking assist control module is capable of detecting faults and storing diagnostic trouble codes (DTCs). If a fault has been detected by the control module, the red lamp flashes and the system is disabled. Follow service information diagnostic procedures because the rear parking assist module cannot usually be accessed using a scan tool. Most systems use the warning lights to indicate trouble codes.

LANE DEPARTURE WARNING SYSTEM

PARTS AND OPERATION The **lane departure warning system (LDWS)** uses cameras to detect if the vehicle is crossing over lane marking lines on the pavement. Some systems use two cameras, one mounted on each outside rearview mirror. Some systems use infrared sensors located under the front bumper to monitor the lane markings on the road surface.

The system names also vary according to vehicle manufacturer, including:

Honda/Acura: lane keep assist system (LKAS)

Toyota/Lexus: lane monitoring system (LMS)

General Motors: lane departure warning (LDW)

Ford: lane departure warning (LDW)

Nissan/Infinity: lane departure prevention (LDP) system

If the cameras detect that the vehicle is starting to cross over a lane dividing line, a warning chime will sound or a vibrating mechanism mounted in the driver's seat cushion is triggered on the side where the departure is being detected. This warning will not occur if the turn signal is on in the same direction as detected. ● **SEE FIGURE 57–52.**

DIAGNOSIS AND SERVICE Before attempting to service or repair a lane departure warning system fault, check service information for an explanation on how the system is supposed to work. If the system is not working as designed, perform a visual inspection of the sensors or cameras, checking for damage from road debris or evidence of body damage, which could affect the sensors. After a visual inspection, follow the vehicle manufacturer's recommended diagnosis procedures to locate and repair the fault in the system.

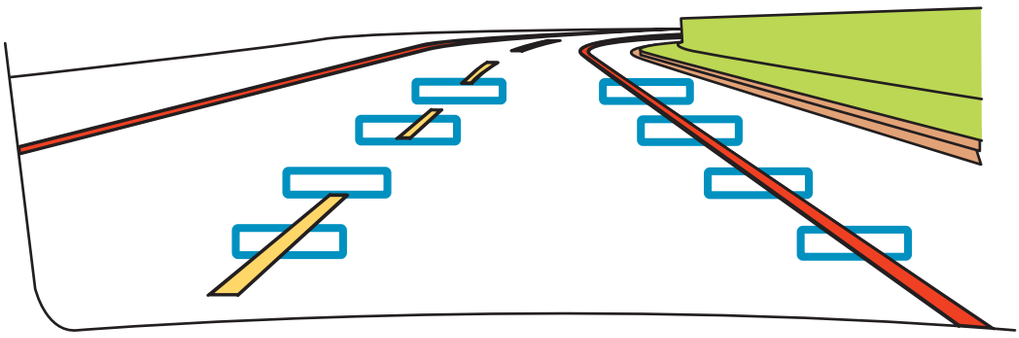


FIGURE 57–52 A lane departure warning system often uses cameras to sense the road lines and warns the driver if the vehicle is not staying within the lane, unless the turn signal is on.

ELECTRONIC DASH INSTRUMENT DIAGNOSIS AND TROUBLESHOOTING

If one or more electronic dash gauges do not work correctly, first check the WOW display that lights all segments to full brilliance whenever the ignition switch is first switched on. If *all* segments of the display do *not* operate, then the entire electronic cluster must be replaced in most cases. If all segments operate during the WOW display but do not function correctly afterwards, the problem is most often a defective sensor or defective wiring to the sensor.

All dash instruments except the voltmeter use a variable-resistance unit as a sensor for the system being monitored. Most new-vehicle dealers are required to purchase essential test equipment, including a test unit that permits the technician to insert various fixed-resistance values in the suspected circuit. For example, if a 45 ohm resistance is put into the fuel gauge circuit that reads from 0 to 90 ohms, a properly operating dash unit should indicate one-half tank. The same tester can produce a fixed signal to test the operation of the speedometer and tachometer. If this type of special test equipment is not available, the electronic dash instruments can be tested using the following procedure.

1. With the ignition switched off, unplug the wire(s) from the sensor for the function being tested. For example, if the oil pressure gauge is not functioning correctly, unplug the wire connector at the oil pressure sending unit.
2. With the sensor wire unplugged, turn the ignition switch on and wait until the WOW display stops. The display for the affected unit should show either fully lighted segments or no lighted segments, depending on the make of the vehicle and the type of sensor.
3. Turn the ignition switch off. Connect the sensor wire lead to ground and turn the ignition switch on. After the WOW display, the display should be the opposite (either fully on or fully off) of the results in step 2.

TESTING RESULTS If the electronic display functions fully on and fully off with the sensor unplugged and then grounded, the problem is a defective sensor. If the electronic display fails to function fully on and fully off when the sensor wire(s) are opened and grounded, the problem is usually in the wiring from the sensor to the electronic dash or it is a defective electronic cluster.

CAUTION: Whenever working on or *near* any type of electronic dash display, always wear a wire attached to your wrist (wrist strap) connected to a good body ground to prevent damaging the electronic dash with static electricity.

TECH TIP

Keep Stock Overall Tire Diameter

Whenever larger (or smaller) wheels or tires are installed, the speedometer and odometer calibration are also thrown off. This can be summarized as follows:

- **Larger diameter tires.** The speed showing on the speedometer is slower than the actual speed. The odometer reading will show fewer miles than actual.
- **Smaller diameter tires.** The speed showing on the speedometer is faster than the actual speed. The odometer reading will show more miles than actual.

General Motors trucks can be recalibrated with a recalibration kit (1988–1991) or with a replacement controller assembly called a digital ratio adapter controller (DRAC) located under the dash. It may be possible to recalibrate the speedometer and odometer on earlier models, before 1988, or vehicles that use speedometer cables by replacing the drive gear in the transmission. Check service information for the procedure on the vehicle being serviced.

MAINTENANCE REMINDER LAMPS

Maintenance reminder lamps indicate that the oil should be changed or that other service is required. There are numerous ways to extinguish a maintenance reminder lamp. Some require the use of a special tool. Always check the owner manual or service information for the exact procedure for the vehicle being serviced. For example, to reset the oil service reminder light on many General Motors vehicles, you have to perform the following:

STEP 1 Turn the ignition key on (engine off).

STEP 2 Depress the accelerator pedal three times and hold it down on the fourth.

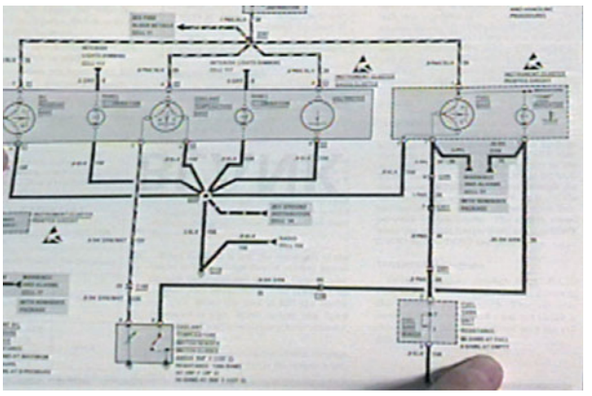
STEP 3 When the reminder light flashes, release the accelerator pedal.

STEP 4 Turn the ignition key to the off position.

STEP 5 Start the engine and the light should be off.



1 Observe the fuel gauge. This General Motors vehicle shows an indicated reading of slightly above one-half tank.



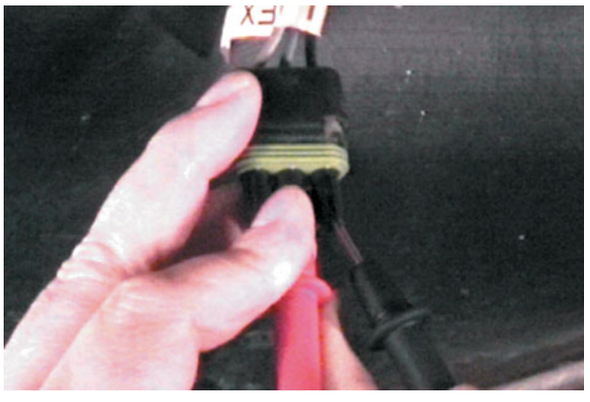
2 Consult the factory service manual for the specifications, wire color, and recommended test procedure.



3 From the service manual, the connector for the fuel gauge-sending unit was located under the vehicle near the rear. A visual inspection indicated that the electrical wiring and connector were not damaged or corroded.



4 To test resistance of the sending unit (tank unit) use a digital multimeter and select ohms (Ω).



5 Following the schematic in the service manual the sending unit resistance can be measured between the pink and the black wires in the connector.



6 The meter displays 50 ohms or slightly above the middle of the normal resistance value for the vehicle of 0 Ω (empty) to 90 Ω (full).

CONTINUED ▶

STEP BY STEP



7 To check if the dash unit can move, the connector is unplugged with the ignition key on (engine off).



8 As the connector is disconnected, the needle of the dash unit moves toward full.



9 After a couple of seconds, the needle disappears above the full reading. The open connector represented infinity ohms and normal maximum reading occurs when the tank unit reads 90 ohms. If the technician does not realize that the needle could disappear, an incorrect diagnosis could be made.



10 To check if the dash unit is capable of reading empty, a fuse jumper wire is connected between the signal wire at the dash end of the connector and a good chassis ground.



11 A check of a dash unit indicated that the needle does accurately read empty.



12 After testing, reconnect the electrical connectors and verify for proper operation of the fuel level gauge.

REVIEW QUESTIONS

1. How does a stepper motor analog dash gauge work?
2. What are LED, LCD, VTF, and CRT dash displays? Describe each.
3. How do you diagnose a problem with a red brake warning lamp?
4. How do you test the dash unit of a fuel gauge?
5. How does a navigation system determine the location of the vehicle?

CHAPTER QUIZ

1. Two technicians are discussing a fuel gauge on a General Motors vehicle. Technician A says that if the ground wire connection to the fuel tank sending unit becomes rusty or corroded, the fuel gauge will read lower than normal. Technician B says that if the power lead to the fuel tank sending unit is disconnected from the tank unit and grounded (ignition on), the fuel gauge should go to empty. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. If an oil pressure warning lamp on a General Motors vehicle is on all the time, yet the engine oil pressure is normal, the problem could be a _____.
   a. Defective (shorted) oil pressure sending unit (sensor)
   b. Defective (open) oil pressure sending unit (sensor)
   c. Wire shorted-to-ground between the sending unit (sensor) and the dash warning lamp
   d. Both a and c
3. When the oil pressure drops to between 3 and 7 psi, the oil pressure lamp lights by _____.
   a. Opening the circuit
   b. Shorting the circuit
   c. Grounding the circuit
   d. Conducting current to the dash lamp by oil
4. A brake warning lamp on the dash remains on whenever the ignition is on. If the wire to the pressure differential switch (usually a part of a combination valve or built into the master cylinder) is unplugged, the dash lamp goes out. Technician A says that this is an indication of a fault in the hydraulic brake system. Technician B says that the problem is probably due to a stuck parking brake cable switch. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
5. A customer complains that every time the lights are turned on in the vehicle, the dash display dims. What is the most probable explanation?
   a. Normal behavior for LED dash displays
   b. Normal behavior for VTF dash displays
   c. Poor ground in lighting circuit causing a voltage drop to the dash lamps
   d. Feedback problem most likely caused by a short-to-voltage between the headlights and dash display
6. Technician A says that LCDs may be slow to work at low temperatures. Technician B says that an LCD dash display can be damaged if pressure is exerted on the front of the display during cleaning. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. Technician A says that backup sensors use LEDs to detect objects. Technician B says that a backup sensor will not work correctly if the paint is thicker than 0.006 in. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. Technician A says that metal-type tinting can affect the navigation system. Technician B says most navigation systems require a monthly payment for use of the GPS satellite. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. Technician A says that the data displayed on the dash can come from the engine computer. Technician B says that the entire dash assembly may have to be replaced even if just one unit fails. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. How does changing the size of the tires affect the speedometer reading?
    a. A smaller diameter tire causes the speedometer to read faster than actual speed and more than actual mileage on the odometer.
    b. A smaller diameter tire causes the speedometer to read slower than the actual speed and less than the actual mileage on the odometer.
    c. A larger diameter tire causes the speedometer to read faster than the actual speed and more than the actual mileage on the odometer.
    d. A larger diameter tire causes the speedometer to read slower than the actual speed and more than the actual mileage on the odometer.

chapter 58

HORN, WIPER, AND BLOWER MOTOR CIRCUITS

OBJECTIVES: **After studying Chapter 58, the reader will be able to:** • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "G" (Horn and Wiper/Washer Diagnosis and Repair) and content area "H" (Accessories Diagnosis and Repair). • Describe how the horn operates. • List the components of a wiper circuit. • Explain how the blower motor can run at different speeds. • Discuss how to diagnosis faults in the horn, wiper, and blower motor circuits.

KEY TERMS: Horns 646 • Pulse wipers 649 • Rain sense wipers 653 • Series-wound field 649 • Shunt field 649 • Variable-delay wipers 649 • Windshield wipers 648

HORNS

PURPOSE AND FUNCTION

Horns are electric devices that emit a loud sound used to alert other drivers or persons in the area. Horns are manufactured in several different tones ranging from 1,800 to 3,550 Hz. Vehicle manufacturers select from various horn tones for a particular vehicle sound. ● **SEE FIGURE 58–1.**

When two horns are used, each has a different tone when operated separately, yet the sound combines when both are operated.



FIGURE 58–1 Two horns are used on this vehicle. Many vehicles use only one horn, often hidden underneath the vehicle.

HORN CIRCUITS

Automotive horns usually operate on full battery voltage wired from the battery, through a fuse, switch, and then to the horns. Most vehicles use a horn *relay.* With a relay, the horn button on the steering wheel or column completes a circuit to ground that closes a relay, and the heavy current flow required by the horn then travels from the relay to the horn. Without a horn relay, the high current of the horns must flow through the steering wheel horn switch. ● **SEE FIGURE 58–2.**

The horn relay is also connected to the body control module, which "beeps" the horn when the vehicle is locked or unlocked, using the key fob remote.

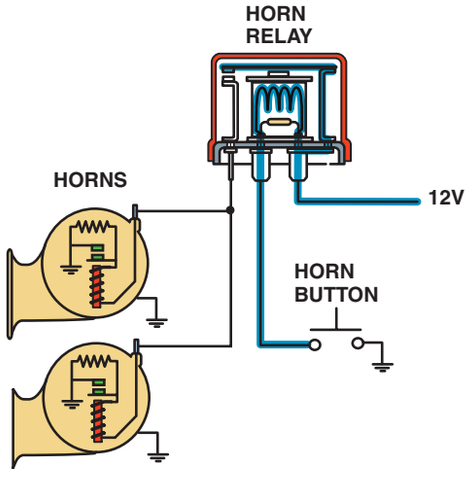


FIGURE 58–2 A typical horn circuit. Note that the horn button completes the ground circuit for the relay.

HORN OPERATION

A vehicle horn is an actuator that converts an electrical signal to sound. The horn circuit includes an armature (a coil of wire) and contacts that are attached to a diaphragm. When energized, the armature causes the diaphragm to move up which then opens a set of contact points that de-energize the armature circuit. As the diaphragm moves down, the contact points close, re-energize the armature circuit, and the diaphragm moves up again. This rapid opening and closing of the contact points causes the diaphragm to vibrate at an audible frequency. The sound created by the diaphragm is magnified as it travels through a trumpet attached to the diaphragm chamber. Most horn systems typically use one or two horns, but some have up to four. Those with multiple horns use both high- and low-pitch units to achieve a harmonious tone. Only a high-pitched unit is used in single-horn applications. The horn assembly is marked with an "H" or "L" for pitch identification.

HORN SYSTEM DIAGNOSIS There are three types of horn failure.

- No horn operation
- Intermittent operation
- Constant operation
- Weak or low volume sound

If a horn does not operate at all, check for the following:

- Burned fuse or fusible link
- Open circuit
- Defective horn
- Faulty relay
- Defective horn switch
- Poor ground (horn mounting)
- Corroded or rusted electrical connector

If a horn operates intermittently, check for the following:

- Loose contact at the switch
- Loose, frayed, or broken wires
- Defective relay

HORN SOUNDS CONTINUOUSLY A horn that sounds continuously and cannot be shut off is caused by horn switch contacts that are stuck closed, or a short-to-ground on the control circuit. This may be the result of a defective horn switch or a faulty relay. Stuck relay contacts keep the circuit complete so the horn sounds constantly. Disconnect the horn and check continuity through the horn switch and relay to locate the source of the problem.

INOPERATIVE HORN To help determine the cause of an inoperative horn, use a fused jumper wire and connect one end to the positive post of the battery and the other end to the wire terminal of the horn itself. Also use a fused jumper wire to substitute a ground path to test or confirm a potential bad ground circuit. If the horn works with jumper wires connected, check ground wires and connections.

- If the horn works, the problem is in the circuit supplying current to the horn.
- If the horn does not work, the horn itself could be defective or the mounting bracket may not be providing a good ground.

HORN SERVICE When a horn malfunctions, circuit tests are made to determine if the horn, relay, switch, or wiring is the source of the failure. Typically, a digital multimeter (DMM) is used to perform voltage drop and continuity checks to isolate the failure.

- **Switch and relay.** A momentary contact switch is used to sound the horn. The horn switch is mounted to the steering wheel in the center of the steering column on some models, and is part of a multifunction switch installed on the steering column.

  CAUTION: If steering wheel removal is required for diagnosis or repair of the horn circuit, follow service information procedures for disarming the airbag circuit prior to steering wheel removal, and for the specified test equipment to use.

  On most late-model vehicles, the horn relay is located in a centralized power distribution center along with other relays, circuit breakers, and fuses. The horn relay bolts onto an inner fender or the bulkhead in the engine compartment of older vehicles. Check the relay to determine if the coil is being energized and if current passes through the power circuit when the horn switch is depressed.

  Obtain an electrical schematic of the horn circuit and use a voltmeter to test input, output, and control voltage.

- **Circuit testing.** Circuit testing involves the following steps.

  STEP 1 Make sure the fuse or fusible link is good before attempting to troubleshoot the circuit.

  STEP 2 Check that the ground connections for the horn are clean and tight. Most horns ground to the chassis through the mounting bolts. High ground circuit resistance due to corrosion, road dirt, or loose fasteners may cause no, or intermittent, horn operation.

  STEP 3 On a system with a relay, test the power output circuit and the control circuit. Check for voltage available at the horn, voltage available at the relay, and continuity through the switch. When no relay is used, there are two wires leading to the horn switch, and a connection to the steering wheel is made with a double contact slip ring. Test points on this system are similar to those of a system with a relay, but there is no control circuit.

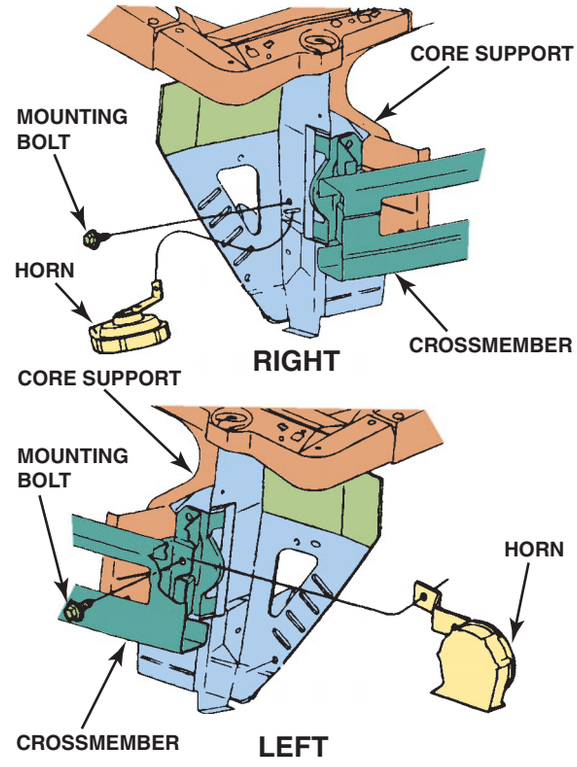


FIGURE 58–3 Horns typically mount to the radiator core support or bracket at the front of the vehicle.

HORN REPLACEMENT Horns are generally mounted on the radiator core support by bolts and nuts or sheet metal screws. It may be necessary to remove the grille or other parts to access the horn mounting screws. If a replacement horn is required, attempt to use a horn of the same tone as the original. The tone is usually indicated by a number or letter stamped on the body of the horn. To replace a horn, simply remove the fasteners and lift the old horn from its mounting bracket.

Clean the attachment area on the mounting bracket and chassis before installing the new horn. Some models use a corrosion-resistant mounting bolt to ensure a ground connection. ● **SEE FIGURE 58–3.**

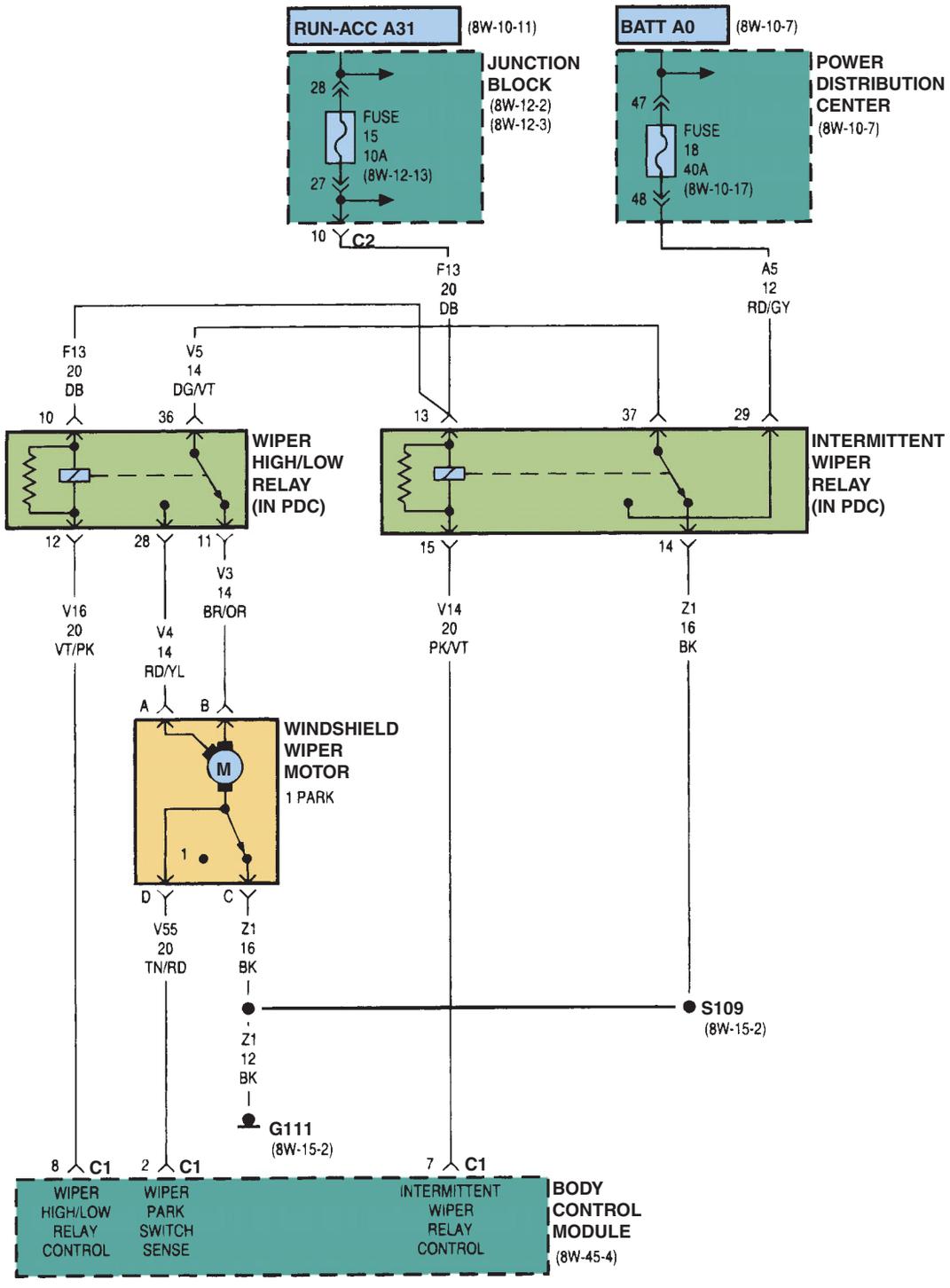


FIGURE 58–4 A circuit diagram is necessary to troubleshoot a windshield wiper problem.

WINDSHIELD WIPER AND WASHER SYSTEM

PURPOSE AND FUNCTION

Windshield wipers are used to keep the viewing area of the windshield clean of rain. Windshield wiper systems and circuits vary greatly between manufacturers as well as between models. Some vehicles combine the windshield wiper and windshield washer functions into a single system. Many minivans and sport utility vehicles (SUVs) also have a rear window wiper and washer system that works independently of the windshield system. In spite of the design differences, all windshield and rear window wiper and washer systems operate in a similar fashion.

COMPUTER CONTROLLED

Most wipers since the 1990s have used the body computer to control the actual operation of the wiper. The wiper controls are simply a command to the computer. The computer may also turn on the headlights whenever the wipers are on, which is the law in some states. ● **SEE FIGURE 58–4.**

WIPER AND WASHER COMPONENTS

A typical combination wiper and washer system consists of the following:

- Wiper motor
- Gearbox

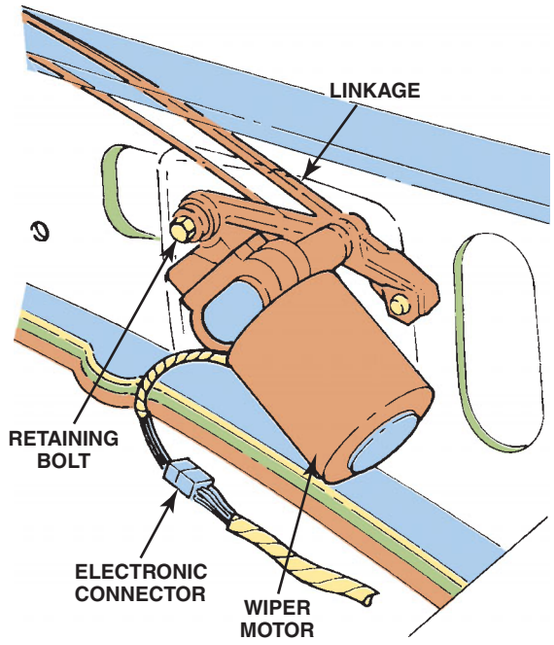


FIGURE 58–5 The motor and linkage bolt to the body and connect to the switch with a wiring harness.

- Wiper arms and linkage
- Washer pump
- Hoses and jets (nozzles)
- Fluid reservoir
- Combination switch
- Wiring and electrical connectors
- Electronic control module

The motor and gearbox assembly is wired to the wiper switch on the instrument panel or steering column or to the wiper control module. ● **SEE FIGURE 58–5.**

Some systems use either a one- or two-speed wiper motor, whereas others have a variable-speed motor.

WINDSHIELD WIPER MOTORS

The windshield wipers ordinarily use a special two-speed electric motor. Most are compound-wound motors, a motor type, which provides for two different speeds.

- **Series-wound field**
- **Shunt field**

One speed is achieved in the series wound field and the other speed in the shunt wound field. The wiper switch provides the necessary electrical connections for either motor speed. Switches in the mechanical wiper motor assembly provide the necessary operation for "parking" and "concealing" of the wipers. ● **SEE FIGURE 58–6** for a typical wiper motor assembly.

- **Wiper motor operation.** Most wiper motors use a permanent magnet motor with a low speed + brush and a high speed + brush. The brushes connect the battery to the internal windings of the motor, and the two brushes provide for two different motor speeds.

  The ground brush is directly opposite the low-speed brush. The high-speed brush is off to the side of the low-speed brush. When current flows through the high-speed brush, there are fewer turns on the armature between the hot and ground brushes, and therefore the resistance is less. With less resistance, more current flows and the armature revolves faster. ● **SEE FIGURES 58–7 AND 58–8.**

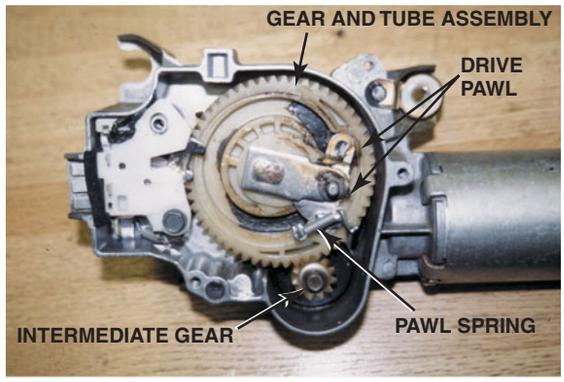


FIGURE 58–6 A typical wiper motor with the housing cover removed. The motor itself has a worm gear on the shaft that turns the small intermediate gear, which then rotates the gear and tube assembly, which rotates the crank arm (not shown) that connects to the wiper linkage.

- **Variable wipers.** The **variable-delay wipers** (also called **pulse wipers**) use an electronic circuit with a variable resistor that controls the time of the charge and discharge of a capacitor. The charging and discharging of the capacitor controls the circuit for the operation of the wiper motor. ● **SEE FIGURE 58–9.**

HIDDEN WIPERS

Some vehicles are equipped with wipers that become hidden when turned off. These wipers are also called *depressed wipers.* The gearbox has an additional linkage arm to provide depressed parking for hidden wipers. This link extends to move the wipers into the park position when the motor turns in reverse of operating direction. With depressed park, the motor assembly includes an internal park switch. The park switch completes a circuit to reverse armature polarity in the motor when the windshield wiper switch is turned off. The park circuit opens once the wiper arms are in the park position. Instead of a depressed park feature, some systems simply extend the cleaning arc below the level of the hood line.

WINDSHIELD WIPER DIAGNOSIS

Windshield wiper failure may be the result of an electrical fault or a mechanical problem, such as binding linkage. Generally, if the wipers operate at one speed setting but not another, the problem is electrical.

To determine if there is an electrical or mechanical problem, access the motor assembly and disconnect the wiper arm linkage from the motor and gearbox. Depending on the type of vehicle, this procedure may involve:

- Removing body trim panels from the covered areas at the base of the windshield to gain access to the linkage connectors
- Switching the motor on to each speed (If the motor operates at all speeds, the problem is mechanical. If the motor still does not operate, the problem is electrical.)

If the wiper motor does not run at all, check for the following:

- Grounded or inoperative switch
- Defective motor
- Circuit wiring fault
- Poor electrical ground connection

If the motor operates but the wipers do not, check for the following:

- Stripped gears in the gearbox or stripped linkage connection
- Loose or separated motor-to-gearbox connection
- Loose linkage to the motor connection

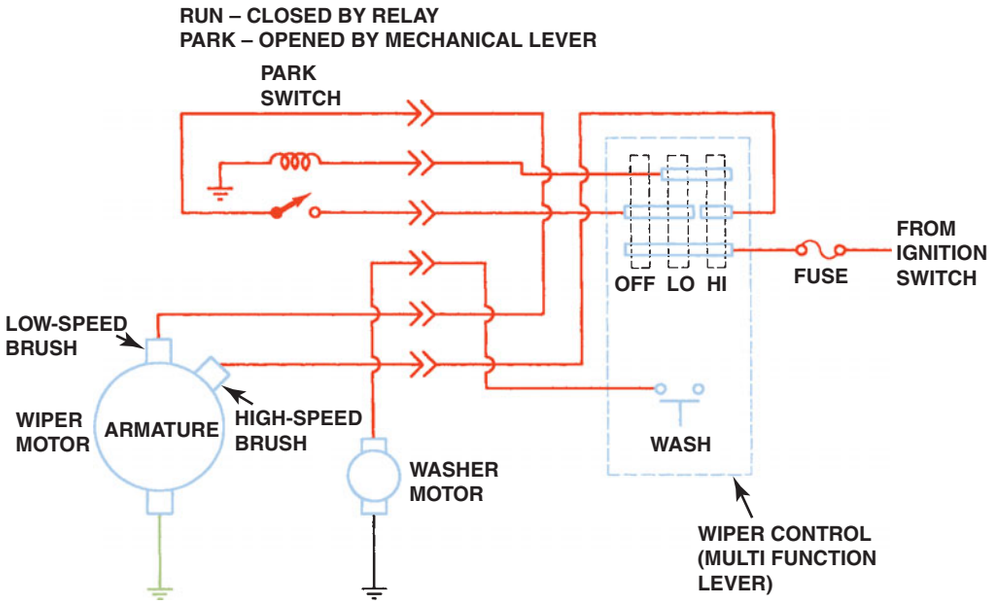


FIGURE 58–7 A wiring diagram of a two-speed windshield wiper circuit using a three-brush, two-speed motor. The dashed line for the multifunction lever indicates that the circuit shown is only part of the total function of the steering column lever.

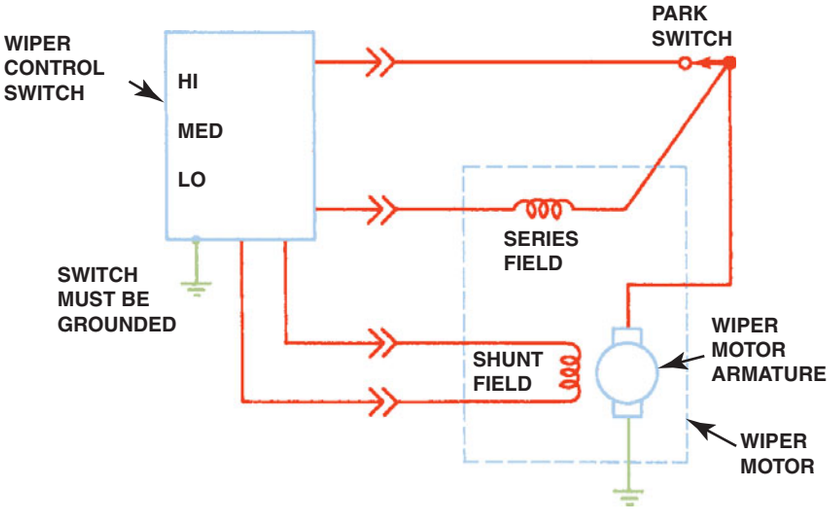


FIGURE 58–8 A wiring diagram of a three-speed windshield wiper circuit using a two-brush motor, but both a series-wound and a shunt field coil.

If the motor does not shut off, check for the following:

- Defective park switch inside the motor
- Defective wiper switch
- Poor ground connection at the wiper switch

WINDSHIELD WIPER TESTING

When the wiper motor does not operate with the linkage disconnected, perform the following steps to determine the fault. ● **SEE FIGURE 58–10.**

To test the wiper system, perform the following steps.

STEP 1 Refer to the circuit diagram or a connector pin chart for the vehicle being serviced to determine the test points for voltage measurements.

STEP 2 Switch the ignition on and set the wiper switch to a speed at which the motor does not operate.

STEP 3 Check for battery voltage available at the appropriate wiper motor terminal for the selected speed. If voltage is available to the motor, an internal motor problem is indicated. No voltage available indicates a switch or circuit failure.

? FREQUENTLY ASKED QUESTION

How Do Wipers Park?

Some vehicles have wiper arms that park lower than the normal operating position so that they are hidden below the hood when not in operation. This is called a *depressed park position.* When the wiper motor is turned off, the park switch allows the motor to continue to turn until the wiper arms reach the bottom edge of the windshield. Then the park switch reverses the current flow through the wiper motor, which makes a partial revolution in the opposite direction. The wiper linkage pulls the wiper arms down below the level of the hood and the park switch is opened, stopping the wiper motor.

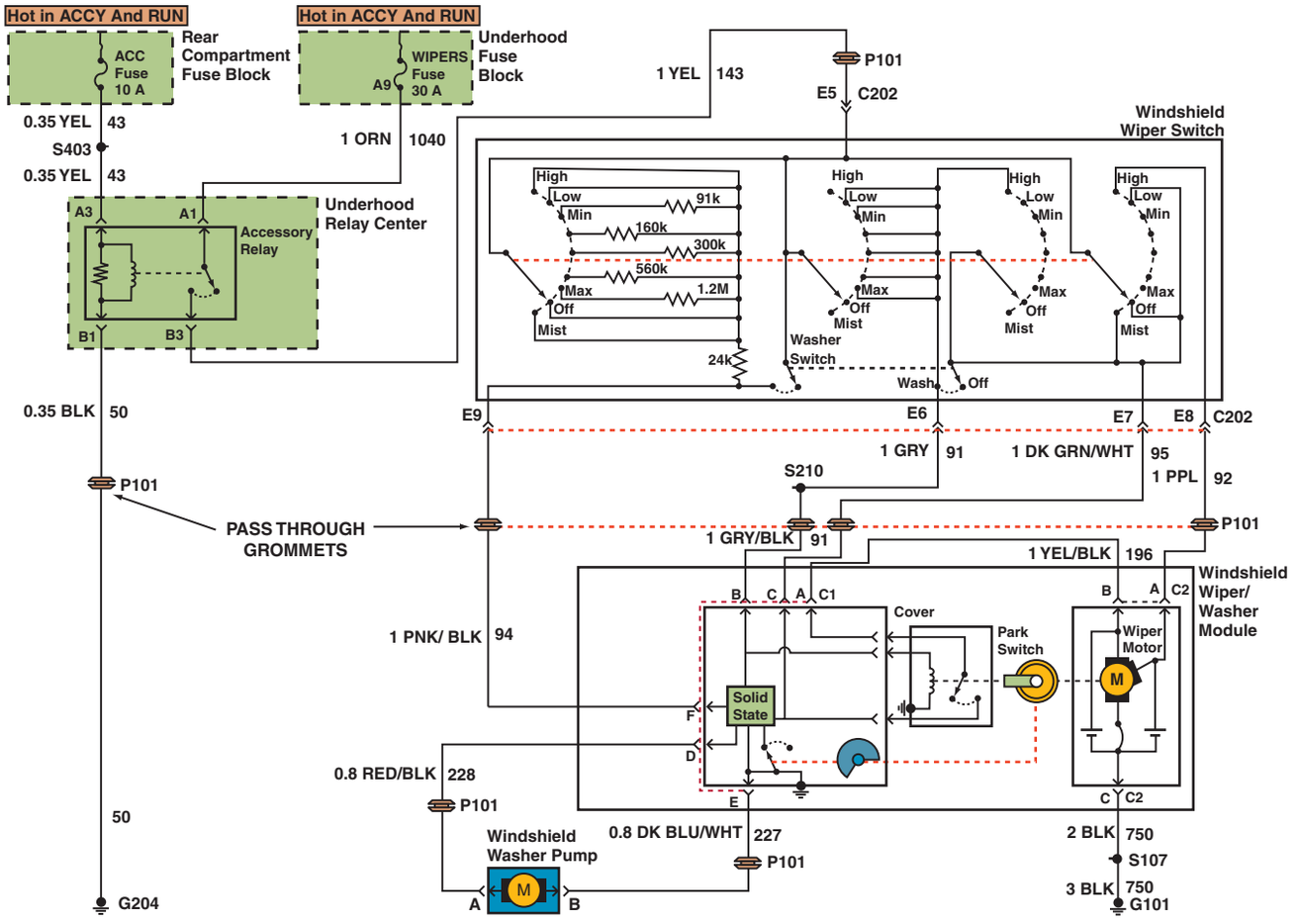
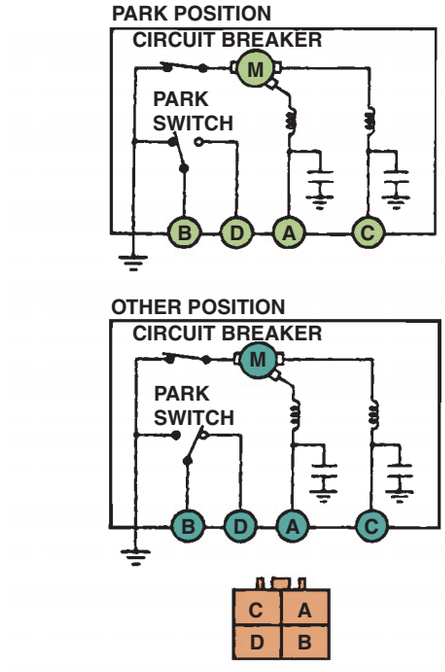


FIGURE 58–9 A variable pulse rate windshield wiper circuit. Notice that the wiring travels from the passenger compartment through pass-through grommets to the underhood area.



TERMINAL	OPERATION SPEED
C	LOW
A	HIGH

FIGURE 58–10 A wiper motor connector pin chart.

STEP 4 Check for proper ground connections.

STEP 5 Check that battery voltage is available at the motor side of the wiper switch. If battery voltage is available, the circuit is open between the switch and motor. No voltage available indicates either a faulty switch or a power supply problem.

STEP 6 Check for battery voltage available at the power input side of the wiper switch. If voltage is available, the switch is defective. Replace the switch. No voltage available to the switch indicates a circuit problem between the battery and switch.

WINDSHIELD WIPER SERVICE

Wiper motors are replaced if defective. The motor usually mounts on the bulkhead (firewall). Bulkhead-mounted units are accessible from under the hood, while the cowl panel needs to be removed to service a motor mounted in the cowl. ● **SEE FIGURE 58–11.**

After gaining access to the motor, removal is simply a matter of disconnecting the linkage, unplugging the electrical connectors, and unbolting the motor. Move the wiper linkage through its full travel by hand to check for any binding before installing the new motor.

Rear window wiper motors are generally located inside the rear door panel of station wagons, or the rear hatch panel on vehicles with a hatchback or liftgate. ● **SEE FIGURE 58–12.**

After removing the trim panel covering the motor, replacement is essentially the same as replacing the front wiper motor.

Wiper control switches are either installed on the steering column or on the instrument panel.

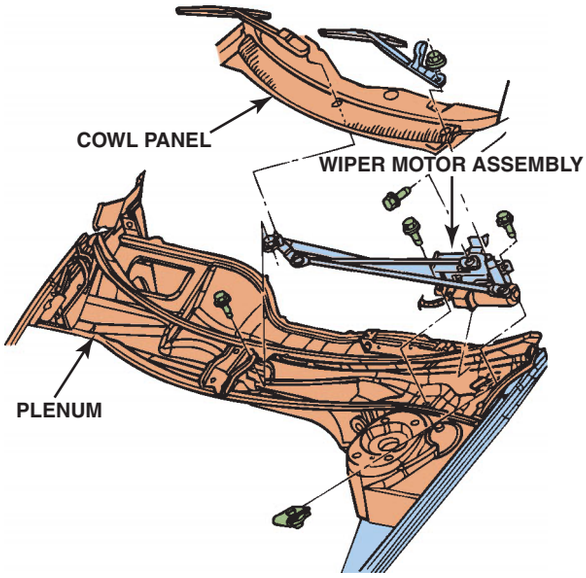


FIGURE 58–11 The wiper motor and linkage mount under the cowl panel on many vehicles.

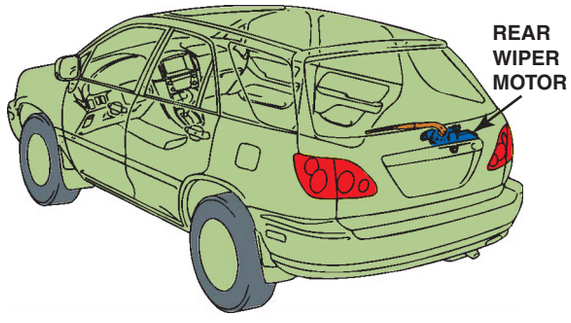


FIGURE 58–12 A single wiper arm mounts directly to the motor on most rear wiper applications.

Steering column wiper switches, which are operated by controls on the end of a switch stalk (usually called a *multifunction switch*), require partial disassembly of the steering column for replacement.

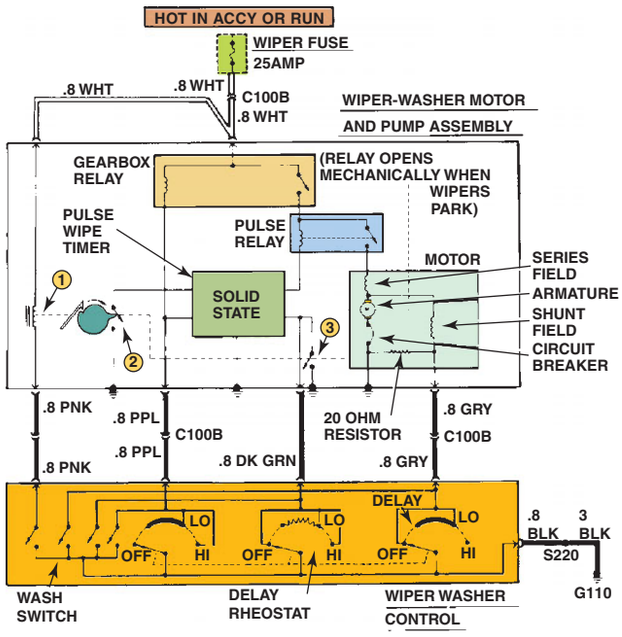
PULSE WIPE SYSTEMS Windshield wipers may also incorporate a delay, or intermittent operation, feature commonly called pulse wipe. The length of the delay, or the frequency of the intermittent operation, is adjustable on some systems. Pulse wipe systems may rely on simple electrical controls, such as a variable-resistance switch, or be controlled electronically through a control module.

With any electronic control system, it is important to follow the diagnosis and test procedures recommended by the manufacturer for that specific vehicle.

A typical pulse, or interval, wiper system uses either a governor or a solid-state module that contains either a variable resistor or rheostat and capacitor. The module connects into the electrical circuitry between the wiper switch and wiper motor. The variable resistor or rheostat controls the length of the interval between wiper pulses. A solid-state pulse wipe timer regulates the control circuit of the pulse relay to direct current to the motor at the prescribed interval. ● **SEE FIGURE 58–13.**

The following troubleshooting procedure applies to most models.

STEP 1 If the wipers do not run at all, check the wiper fuse, fusible link, or circuit breaker and verify that voltage is available to the switch.



① RATCHET RELEASE SOLENOID
(OPERATED WHEN WASH SWITCH DEPRESSED)
② WASHER OVERRIDE SWITCH
(CLOSED DURING WASH CYCLE)
③ HOLDING SWITCH
(OPEN AT THE END OF EACH SWEEP)

FIGURE 58–13 Circuit diagram of a rheostat-controlled, electronically timed interval wiper.

STEP 2 Refer to a wiring diagram of the switch to determine how current is routed through it to the motor in the different positions.

STEP 3 Disconnect the switch and use fused jumper wires to apply power directly to the motor on the different speed circuits.

- If the motor now runs, the problem is in the switch or module.
- Check for continuity in the circuit for each speed through the control-to-ground if the wiper motor runs at some, but not all, speeds.

WINDSHIELD WASHER OPERATION Most vehicles use a positive-displacement or centrifugal-type washer pump located in the washer reservoir. A momentary contact switch, which is often part of a steering column–mounted combination switch assembly, energizes the washer pump. Washer pump switches are installed either on the steering column or on the instrument panel. The nozzles can be located on the bulkhead or in the hood depending on the vehicle.

WINDSHIELD WASHER DIAGNOSIS Inoperative windshield washers may be caused by the following:

- Blown fuse or open circuit
- Empty reservoir
- Clogged nozzle
- Broken, pinched, or clogged hose
- Loose or broken wire
- Blocked reservoir screen
- Leaking reservoir
- Defective pump

To diagnose the washer system, follow service information procedures that usually include the following steps.

TECH TIP

Use a Scan Tool to Check Accessories

Most vehicles built since 2000 can have the lighting and accessory circuits checked using a scan tool. A technician can use the following:

- Factory scan tool, such as:
  - Tech 2 or Multiple Diagnostic Interface (MDI) (General Motors vehicle)
  - DRB III or Star Scan or Star Mobile or WiTech (Chrysler-Jeep vehicles)
  - New Generation Star or IDS (Ford)
  - Honda Diagnostic System (HDS)
  - TIS Tech Stream (Toyota/Lexus)
- Enhanced aftermarket scan tool that has body bidirectional control capability, including:
  - Snap-on Modis, Solus, or Verus
  - OTC Genisys
  - Autoengenuity

Using a bidirectional scan tool allows the technician to command the operation of electrical accessories such as windows, lights, and wipers. If the circuit operates correctly when commanded by the scan tool and does not function using the switche(s), follow service information instructions to diagnose the switch circuits.

STEP 1 To quick check any washer system, make sure the reservoir has fluid and is not frozen, and then disconnect the pump hose and operate the washer switch.

NOTE: Always use good-quality windshield washer fluid from a closed container to prevent contaminated fluid from damaging the washer pump. Radiator antifreeze (ethylene glycol) should never be used in any windshield wiper system.

● **SEE FIGURE 58–14.**

STEP 2 If fluid squirts from the pump, the delivery system is at fault, not the motor, switch, or circuitry.

STEP 3 If no fluid squirts from the pump, the problem is most likely a circuit failure, defective pump, or faulty switch.

STEP 4 A clogged reservoir screen also may be preventing fluid from entering the pump.

WINDSHIELD WASHER SERVICE When a fluid delivery problem is indicated, check for:

- Blocked, pinched, broken, or disconnected hose
- Clogged nozzles
- Blocked washer pump outlet

If the pump motor does not operate, check for battery voltage available at the pump while operating the washer switch. If voltage is available and the pump does not run, check for continuity on the pump ground circuit. If there is no voltage drop on the ground circuit, replace the pump motor.

If battery voltage is not available at the motor, check for power through the washer switch. If voltage is available at and through the switch, there is a problem in the wiring between the switch and pump. Perform voltage drop tests to locate the fault. Repair the wiring as needed and retest.

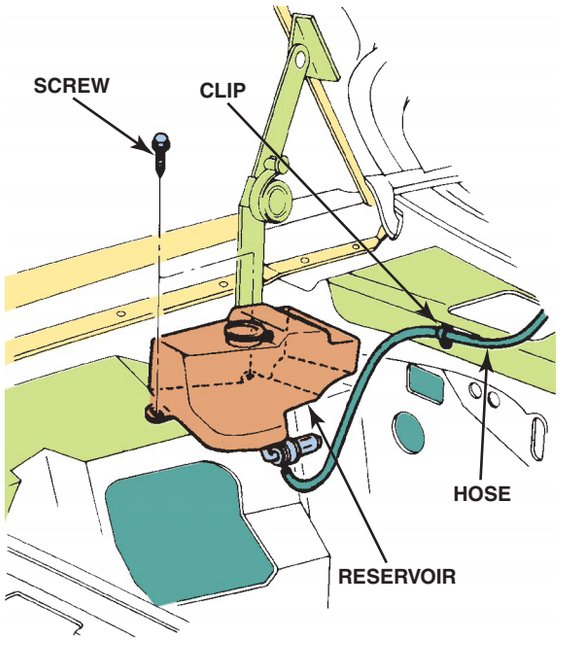


FIGURE 58–14 Disconnect the hose at the pump and operate the switch to check a washer pump.

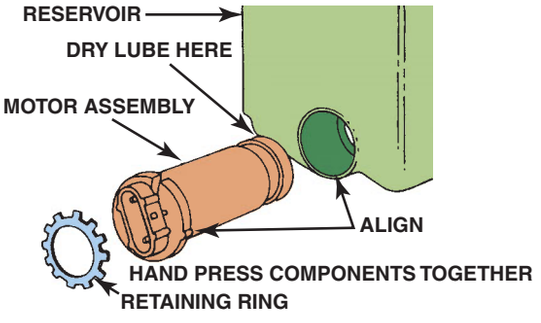


FIGURE 58–15 Washer pumps usually install into the reservoir and are held in place with a retaining ring.

Washer motors are not repairable and are simply replaced if defective. Centrifugal or positive-displacement pumps are located on or inside the washer reservoir tank or cover and secured with a retaining ring or nut. ● **SEE FIGURE 58–15.**

RAIN SENSE WIPER SYSTEM

PARTS AND OPERATION **Rain sense wiper** systems use a sensor located at the top of the windshield on the inside to detect rain droplets. This sensor is called the *rain sense module (RSM)* by General Motors. It determines and adjusts the time delay of the wiper based on how much moisture it detects on the windshield. The wiper switch can be left on the sense position all of the time and if no rain is sensed, the wipers will not swipe. ● **SEE FIGURES 58–16 AND 58–17.**

The control knob is rotated to the desired wiper sensibility level.

The microprocessor in the RSM sends a command to the body control module (BCM). RSM is a triangular-shaped black plastic housing. Fine openings on the windshield side of the housing are



FIGURE 58–16 A typical rain sensing module located on the inside of the windshield near the inside rearview mirror.

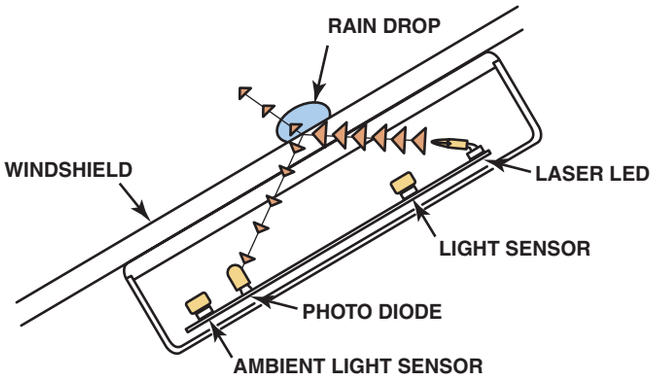


FIGURE 58–17 The electronics in the rain sense wiper module can detect the presence of rain drops under various lighting conditions.

fitted with eight convex clear plastic lenses. The unit contains four infrared (IR) diodes, two photocells, and a microprocessor.

The IR diodes generate IR beams that are aimed by four of the convex optical lenses near the base of the module through the windshield glass. Four additional convex lenses near the top of the RSM are focused on the IR light beam on the outside of the windshield glass and allow the two photocells to sense changes in the intensity of the IR light beam. When sufficient moisture accumulates, the RSM detects a change in the monitored IR light beam intensity. The RSM processes the signal BCM over the data BUS to command a swipe of the wiper.

DIAGNOSIS AND SERVICE

If there is a complaint about the rain sense wipers not functioning correctly, check the owner manual to be sure that they are properly set and adjusted. Also, verify that the windshield wipers are functioning correctly on all speeds before diagnosing the rain sensor circuits. Always follow the vehicle manufacturer's recommended diagnosis and testing procedures.

BLOWER MOTOR

PURPOSE AND FUNCTION

The same blower motor moves air inside the vehicle for:

1. Air conditioning
2. Heat
3. Defrosting

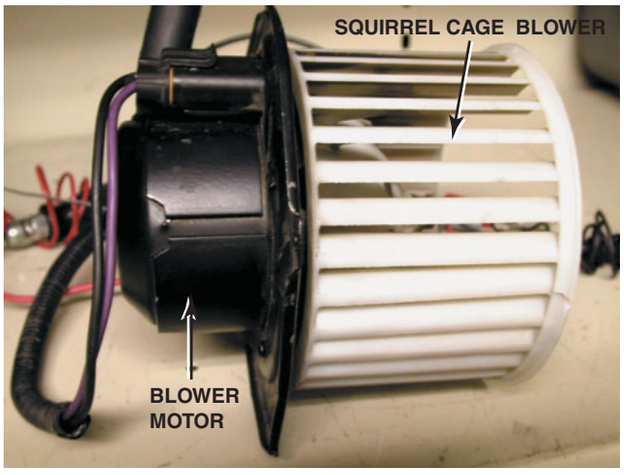


FIGURE 58–18 A squirrel cage blower motor. A replacement blower motor usually does not come equipped with the squirrel cage blower, so it has to be switched from the old motor.

4. Defogging
5. Venting of the passenger compartment

The motor turns a squirrel cage-type fan. A squirrel cage-type fan is able to move air without creating a lot of noise. The fan switch controls the path that the current follows to the blower motor. ● **SEE FIGURE 58–18.**

PARTS AND OPERATION

The motor is usually a permanent magnet, one-speed motor that operates at its maximum speed with full battery voltage. The switch gets current from the fuse panel with the ignition switch on, and then directs full battery voltage to the blower motor for high speed and to the blower motor through resistors for lower speeds.

VARIABLE SPEED CONTROL

The fan switch controls the path of current through a resistor pack to obtain different fan speeds of the blower motor. The electrical path can be:

- Full battery voltage for high-speed operation
- Through one or more resistors to reduce the voltage and the current to the blower motor which then rotates at a slower speed

The resistors are located near the blower motor and mounted in the duct where the airflow from the blower can cool the resistors. The current flow through the resistor is controlled by the switch and often uses a relay to carry the heavy current (10 to 12 amperes) needed to power the fan. Normal operation includes:

- **Low speed.** Current flows through three resistors in series to drop the voltage to about 4 volts and 4 amperes.
- **Medium speed.** Current is directed through two resistors in series to lower the voltage to about 6 volts and 6 amperes.
- **Medium-high speed.** Current is directed through one resistor resulting in a voltage of about 9 volts and 9 amperes.
- **High speed.** Full battery voltage, usually through a relay, is applied to the blower motor resulting in a current of about 12 amperes.

● **SEE FIGURES 58–19 AND 58–20.**

NOTE: Most Ford and some other vehicles place the blower motor resistors on the ground side of the motor circuit. The location of the resistors does not affect the operation because they are connected in series.

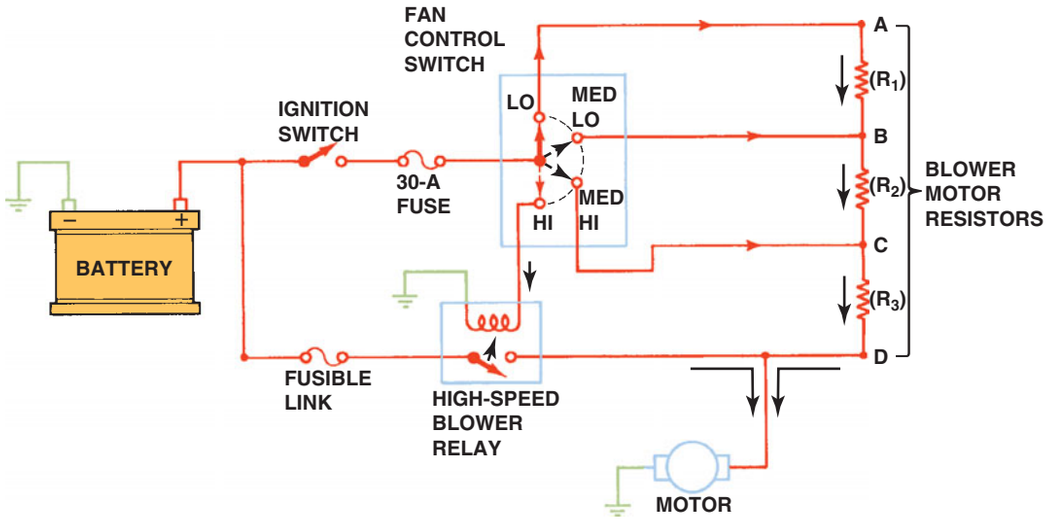


FIGURE 58–19 A typical blower motor circuit with four speeds. The three lowest fan speeds (low, medium-low, and medium-high) use the blower motor resistors to drop the voltage to the motor and reduce current to the motor. On high, the resistors are bypassed. The "high" position on the fan switch energizes a relay, which supplies the current for the blower on high through a fusible link.

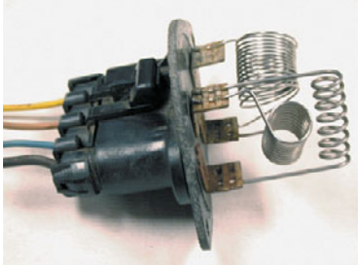


FIGURE 58–20 A typical blower motor resistor pack used to control blower motor speed. Some blower motor resistors are flat and look like a credit card and are called "credit card resistors".



FIGURE 58–21 A brushless DC motor that uses the body computer to control the speed. (*Courtesy of Sammy's Auto Service, Inc.*)

Some blower motors are electronically controlled by the body control module (BCM) and include electronic circuits to achieve a variable speed. ● **SEE FIGURE 58–21.**

BLOWER MOTOR DIAGNOSIS If the blower motor does not operate at any speed, the problem could be any of the following:

1. Defective ground wire or ground wire connection
2. Defective blower motor (not repairable; must be replaced)
3. Open circuit in the power-side circuit, including fuse, wiring, or fan switch

TECH TIP

The 20 Ampere Fuse Test

Most blower motors operate at about 12 A on high speed. If the bushings (bearings) on the armature of the motor become worn or dry, the motor turns more slowly. Because a motor also produces counterelectromotive force (CEMF) as it spins, a slower-turning motor will actually draw more amperes than a fast-spinning motor.

If a blower motor draws too many amperes, the resistors or the electronic circuit controlling the blower motor can fail. Testing the actual current draw of the motor is sometimes difficult because the amperage often exceeds the permissible amount for most digital meters.

One test recommended by General Motors Co. is to unplug the power lead to the motor (retain the ground on the motor) and use a fused jumper lead with one end connected to the battery's positive terminal and the other end to the motor terminal. Use a 20 A fuse in the test lead, and operate the motor for several minutes. If the blower motor is drawing more than 20 A, the fuse will blow. Some experts recommend using a 15 A fuse. If the 15 A fuse blows and the 20 A fuse does not, then you know the approximate blower motor current draw.

If the blower works on lower speeds but not on high speed, the problem is usually an inline fuse or high-speed relay that controls the heavy current flow for high-speed operation. The high-speed fuse or relay usually fails as a result of internal blower motor bushing wear, which causes excessive resistance to motor rotation. At slow blower speeds, the resistance is not as noticeable and the blower operates normally. The blower motor is a sealed unit, and if defective, must be replaced as a unit. The squirrel cage fan usually needs to be removed from the old motor and attached to the replacement motor. If the blower motor operates normally at high speed but not at any of the lower speeds, the problem could be melted wire resistors or a defective switch.

The blower motor can be tested using a clamp-on DC ammeter. **SEE FIGURE 58–22.**

Most blower motors do not draw more than 15 A on high speed. A worn or defective motor usually draws more current than normal and could damage the blower motor resistors or blow a fuse if not replaced.



FIGURE 58–22 Using a mini AC/DC clamp-on multimeter to measure the current draw of a blower motor.

ELECTRICAL ACCESSORY SYMPTOM GUIDE

The following list will assist technicians in troubleshooting electrical accessory systems.

Blower Motor Problem	Possible Causes and/or Solutions
Blower motor does not operate.	1. Blown fuse 2. Poor ground connection on blower motor 3. Defective motor (Use a fused jumper wire connected between the positive terminal of the battery and the blower motor power lead connection [lead disconnected] to check for blower motor operation.) 4. Defective control switch 5. Resistor block open or defective blower motor control module
Blower motor operates only on high speed.	1. Open in the resistors located in the air box near the blower motor 2. Stuck or defective high-speed relay 3. Defective blower motor control switch
Blower motor operates in lower speed(s) only, no high speed.	1. Defective high-speed relay or blower high-speed fuse **NOTE: If the high-speed fuse blows a second time, check the current draw of the motor and replace the blower motor if the current draw is above specifications. Check for possible normal operation if the rear window defogger is not in operation; some vehicles electrically prevent simultaneous operation of the high-speed blower and rear window defogger to help reduce the electrical loads.**

Windshield Wiper or Washer Problem	Possible Causes and/or Solutions
Windshield wipers are inoperative.	1. Blown fuse 2. Poor ground on the wiper motor or the control switch 3. Defective motor or linkage problem
Windshield wipers operate on high speed or low speed only.	1. Defective switch 2. Defective motor assembly 3. Poor ground on the wiper control switch
Windshield washers are inoperative.	1. Defective switch 2. Empty reservoir or clogged lines or discharge nozzles 3. Poor ground on the washer pump motor

Horn Problem	Possible Causes and/or Solutions
Horn(s) are inoperative.	1. Poor ground on horn(s) 2. Defective relay (if used); open circuit in the steering column 3. Defective horn (Use a fused jumper wire connected between the positive terminal of the battery and the horn [horn wire disconnected] to check for proper operation of the horn.)
Horn(s) produce low volume or wrong sound.	1. Poor ground at horn 2. Incorrect frequency of horn
Horn blows all the time.	1. Stuck horn relay (if used) 2. Short-to-ground in the wire to the horn button

REVIEW QUESTIONS

1. What are the three types of horn failure?
2. How is the horn switch used to operate the horn?
3. How do you determine if a windshield wiper problem is electrical or mechanical?
4. Why does a defective blower motor draw more current (amperes) than a good motor?

CHAPTER QUIZ

1. Technician A says that a defective high-speed blower motor relay could prevent high-speed blower operation, yet allows normal operation at low speeds. Technician B says that a defective (open) blower motor resistor can prevent low-speed blower operation, yet permit normal high-speed operation. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
2. To determine if a windshield wiper problem is electrical or mechanical, the service technician should _____.
   a. Disconnect the linkage arm from the windshield wiper motor and operate the windshield wiper
   b. Check to see if the fuse is blown
   c. Check the condition of the wiper blades
   d. Check the washer fluid for contamination
3. A weak-sounding horn is being diagnosed. Technician A says that a poor ground connector at the horn itself can be the cause. Technician B says an open relay can be the cause. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
4. What controls the operation of a pulse wiper system?
   a. Resistor that controls current flow to the wiper motor
   b. Solid-state (electronic) module
   c. Variable-speed gem set
   d. Transistor
5. Which pitch horn is used for a single horn application?
   a. High pitch
   b. Low pitch
6. The horn switch on the steering wheel on a vehicle that uses a horn relay _____.
   a. Sends electrical power to the horns
   b. Provides the ground circuit for the horn
   c. Grounds the horn relay coil
   d. Provides power (12 V) to the horn relay
7. A rain sense wiper system uses a rain sensor that is usually mounted _____.
   a. Behind the grille
   b. Outside of the windshield at the top
   c. Inside the windshield at the top
   d. On the roof
8. Technician A says a blower motor can be tested using a fused jumper lead. Technician B says a blower motor can be tested using a clamp-on ammeter. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
9. A defective blower motor draws more current than a good motor because the _____.
   a. Speed of the motor increases
   b. CEMF decreases
   c. Airflow slows down, which decreases the cooling of the motor
   d. Both a and c
10. Windshield washer pumps can be damaged if _____.
    a. Pure water is used in freezing weather
    b. Contaminated windshield washer fluid is used
    c. Ethylene glycol (antifreeze) is used
    d. All of the above

chapter 59 ACCESSORY CIRCUITS

OBJECTIVES: After studying Chapter 59, the reader will be able to: • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "H" (Accessories Diagnosis and Repair). • Explain how the body control module or body computer controls the operation of electrical accessories. • Explain how cruise control operates and how to diagnose the circuit. • Describe how power door locks, windows, and seats operate. • Describe how a keyless remote can be reprogrammed. • Explain how the theft deterrent system works.

KEY TERMS: Adjustable pedals 670 • Backlight 662 • CHMSL 659 • Control wires 666 • Cruise control 658 • Direction wires 666 • Electric adjustable pedals (EAP) 670 • ETC 659 • HomeLink 664 • Independent switches 664 • Key fob 671 • Lockout switch 664 • Lumbar 667 • Master control switch 664 • Peltier effect 669 • Permanent magnet electric motors 664 • Rubber coupling 666 • Screw jack assembly 666 • Thermoelectric device (TED) 669 • Window regulator 664

PARTS INVOLVED

Cruise control (also called *speed control*) is a combination of electrical and mechanical components designed to maintain a constant, set vehicle speed without driver pressure on the accelerator pedal. Major components of a typical cruise control system include the following:

1. **Servo unit.** The servo unit attaches to the throttle linkage through a cable or chain.

   The servo unit controls the movement of the throttle by receiving a controlled amount of vacuum from a control module. ● **SEE FIGURE 59–1**.

   Some systems use a stepper motor and do not use engine vacuum.

2. **Computer or cruise control module.** This unit receives inputs from the brake switch, throttle position (TP) sensor, and vehicle speed sensor. It operates the solenoids or stepper motor to maintain the set speed.

3. **Speed set control.** A speed set control is a switch or control located on the steering column, steering wheel, dash, or console. Many cruise control units feature coast, accelerate, and resume functions. ● **SEE FIGURE 59–2**.

4. **Safety release switches.** When the brake pedal is depressed, the cruise control system is disengaged through use of an electrical or vacuum switch, usually located on the brake pedal bracket. Both electrical and vacuum releases are used to be certain that the cruise control system is released, even in the event of failure of one of the release switches.

CRUISE CONTROL OPERATION

A typical cruise control system can be set only if the vehicle speed is 30 mph or more. In a noncomputer-operated system, the transducer contains a low-speed electrical switch that closes when the speed-sensing section of the transducer senses a speed exceeding the minimum engagement speed.

NOTE: Toyota-built vehicles do not retain the set speed in memory if the vehicle speed drops below 25 mph (40 km/h). The driver is required to set the desired speed again. This is normal operation and not a fault with the cruise control system.

When the set button is depressed on the cruise control, solenoid values on the servo unit allow engine vacuum to be applied to one side of the diaphragm, which is attached to the throttle plate of the engine through a cable or linkage. The servo unit usually contains two solenoids to control the opening and closing of the throttle.

- One solenoid opens and closes to control the passage, which allows engine vacuum to be applied to the diaphragm of the servo unit, increasing the throttle opening.
- One solenoid bleeds air back into the sensor chamber to reduce the throttle opening.

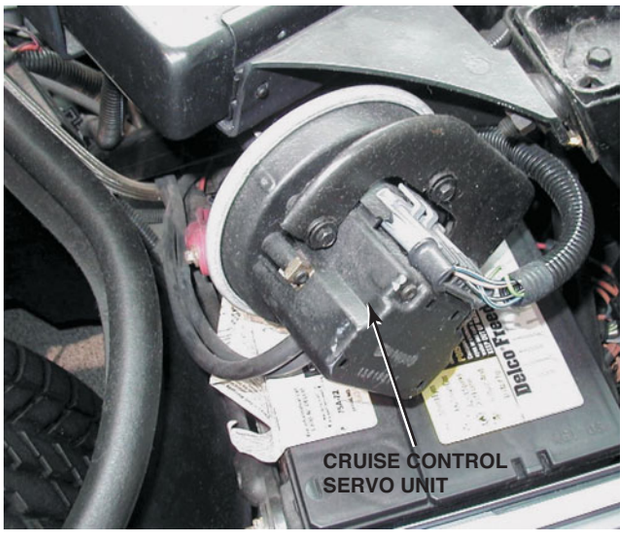


FIGURE 59–1 This cruise control servo unit has an electrical connection with wires that go to the cruise control module or the vehicle computer, depending on the vehicle. The vacuum hoses supply engine manifold vacuum to the rubber diaphragm that moves the throttle linkage to maintain the preset speed.



FIGURE 59–2 A cruise control used on a Toyota/Lexus.

WARNING

Most vehicle manufacturers warn in the owner manual that cruise control should not be used when it is raining or if the roads are slippery. Cruise control systems operate the throttle and, if the drive wheels start to hydroplane, the vehicle slows, causing the cruise control unit to accelerate the engine. When the engine is accelerated and the drive wheels are on a slippery road surface, vehicle stability will be lost and might possibly cause a crash.

TECH TIP

Bump Problems

Cruise control problem diagnosis can involve a complex series of checks and tests. The troubleshooting procedures vary among manufacturers (and year), so a technician should always consult a service manual for the exact vehicle being serviced. However, every cruise control system uses a brake safety switch and, if the vehicle has manual transmission, a clutch safety switch. The purpose of these safety switches is to ensure that the cruise control system is disabled if the brakes or the clutch is applied. Some systems use redundant brake pedal safety switches, one electrical to cut off power to the system and the other a vacuum switch used to bleed vacuum from the actuating unit.

If the cruise control "cuts out" or disengages itself while traveling over bumpy roads, the most common cause is a misadjusted brake (and/or clutch) safety switch(es). Often, a simple readjustment of these safety switches will cure the intermittent cruise control disengagement problems.

CAUTION: Always follow the manufacturer's recommended safety switch adjustment procedures. If the brake safety switch(es) is misadjusted, it could keep pressure applied to the master brake cylinder, resulting in severe damage to the braking system.

The throttle position (TP) sensor or a position sensor, inside the servo unit, sends the throttle position information to the cruise control module.

Most computer-controlled cruise control systems use the vehicle's speed sensor input to the engine control computer for speed reference. Computer-controlled cruise control units also use servo units for throttle control, control switches for driver control of cruise control functions, and both electrical and vacuum brake pedal release switches. ● **SEE FIGURE 59–3.**

TROUBLESHOOTING CRUISE CONTROL

Cruise control system troubleshooting is usually performed using the step-by-step procedure as specified by the vehicle manufacturer.

The usual steps in the diagnosis of an inoperative or incorrectly operating mechanical-type cruise control include the following:

STEP 1 Use a factory or enhanced scan tool to retrieve any cruise control diagnostic trouble codes (DTCs). Perform bidirectional testing if possible using the scan tool.

STEP 2 Check that the cruise control fuse is not blown and that the cruise control dash light is on when the cruise control is turned on.

STEP 3 Check for proper operation of the brake and/or clutch switch.

TECH TIP

Check the Third Brake Light

On many General Motors vehicles, the cruise control will not work if the third brake light is out. This third brake light is called the **center high-mounted stop light (CHMSL).** Always check the brake lights first if the cruise control does not work on a General Motors vehicle.

STEP 4 Inspect the throttle cable and linkage between the sensor unit and the throttle plate for proper operation without binding or sticking.

STEP 5 Check the vacuum hoses for cracks or other faults.

STEP 6 Check that the vacuum servo unit (if equipped), using a hand-operated vacuum pump, can hold vacuum without leaking.

STEP 7 Check the servo solenoids for proper operation, including a resistance measurement check.

ELECTRONIC THROTTLE CRUISE CONTROL

PARTS AND OPERATION Many vehicles are equipped with an **electronic throttle control (ETC)** system. Vehicles equipped with such a system do not use throttle actuators for the cruise control. The ETC system operates the throttle under all engine operating conditions. An ETC system uses a DC electric motor to move the throttle plate that is spring loaded to a partially open position. The motor actually closes the throttle at idle against spring pressure. The spring-loaded position is the default position and results in a high idle speed. The powertrain control module (PCM) uses the input signals from the *accelerator pedal position (APP)* sensor to determine the desired throttle position. The PCM then commands the throttle to the necessary position of the throttle plate. ● **SEE FIGURE 59–4.**

The cruise control on a vehicle equipped with an electronic throttle control system consists of a switch to set the desired speed. The PCM receives the vehicle speed information from the vehicle speed (VS) sensor and uses the ETC system to maintain the set speed.

DIAGNOSIS AND SERVICE Any fault in the APP sensor or ETC system will disable the cruise control function. Always follow the specified troubleshooting procedures, which will usually include the use of a scan tool to properly diagnose the ETC system.

RADAR CRUISE CONTROL

PURPOSE AND FUNCTION The purpose of a radar cruise control system is to give the driver more control over the vehicle by keeping an assured clear distance behind the vehicle in front. If the vehicle in front slows, the radar cruise control detects the slowing vehicle and automatically reduces the speed of the vehicle to keep a safe distance. Then if the vehicle speeds up, the radar cruise control also allows the vehicle to increase to the preset speed. This makes driving in congested areas easier and less tiring.

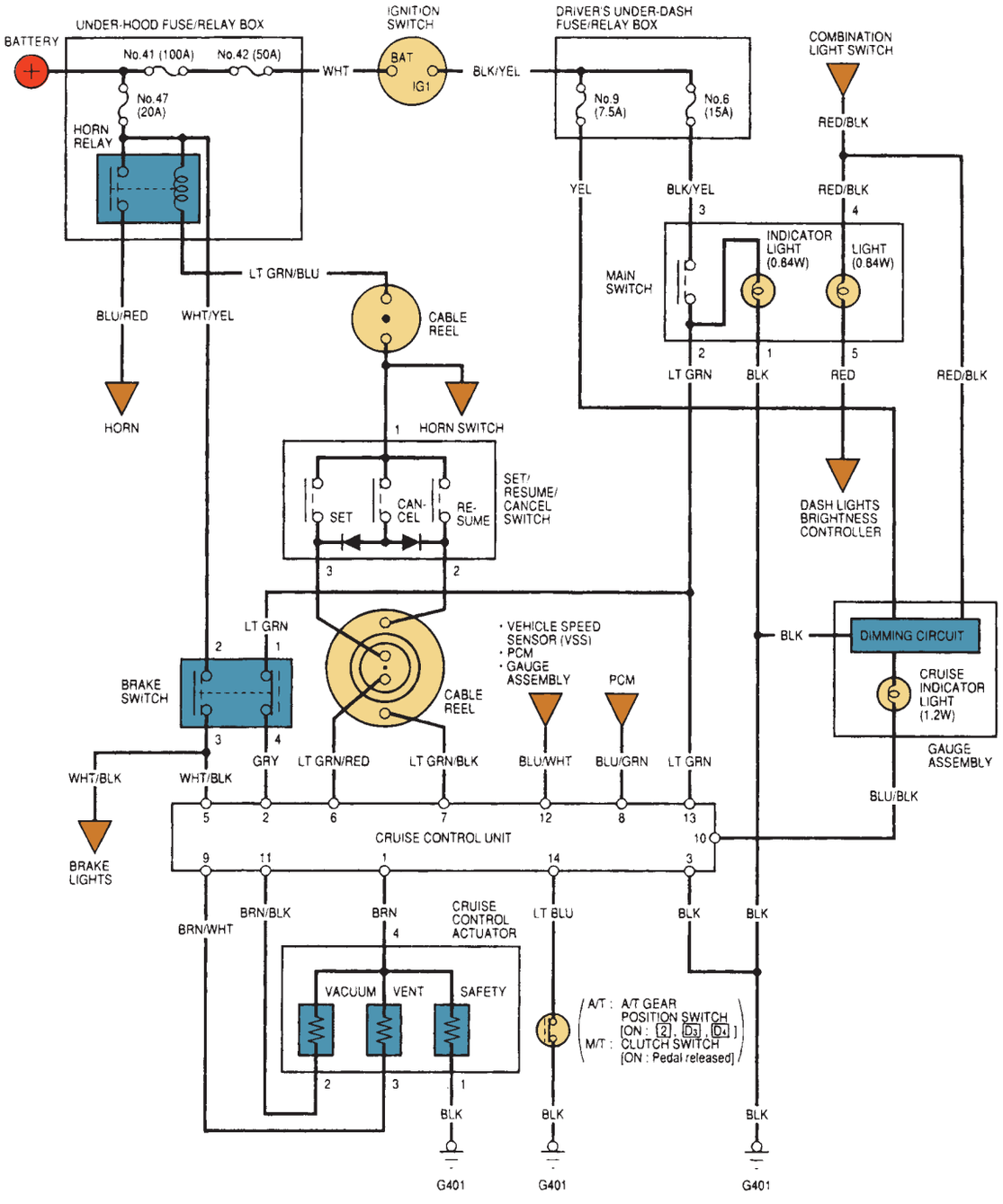


FIGURE 59–3 Circuit diagram of a typical electronic cruise control system.



FIGURE 59–4 A typical electronic throttle with the protective covers removed.

TECH TIP

Use Trailer Tow Mode

Some customers complain that when using cruise control while driving in hilly or mountainous areas that the speed of the vehicle will sometimes go 5 to 8 mph below the set speed. The automatic transmission then downshifts, the engine speed increases, and the vehicle returns to the set speed. To help avoid the slowdown and rapid acceleration, ask the customer to select the trailer towing position. When this mode is selected, the automatic transmission downshifts almost as soon as the vehicle speed starts to decrease. This results in a smoother operation and is less noticeable to both the driver and passengers. ● **SEE FIGURE 59–5.**

TERMINOLOGY Depending on the manufacturer, radar cruise control is also referred to as the following:

- **Adaptive cruise control** (Audi, Ford, General Motors, and Hyundai)
- **Dynamic cruise control** (BMW, Toyota/Lexus)
- **Active cruise control** (Mini Cooper, BMW)
- **Autonomous cruise control** (Mercedes)

It uses forward-looking radar to sense the distance to the vehicle in front and maintains an assured clear distance. This type of cruise control system works within the following conditions.

1. Speeds from 20 to 100 mph (30 to 161 km/h)
2. Designed to detect objects as far away as 500 ft (150 m)

The cruise control system is able to sense both distance and relative speed. ● **SEE FIGURE 59–6.**

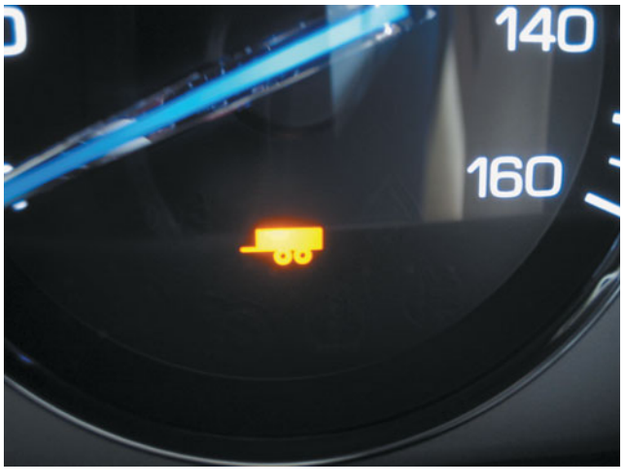


FIGURE 59–5 A trailer icon lights on the dash of this Cadillac when the transmission trailer towing mode is selected.

PARTS AND OPERATION Radar cruise control systems use long-range radar (LRR) to detect faraway objects in front of the moving vehicle. Some systems use a short-range radar (SRR) and/or infrared (IR) or optical cameras to detect distances for when the distance between the moving vehicle and another vehicle in front is reduced. ● **SEE FIGURE 59–7.**

The radar frequencies include:

- 76 to 77 GHz (long-range radar)
- 24 GHz (short-range radar)

? FREQUENTLY ASKED QUESTION

Will Radar Cruise Control Set Off My Radar Detector?

It is doubtful. The radar used for radar cruise control systems operates on frequencies that are not detectable by police radar detector units. Cruise control radar works on the following frequencies.

- 76 to 77 GHz (long range)
- 24 GHz (short range)

The frequencies used for the various types of police radar include:

- X-band: 8 to 12 GHz
- K-band: 24 GHz
- Ka-band: 33 to 36 GHz

The only time there may be interference is when the radar cruise control, as part of a precollision system, starts to use short-range radar (SRR) in the 24 GHz frequency. This would trigger the radar detector but would be an unlikely event and just before a possible collision with a vehicle coming toward you.

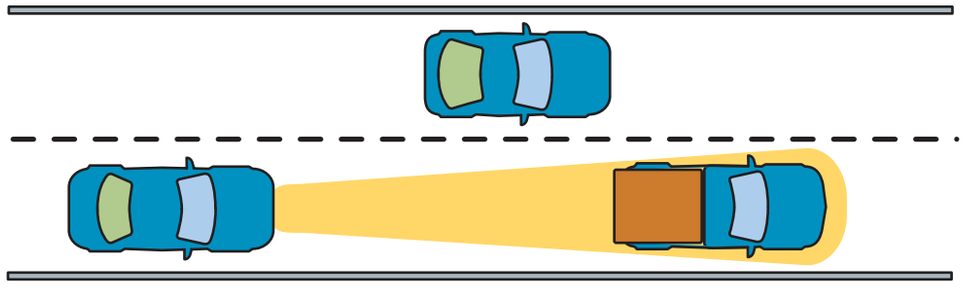


FIGURE 59–6 Radar cruise control uses sensors to keep the distance the same even when traffic slows ahead.

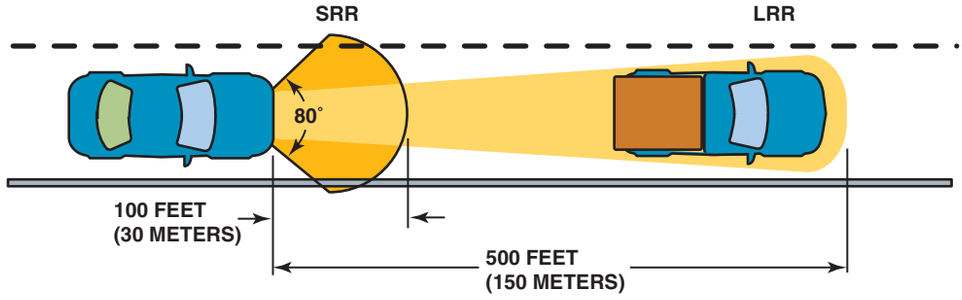


FIGURE 59–7 Most radar cruise control systems use radar, both long and short range. Some systems use optical or infrared cameras to detect objects.

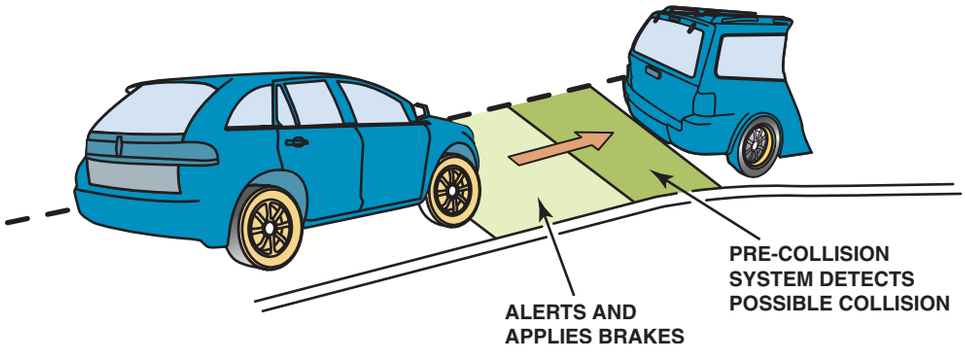


FIGURE 59–8 A precollision system is designed to prevent a collision first, and then interacts to prepare for a collision if needed.

PRECOLLISION SYSTEM

PURPOSE AND FUNCTION The purpose and function of a precollision system is to monitor the road ahead and prepare to avoid a collision, and to protect the driver and passengers. A precollision system uses components of the following systems.

1. The long-range and short-range radar or detection systems used by a radar cruise control system to detect objects in front of the vehicle
2. Antilock brake system (ABS)
3. Adaptive (radar) cruise control
4. Brake assist system

TERMINOLOGY Precollision systems can be called various names depending on the make of the vehicle. Some commonly used names for a precollision or precrash system include:

- **Ford/Lincoln:** Collision Warning with Brake Support
- **Honda/Acura:** Collision Mitigation Brake System (CMBS)
- **Mercedes-Benz:** Pre-Safe or Attention Assist
- **Toyota/Lexus:** Pre-Collision System (PCS) or Advanced Pre-Collision System (APCS)
- **General Motors:** Pre-Collision System (PCS)
- **Volvo:** Collision Warning with Brake Support or Collision Warning with Brake Assist

OPERATION The system functions by monitoring objects in front of the vehicle and can act to avoid a collision by the following actions.

- Sounds an alarm
- Flashes a warning lamp
- Applies the brakes and brings the vehicle to a full stop (if needed), if the driver does not react

SEE FIGURE 59–8.

If the system is unable to prevent a collision, the system will perform the following actions.

1. Apply the brakes full force to reduce vehicle speed as much as possible
2. Close all windows and the sunroof to prevent the occupants from being ejected from the vehicle
3. Move the seats to an upright position

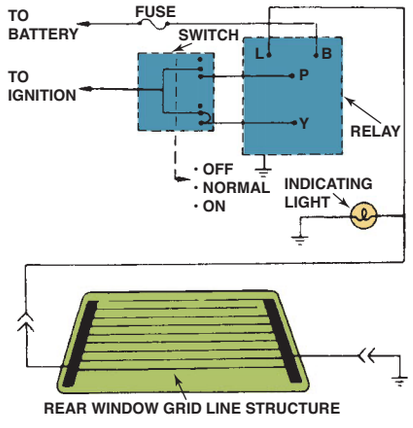


FIGURE 59–9 A switch and relay control current through the heating grid of a rear window defogger.

4. Raise the headrest (if electrically powered)
5. Pretension the seat belts
6. Airbags and seat belt tensioners function as designed during the collision

HEATED REAR WINDOW DEFOGGERS

PARTS AND OPERATION An electrically heated rear window defogger system uses an electrical grid baked on the glass that warms the glass to about 85°F (29°C) and clears it of fog or frost. The rear window is also called a **backlight.** The rear window defogger system is controlled by a driver-operated switch and a timer relay.

SEE FIGURE 59–9.

The timer relay is necessary because the window grid can draw up to 30 A, and continued operation would put a strain on the battery and the charging system. Generally, the timer relay permits current to flow through the rear window grid for only 10 minutes. If the window is still not clear of fog after 10 minutes, the driver can turn the defogger on again, but after the first 10 minutes any additional defogger operation is limited to 5 minutes.

PRECAUTION Electric grid-type rear window defoggers can be damaged easily by careless cleaning or scraping of the inside of the rear window glass. Short, broken sections of the rear window grid can be repaired using a special epoxy-based electrically conductive

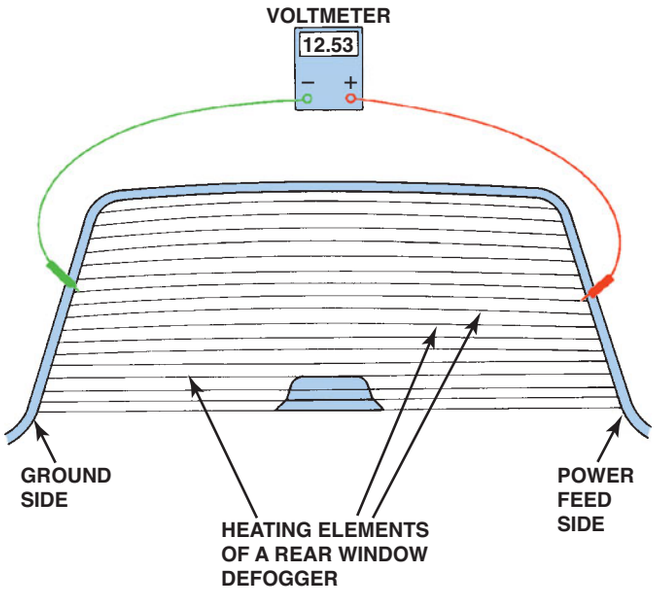


FIGURE 59–10 A rear window defogger electrical grid can be tested using a voltmeter to check for a decreasing voltage as the meter lead is moved from the power side toward the ground side. As the voltmeter positive lead is moved along the grid (on the inside of the vehicle), the voltmeter reading should steadily decrease as the meter approaches the ground side of the grid.

material. If more than one section is damaged or if the damaged grid length is greater than approximately 1.5 in. (3.8 cm), a replacement rear window glass may be required to restore proper defogger operation.

The electrical current through the grids depends, in part, on the temperature of the conductor grids. As the temperature decreases, the resistance of the grids decreases and the current flow increases, helping to warm the rear glass. As the temperature of the glass increases, the resistance of the conductor grids increases and the current flow decreases. Therefore, the defogger system tends to self-regulate the electrical current requirements to match the need for defogging.

NOTE: Some vehicles use the wire grid of the rear window defogger as the radio antenna. Therefore, if the grid is damaged, radio reception can also be affected.

HEATED REAR WINDOW DEFOGGER DIAGNOSIS

Troubleshooting a nonfunctioning rear window defogger unit involves using a test light or a voltmeter to check for voltage to the grid. If no voltage is present at the rear window, check for voltage at the switch and relay timer assembly. A poor ground connection on the opposite side of the grid from the power side can also cause the rear defogger not to operate. Because most defogger circuits use an indicator light switch and a relay timer, it is possible to have the indicator light on, even if the wires are disconnected at the rear window grid. A voltmeter can be used to test the operation of the rear window defogger grid. ● **SEE FIGURE 59–10.**

With the negative test terminal attached to a good body ground, carefully probe the grid conductors. There should be a decreasing voltage reading as the probe is moved from the power ("hot") side of the grid toward the ground side of the grid.

REPAIR OR REPLACEMENT

If there is a broken grid wire, it can be repaired using an electrically conductive substance available in a repair kit.

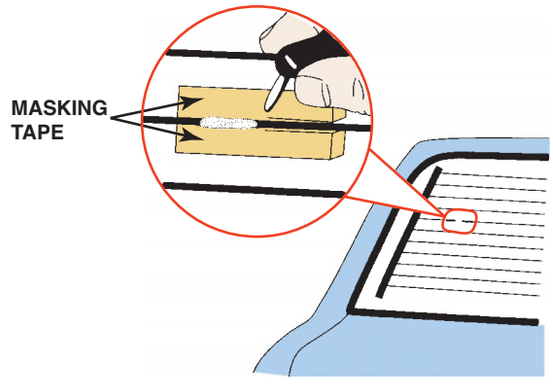


FIGURE 59–11 The typical repair material contains conductive silver-filled polymer, which dries in 10 minutes and is usable in 30 minutes.

TECH TIP

The Breath Test

It is difficult to test for the proper operation of all grids of a rear window defogger unless the rear window happens to be covered with fog. A common trick that works is to turn on the rear defogger and exhale onto the outside of the rear window glass. In a manner similar to that of people cleaning eyeglasses with their breath, this procedure produces a temporary fog on the glass so that all sections of the rear grids can quickly be checked for proper operation.

Most vehicle manufacturers recommend that grid wire less than 2 in. (5 cm) long be repaired. If a bad section is longer than 2 in., the entire rear window will need to be replaced. ● **SEE FIGURE 59–11.**

HEATED MIRRORS

PURPOSE AND FUNCTION

The purpose and function of heated outside mirrors is to heat the surface of the mirror, which evaporates moisture on the surface. The heat helps keep ice and fog off the mirrors, to allow for better driver visibility.

PARTS AND OPERATION

Heated outside mirrors are often tied into the same electrical circuit as the rear window defogger. Therefore, when the rear defogger is turned on, the heating grid on the backside of the mirror is also turned on. Some vehicles use a switch for each mirror.

DIAGNOSIS

The first step in any diagnosis procedure is to verify the customer concern. Check the owner's manual or service information for the proper method to use to turn on the heated mirrors.

NOTE: Heated mirrors are not designed to melt snow or a thick layer of ice.

If a fault has been detected, follow service information instructions for the exact procedure to follow. If the mirror itself is found to be defective, it is usually replaced as an assembly instead of being repaired.



FIGURE 59–12 Typical HomeLink garage door opener buttons. Notice that three different units can be controlled from the vehicle using the HomeLink system.

HOMELINK GARAGE DOOR OPENER

OPERATION

HomeLink is a device installed in many new vehicles that duplicates the radio-frequency code of the original garage door opener. The frequency range which HomeLink is able to operate is 288 to 418 MHz. The typical vehicle garage door opening system has three buttons that can be used to operate one or more of the following devices.

1. Garage doors equipped with a radio transmitter electric opener
2. Gates
3. Entry door locks
4. Lighting or small appliances

The devices include both fixed-frequency devices, usually older units, and rolling (encrypted) code devices. ● **SEE FIGURE 59–12.**

PROGRAMMING A VEHICLE GARAGE DOOR OPENER

When a vehicle is purchased, it must be programmed using the transmitter for the garage door opener or other device.

NOTE: The HomeLink garage door opening controller can only be programmed by using a transmitter. If an automatic garage door system does not have a remote transmitter, HomeLink cannot be programmed.

Normally, the customer is responsible for programming the HomeLink to the garage door opener. However, some customers may find that help is needed from the service department. The steps that are usually involved in programming HomeLink in the vehicle to the garage door opener are as follows:

STEP 1 Unplug the garage door opener during programming to prevent it from being cycled on and off, which could damage the motor.

STEP 2 Check that the frequency of the handheld transmitter is between 288 and 418 MHz.

STEP 3 Install new batteries in the transmitter to be assured of a strong signal being transmitted to the HomeLink module in the vehicle.

STEP 4 Turn the ignition on, engine off (KOEO).

STEP 5 While holding the transmitter 4 to 6 in. away from the HomeLink button, press and hold the HomeLink button while pressing and releasing the handheld transmitter every two seconds. Continue pressing and releasing the transmitter until the indicator light near the HomeLink button changes from slow blink to a rapid flash.

STEP 6 Verify that the vehicle garage door system (HomeLink) button has been programmed. Press and hold the garage door button. If the indicator light blinks rapidly for two seconds and then comes on steady, the system has been successfully programmed using a rolling code design. If the indicator light is on steady, then it has been successfully programmed to a fixed-frequency device.

DIAGNOSIS AND SERVICE

If a fault occurs with the HomeLink system, first verify that the garage door opener is functioning correctly. Also, check if the garage door opener remote control is capable of operating the door. Repair the garage door opener system as needed.

If the problem still exists, attempt reprogramming the HomeLink vehicle system, being sure that the remote has a newly purchased battery.

POWER WINDOWS

SWITCHES AND CONTROLS

Power windows use electric motors to raise and lower door glass. They can be operated by both a **master control switch** located beside the driver and additional **independent switches** for each electric window. Some power window systems use a **lockout switch** located on the driver's controls to prevent operation of the power windows from the independent switches. Power windows are designed to operate only with the ignition switch in the on (run) position, although some manufacturers use a time delay for accessory power after the ignition switch is turned off. This feature permits the driver and passengers an opportunity to close all windows or operate other accessories for about 10 minutes or until a vehicle door is opened after the ignition has been turned off. This feature is often called *retained accessory power.*

POWER WINDOW MOTORS

Most power window systems use **permanent magnet (PM) electric motors.** It is possible to run a PM motor in the reverse direction simply by reversing the polarity of the two wires going to the motor. Most power window motors do not require that the motor be grounded to the body (door) of the vehicle. The ground for all the power windows is most often centralized near the driver's master control switch. The up-and-down motion of the individual window motors is controlled by double-pole, double-throw (DPDT) switches. These DPDT switches have five contacts and permit battery voltage to be applied to the power window motor, as well as reverse the polarity and direction of the motor. Each motor is protected by an electronic circuit breaker. These circuit breakers are built into the motor assembly and are not a separate replaceable part. ● **SEE FIGURE 59–13.**

The power window motors rotate a mechanism called a **window regulator.** The window regulator is attached to the door glass and controls opening and closing of the glass. Door glass adjustments such as glass tilt and upper and lower stops are usually the same for both power and manual windows. ● **SEE FIGURE 59–14.**

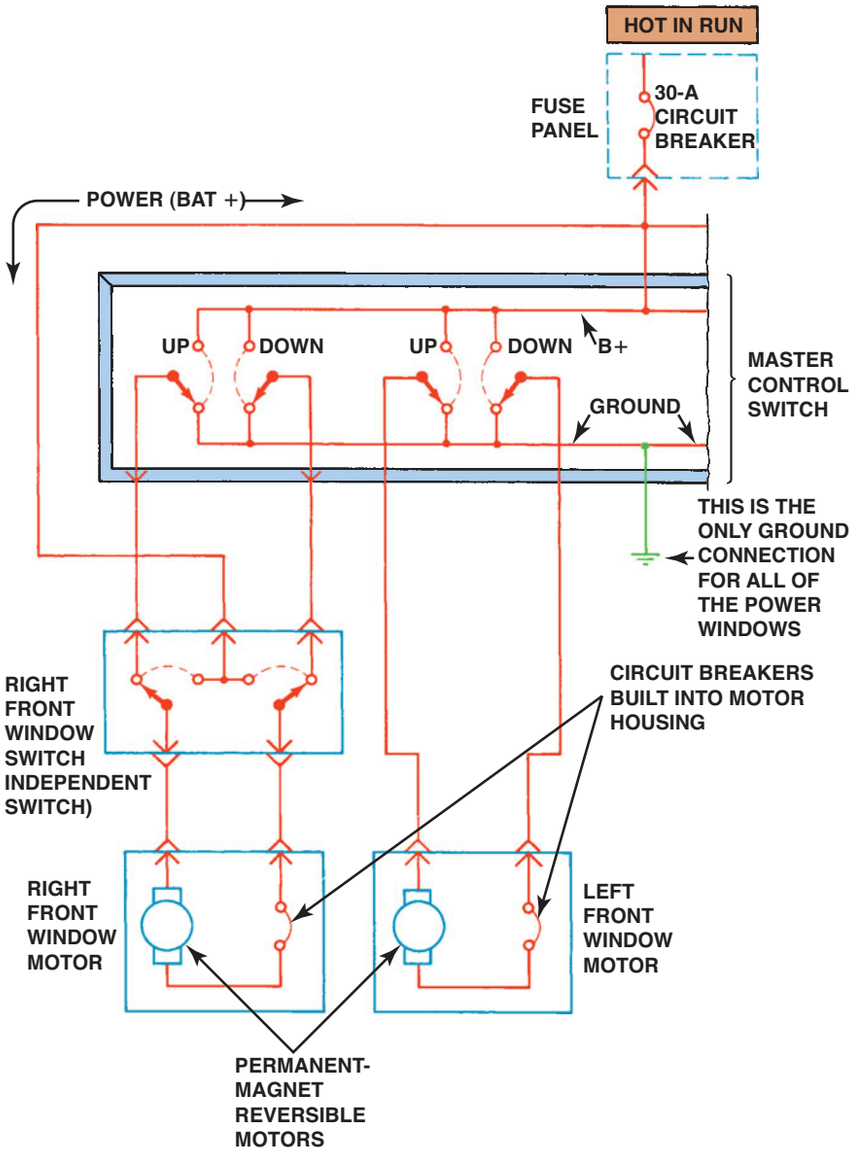


FIGURE 59–13 A typical power window circuit using PM motors. Control of the direction of window operation is achieved by directing the polarity of the current through the nongrounded motors. The only ground for the entire system is located at the master control (driver's side) switch assembly.

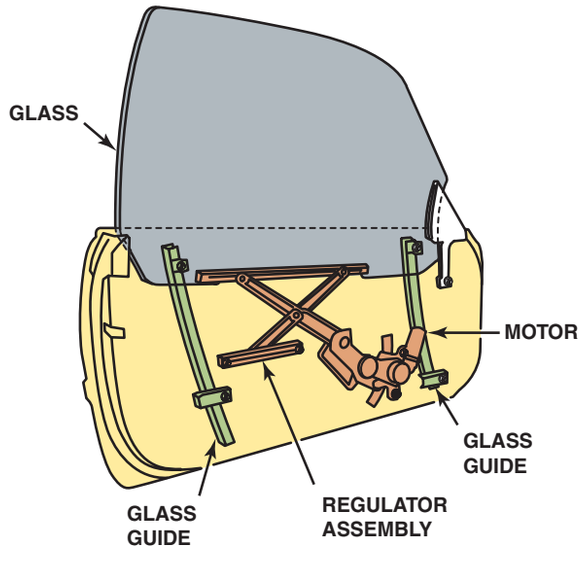


FIGURE 59–14 An electric motor and a regulator assembly raise and lower the glass on a power window.

AUTO DOWN/UP FEATURES Many power windows are equipped with an auto down feature that allows windows to be lowered all of the way if the control switch is moved to a detent or held down for longer than 0.3 second. The window will then move down all the way to the bottom, and then the motor stops.

Many vehicles are equipped with the auto up feature that allows the driver to raise the driver's side or all windows in some cases, with just one push of the button. A sensor in the window motor circuit measures the current through the motor. The circuit is opened if the window touches an object, such as a hand or finger. When the window reaches the top or hits an object, the current through the window motor increases. When the upper limit amperage draw is reached, the motor circuit is opened and the window either stops or reverses. Most newer power windows use network communications modules to operate the power windows, and the switches are simply voltage signals to the module which supplies current to the individual window motors. ● **SEE FIGURE 59–15.**

TROUBLESHOOTING POWER WINDOWS Before troubleshooting a power window problem, check for proper operation of all power windows. Check service information for the exact procedure

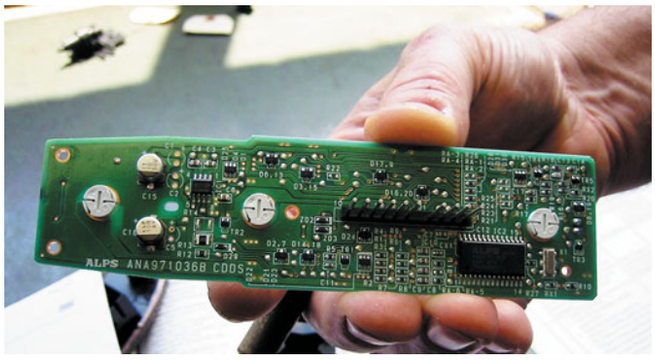


FIGURE 59–15 A master power window control panel with the buttons and the cover removed.

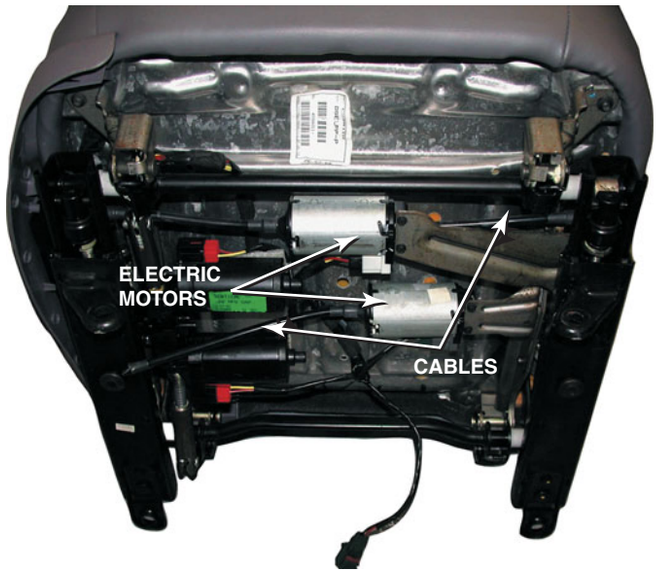


FIGURE 59–16 A power seat uses electric motors under the seat, which drive cables that extend to operate screw jacks (up and down) or gears to move the seat forward and back.

TECH TIP

Programming Auto Down Power Windows

Many vehicles are equipped with automatic operation that can cause the window to go all the way down (or up) if the switch is depressed beyond a certain point or held for a fraction of a second. Sometimes this feature is lost if the battery in the vehicle has been disconnected. Although this programming procedure can vary depending on the make and model, many times the window(s) can be reprogrammed without using a scan tool by simply depressing and holding the down button for 10 seconds. If the vehicle is equipped with an auto up feature, repeat the procedure by holding the button up for 10 seconds. Always check service information for the vehicle being serviced.

to follow. In a newer system, a scan tool can be used to perform the following:

- Check for B (body) or U (network) diagnostic trouble codes (DTCs)
- Operate the power windows using the bidirectional control feature
- Relearn or program the operation of the power windows after a battery disconnect

For older systems, if one of the **control wires** that run from the independent switch to the master switch is cut (open), the power window may operate in only one direction. The window may go down but not up, or vice versa. However, if one of the **direction wires** that run from the independent switch to the motor is cut (open), the window will not operate in either direction. The direction wires and the motor must be electrically connected to permit operation and change of direction of the electric lift motor in the door.

1. If *both* rear door windows fail to operate from the independent switches, check the operation of the window lockout (if the vehicle is so equipped) and the master control switch.
2. If one window can move in one direction only, check for continuity in the control wires (wires between the independent control switch and the master control switch).
3. If *all* windows fail to work or fail to work occasionally, check, clean, and tighten the ground wire(s) located either behind the driver's interior door panel or under the dash on the driver's side. A defective fuse or circuit breaker could also cause all the windows to fail to operate.
4. If one window fails to operate in both directions, the problem could be a defective window lift motor. The window could be stuck in the track of the door, which could cause the circuit breaker built into the motor to open the circuit to protect the wiring, switches, and motor from damage. To check for a stuck door glass, attempt to move (even slightly) the door glass up and down, forward and back, and side to side. If the window glass can move slightly in all directions, the power window motor should be able to at least move the glass.
5. Always refer to and follow service information when diagnosing power window circuits.

POWER SEATS

PARTS AND OPERATION A typical power-operated seat includes a reversible electric motor and a transmission assembly that may have three solenoids and six *drive cables* that turn the six seat adjusters. A six-way power seat offers seat movement forward and backward, plus seat cushion movement up and down at the front and the rear. The drive cables are similar to speedometer cables because they rotate inside a cable housing and connect the power output of the seat transmission to a gear or screw jack assembly that moves the seat. ● **SEE FIGURE 59–16.**

A **screw jack assembly** is often called a *gear nut.* It is used to move the front or back of the seat cushion up and down.

A **rubber coupling,** usually located between the electric motor and the transmission, and prevents electric motor damage in the event of a jammed seat. This coupling is designed to prevent motor damage.

Most power seats use a permanent magnet motor that can be reversed by simply reversing the polarity of the current sent to the motor by the seat switch. ● **SEE FIGURE 59–17.**

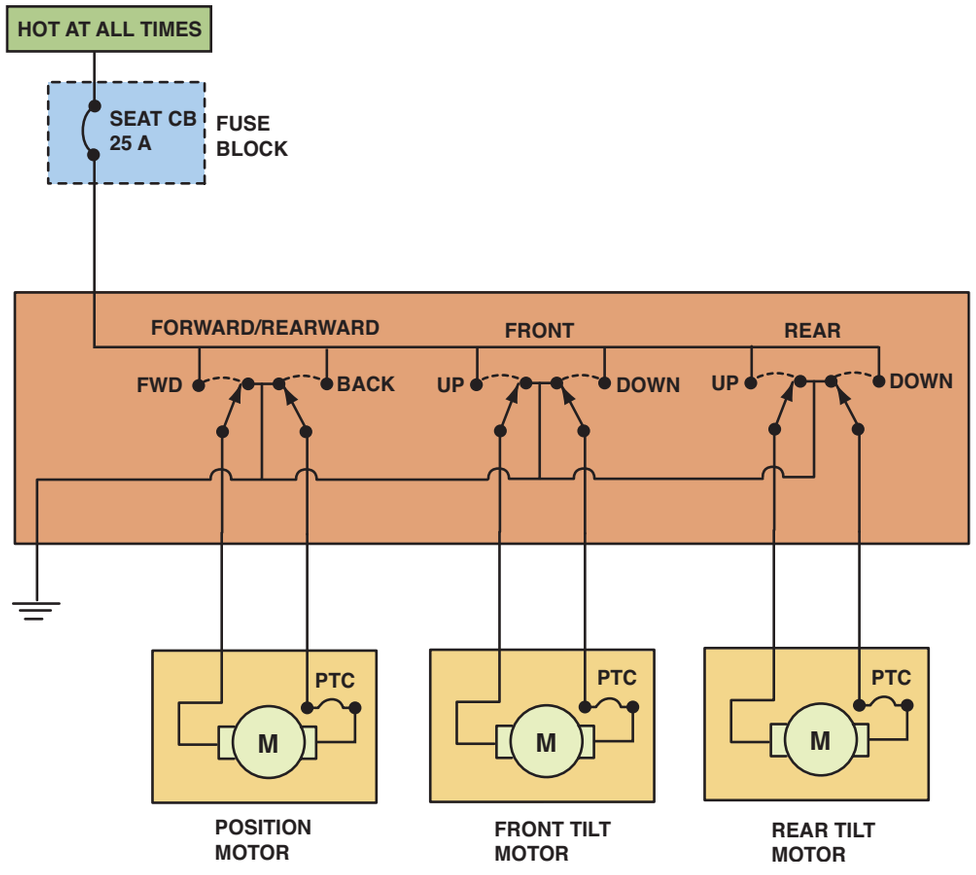


FIGURE 59–17 A typical power seat circuit diagram. Notice that each motor has a built-in electronic (solid-state) PTC circuit protector. The seat control switch can change the direction in which the motor(s) runs by reversing the direction in which the current flows through the motor.

POWER SEAT MOTOR(S) Most PM motors have a built-in circuit breaker or PTC circuit protector to protect the motor from overheating. Many Ford power seat motors use three separate armatures inside one large permanent magnet field housing. Some power seats use a series-wound electric motor with two separate field coils, one field coil for each direction of rotation. This type of power seat motor typically uses a relay to control the direction of current from the seat switch to the corresponding field coil of the seat motor. This type of power seat can be identified by the "click" heard when the seat switch is changed from up to down or front to back, or vice versa. The click is the sound of the relay switching the field coil current. Some power seats use as many as eight separate PM motors that operate all functions of the seat, including headrest height, seat length, and side bolsters, in addition to the usual six-way power seat functions.

NOTE: Some power seats use a small air pump to inflate a bag (or bags) in the lower part of the back of the seat, called the lumbar, because it supports the lumbar section of the spine. The lumbar section of the seat can also be changed, using a lever or knob that the driver can move to change the seat section for the lower back.

MEMORY SEAT Memory seats use a potentiometer to sense the position of the seat. The seat position can be programmed into the body control module (BCM) or memory seat module and stored by position number 1, 2, or 3. The driver pushes the desired button and the seat moves to the stored position. ● **SEE FIGURE 59–18** on page 668.

TECH TIP

Easy Exit Seat Programming

Some vehicles are equipped with memory seats that allow the seat to move rearward when the ignition is turned off to allow easy exit from the vehicle. Vehicles equipped with this feature include an *exit/entry* button that is used to program the desired exit/entry position of the seat for each of two drivers.

If the vehicle is not equipped with this feature and only one driver primarily uses the vehicle, the second memory position can be programmed for easy exit and entry. Simply set position 1 to the desired seat position and position 2 to the entry/exit position. Then, when exiting the vehicle, press memory 2 to allow easy exit and easy entry the next time. Press memory 1 when in the vehicle to return the seat memory to the desired driving position.

On some vehicles, the memory seat position is also programmed into the remote keyless entry key fob.

TROUBLESHOOTING POWER SEATS Power seats are usually wired from the fuse panel so they can be operated without having to turn the ignition switch to on (run). If a power seat does not

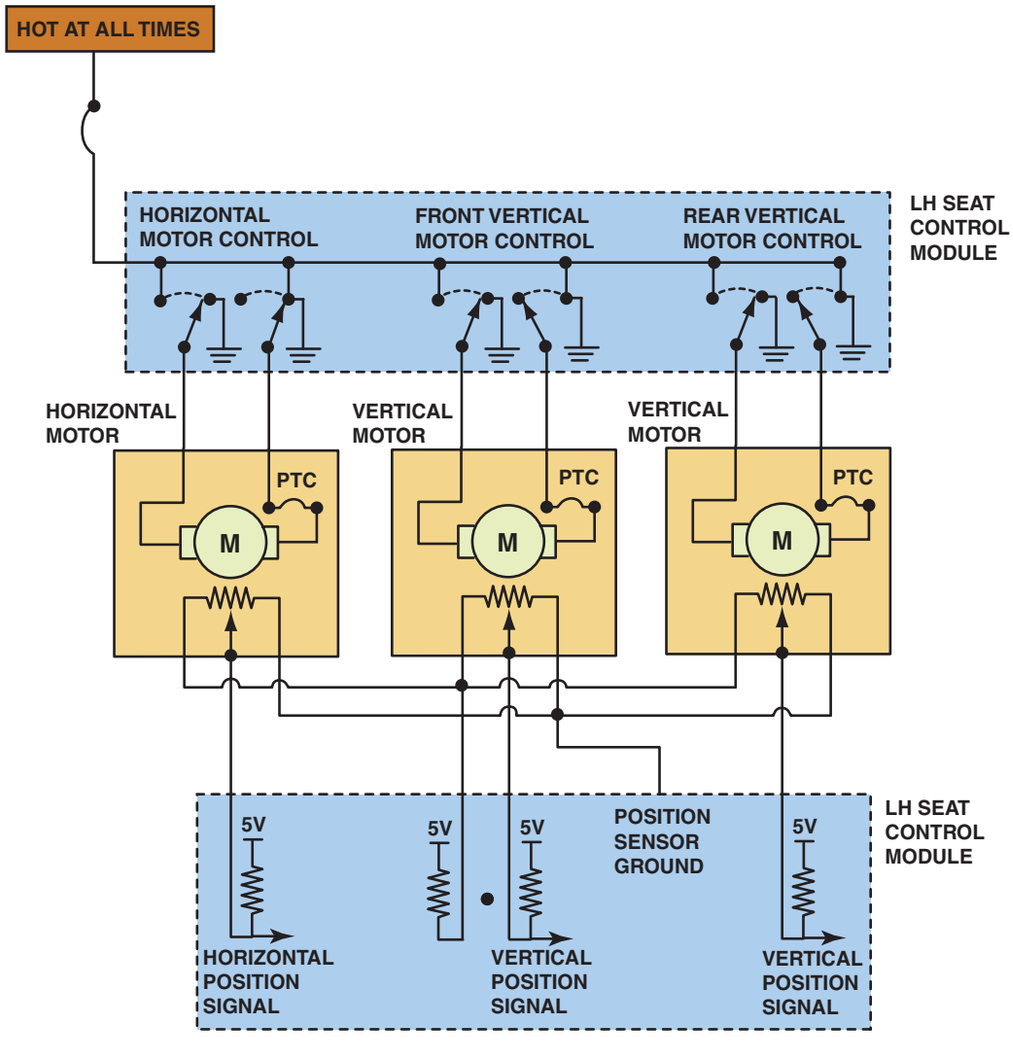


FIGURE 59–18 A typical memory seat module showing the three-wire potentiometer used to determine seat position.

TECH TIP

What Every Driver Should Know About Power Seats

Power seats use an electric motor or motors to move the position of the seat. These electric motors turn small cables that operate mechanisms that move the seat. *Never* place rags, newspapers, or any other object under a power seat. Even ice scrapers can get caught between moving parts of the seat and can often cause serious damage or jamming of the power seat.

operate or make any noise, the circuit breaker (or fuse, if the vehicle is so equipped) should be checked first. The steps usually include:

STEP 1 Check service information for the exact procedure to follow when diagnosing power seats. If the seat relay clicks, the circuit breaker is functioning, but the relay or electric motor may be defective.

STEP 2 Remove the screws or clips that retain the controls to the inner door panel or seat and check for voltage at the seat control.

STEP 3 Check the ground connection(s) at the transmission and clutch control solenoids (if equipped). The solenoids must be properly grounded to the vehicle body for the power seat circuit to operate.

If the power seat motor runs but does not move the seat, the most likely fault is a worn or defective rubber clutch sleeve between the electric seat motor and the transmission.

If the seat relay clicks but the seat motor does not operate, the problem is usually a defective seat motor or defective wiring between the motor and the relay. If the power seat uses a motor relay, the motor has a double reverse-wound field for reversing the motor direction. This type of electric motor must be properly grounded. Permanent magnet motors do not require grounding for operation.

NOTE: Power seats are often difficult to service because of restricted working room. If the entire seat cannot be removed from the vehicle because the track bolts are covered, attempt to remove the seat from the top of the power seat assembly. These bolts are almost always accessible regardless of seat position.

ELECTRICALLY HEATED SEATS

PARTS AND OPERATION Heated seats use electric heating elements in the seat bottom, as well as in the seat back in many vehicles. The heating element is designed to warm the seat and/or back of the seat to about 100°F (37°C) or close to normal



FIGURE 59–19 The heating element of a heated seat is a replaceable part, but service requires that the upholstery be removed. The yellow part is the seat foam material and the entire white cover is the replaceable heating element. This is then covered by the seat material.

body temperature (98.6°F). Many heated seats also include a high-position or a variable temperature setting, so the temperature of the seats can therefore be as high as 110°F (44°C).

A temperature sensor in the seat cushion is used to regulate the temperature. The sensor is a variable resistor which changes with temperature and is used as an input signal to a heated seat control module. The heated seat module uses the seat temperature input, as well as the input from the high-low (or variable) temperature control, to turn the current on or off to the heating element in the seat. Some vehicles are equipped with heated seats in both the rear and the front seats.

DIAGNOSIS AND SERVICE When diagnosing a heated seat concern, start by verifying that the switch is in the on position and that the temperature of the seat is below normal body temperature. Using service information, check for power and ground at the control module and to the heating element in the seat. Most vehicle manufacturers recommend replacing the entire heating element if it is defective. ● **SEE FIGURE 59–19.**

HEATED AND COOLED SEATS

PARTS AND OPERATION Most electrically heated and cooled seats use a **thermoelectric device (TED)** located under the seat cushion and seat back. The thermoelectric device consists of positive and negative connections between two ceramic plates. Each ceramic plate has copper fins to allow the transfer of heat to air passing over the device and directed into the seat cushion. The thermoelectric device uses the **Peltier effect,** named after the inventor, Jean C. A. Peltier, a French clockmaker. When electrical current flows through the module, one side is heated and the other side is cooled. Reversing the polarity of the current changes which side is heated. ● **SEE FIGURE 59–20.**

Most vehicles equipped with heated and cooled seats use two modules per seat, one for the seat cushion and one for the seat back. When the heated and cooled seats are turned on, air is forced through a filter and then through the thermoelectric modules. The air is then directed through passages in the foam of the seat cushion and seat back. Each thermoelectric device has a temperature sensor, called a thermistor. The control module uses sensors to determine the temperature of the fins in the thermoelectric device so the controller can maintain the set temperature.

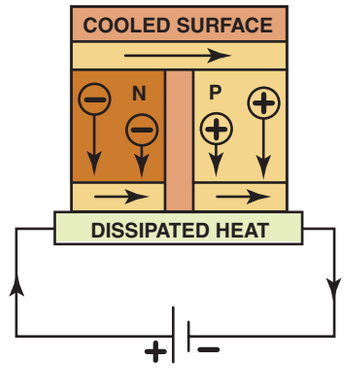


FIGURE 59–20 A Peltier effect device is capable of heating or cooling, depending on the polarity of the applied current.

TECH TIP

Check the Seat Filter

Heated and cooled seats often use a filter to trap dirt and debris to help keep the air passages clean. If a customer complains of a slow heating or cooling of the seat, check the air filter and replace or clean as necessary. Check service information for the exact location of the seat filter and for instructions on how to remove and/or replace it.

DIAGNOSIS AND SERVICE The first step in any diagnosis is to verify that the heated-cooled seat system is not functioning. Check the owner's manual or service information for the specified procedures. If the system works partially, check the air filter, usually located under the seat for each thermoelectric device. A partially clogged filter can restrict airflow and reduce the heating or cooling effect. If the system control indicator light is not on or the system does not work at all, check for power and ground at the thermoelectric devices. Always follow the vehicle manufacturer's recommended diagnosis and service procedures.

HEATED STEERING WHEEL

PARTS INVOLVED A heated steering wheel usually consists of the following components.

- Steering wheel with a built-in heater in the rim
- Heated steering wheel control switch
- Heated steering wheel control module

OPERATION When the steering wheel heater control switch is turned on, a signal is sent to the control module and electrical current flows through the heating element in the rim of the steering wheel. ● **SEE FIGURE 59–21.**



FIGURE 59–21 The heated steering wheel is controlled by a switch on the steering wheel in this vehicle.

The system remains on until the ignition switch is turned off or the driver turns off the control switch. The temperature of the steering wheel is usually calibrated to stay at about 90°F (32°C), and it requires three to four minutes to reach that temperature depending on the outside temperature.

DIAGNOSIS AND SERVICE Diagnosis of a heated steering wheel starts with verifying that the heated steering wheel is not working as designed.

NOTE: Most heated steering wheels do not work if the temperature inside the vehicle is about 90°F (32°C) or higher.

If the heated steering wheel is not working, follow the service information testing procedures which would include a check of the following:

1. Check the heated steering wheel control switch for proper operation. This is usually done by checking for voltage at both terminals of the switch. If voltage is available at only one of the two terminals of the switch and the switch has been turned on and off, an open (defective) switch is indicated.
2. Check for voltage and ground at the terminals leading to the heating element. If voltage is available at the heating element and the ground has less than 0.2 volt drop to a good chassis ground, the heating element is defective. The entire steering wheel has to be replaced if the element is defective.

Always follow the vehicle manufacturer's recommended diagnosis and testing procedures.

ADJUSTABLE PEDALS

PURPOSE AND FUNCTION **Adjustable pedals,** also called **electric adjustable pedals (EAP),** place the brake pedal and the accelerator pedal on movable brackets that are motor operated. A typical adjustable pedal system includes the following components.

- **Adjustable pedal position switch.** Allows the driver to position the pedals
- **Adjustable pedal assembly.** Includes the motor, threaded adjustment rods, and a pedal position sensor

SEE FIGURE 59–22.

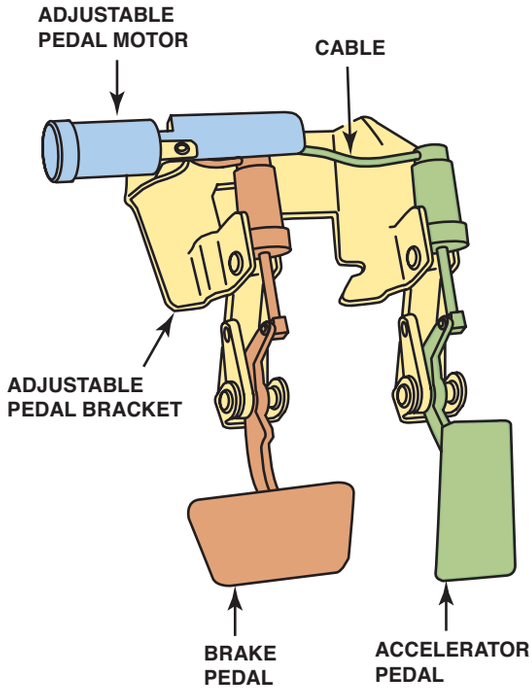


FIGURE 59–22 A typical adjustable pedal assembly. Both the accelerator and the brake pedal can be moved forward and rearward by using the adjustable pedal position switch.

TECH TIP

Check the Remote

The memory function may be programmed to a particular key fob remote, which would command the adjustable pedals to move to the position set in memory. Always check both remote settings before attempting to repair a problem that may not be a problem.

The position of the pedals, as well as the position of the seat system, is usually included as part of the memory seat function and can be set for two or more drivers.

DIAGNOSIS AND SERVICE The first step when there is a customer concern about the functioning of the adjustable pedals is to verify that the unit is not working as designed. Check the owner manual or service information for the proper operation. Follow the vehicle manufacturer's recommended troubleshooting procedure. Many diagnostic procedures include the use of a factory scan tool with bidirectional control capabilities to test this system.

OUTSIDE FOLDING MIRRORS

Mirrors that can be electrically folded inward are a popular feature, especially on larger sport utility vehicles. A control inside is used to fold both mirrors inward when needed, such as when entering a garage or close parking spot. For diagnosis and servicing of outside folding mirrors, check service information for details.



FIGURE 59–23 Electrically folded mirror in the folded position.

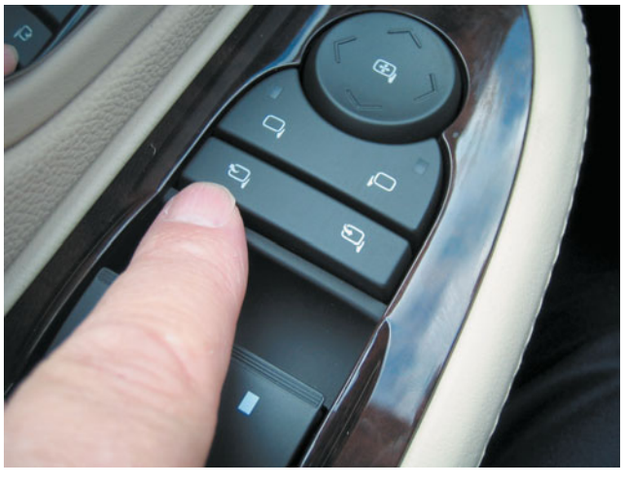


FIGURE 59–24 The electric mirror control is located on the driver's side door panel on this Cadillac Escalade.

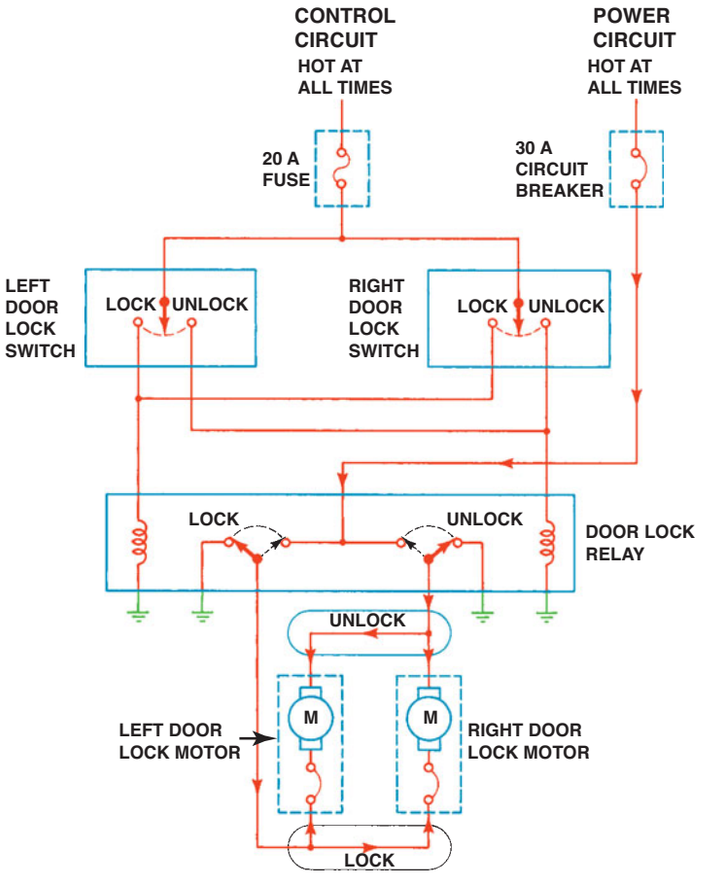


FIGURE 59–25 A typical electric power door lock circuit diagram. Note that the control circuit is protected by a fuse, whereas the power circuit is protected by a circuit breaker. As with the operation of power windows, power door locks typically use reversible permanent magnet (PM) nongrounded electric motors. These motors are geared mechanically to the lock-unlock mechanism.

REAL WORLD FIX

The Case of the Haunted Mirrors

The owner complained that while driving, either one or the other outside mirror would fold in without any button being depressed. Unable to verify the customer concern, the service technician looked at the owner's manual to find out exactly how the mirrors were supposed to work. In the manual, a caution statement said that if the mirror is electrically folded inward and then manually pushed out, the mirror will not lock into position. The power folding mirrors must be electrically cycled outward, using the mirror switches to lock them in position. After cycling both mirrors inward and outward electrically, the problem was solved. ● **SEE FIGURES 59–23 AND 59–24.**

ELECTRIC POWER DOOR LOCKS

Electric power door locks use a permanent magnet (PM) reversible motor to lock or unlock all vehicle door locks from a control switch or switches.

The electric motor uses a built-in circuit breaker and operates the lock-activating rod. PM reversible motors do not require grounding because, as with power windows, the motor control is determined by the polarity of the current through the two motor wires. ● **SEE FIGURE 59–25.**

Some two-door vehicles do *not* use a power door lock relay because the current flow for only two PM motors can be handled through the door lock switches. However, most four-door vehicles and vans with power locks on rear and side doors use a relay to control the current flow necessary to operate four or more power door lock motors. The door lock relay is controlled by the door lock switch and is commonly the location of the one and only *ground* connection for the entire door lock circuit.

KEYLESS ENTRY

Even though some Ford vehicles use a keypad located on the outside of the door, most keyless entry systems use a wireless transmitter built into the key or key fob. A **key fob** is a decorative tab or item on a key chain. ● **SEE FIGURE 59–26.**

The transmitter broadcasts a signal that is received by the electronic control module, which is generally mounted in the trunk or under the instrument panel. ● **SEE FIGURE 59–27.**

The electronic control unit sends a voltage signal to the door lock actuator(s) located in the doors. Generally, if the transmitter unlock button is depressed once, only the driver's door is unlocked. If the unlock button is depressed twice, then all doors unlock.

ROLLING CODE RESET PROCEDURE Many keyless remote systems use a rolling code type of transmitter and receiver. In a conventional system, the transmitter emits a certain fixed frequency, which is received by the vehicle control module. This single frequency can be intercepted and rebroadcast to open the vehicle.

A rolling code type of transmitter emits a different frequency every time the transmitter button is depressed and then rolls over to another frequency so that it cannot be intercepted. Both the transmitter and the receiver must be kept in synchronized order so that the remote will function correctly.

If the transmitter is depressed when it is out of range from the vehicle, the proper frequency may not be recognized by the receiver, which did not roll over to the new frequency when the transmitter was depressed. If the transmitter does not work, try to resynchronize the transmitter to the receiver by depressing and holding both the lock and the unlock button for 10 seconds when within range of the receiver.



FIGURE 59–26 A key fob remote with the cover removed showing the replaceable battery.

KEYLESS ENTRY DIAGNOSIS A small battery powers the transmitter, and a weak battery is a common cause of remote power locks failing to operate. If the keyless entry system fails to operate after the transmitter battery has been replaced, check the following items.

- Mechanical binding in the door lock
- Low vehicle battery voltage
- Blown fuse
- Open circuit to the control module
- Defective control module
- Defective transmitter

PROGRAMMING A NEW REMOTE If a new or additional remote transmitter is to be used, it must be programmed to the vehicle. The programming procedure varies and may require the use of a scan tool. Check service information for the exact procedure to follow. ● **SEE CHART 59–1.**

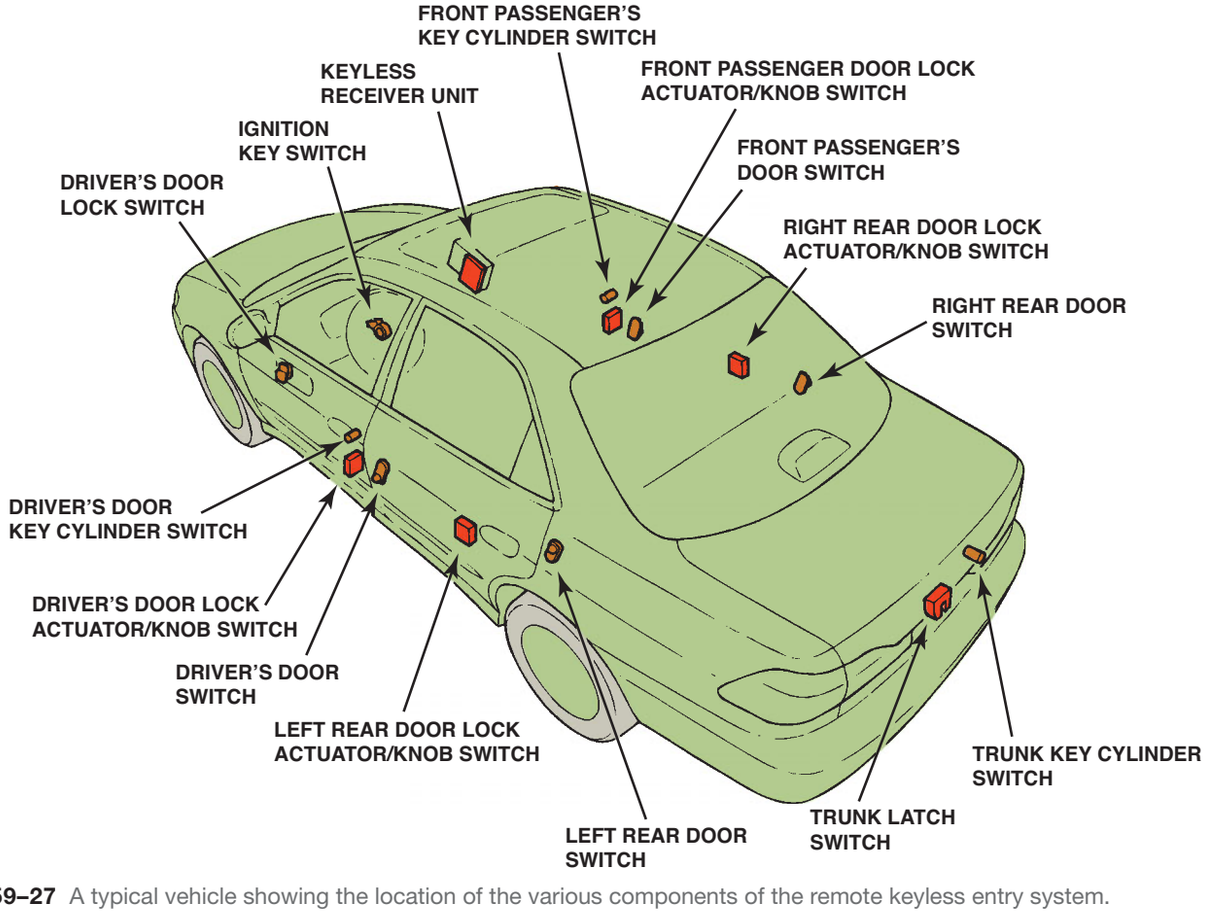


FIGURE 59–27 A typical vehicle showing the location of the various components of the remote keyless entry system.

MAKE/MODEL	NOTES	PROCEDURE
Acura RSX MDX 3.2TL RSX **Honda** Accord Civic CR-V Odyssey	Be careful to maintain the time limits between steps. Ensure that the hood, tailgate, and doors are closed. Aim the transmitter at the receiver in the power window master switch. The keyless receiver can store up to three codes. If a fourth code is stored, the first code that was input will be erased.	1. Turn the ignition on. 2. Within 1 to 4 seconds, press the lock or unlock button. 3. Within 1 to 4 seconds, turn the ignition off. 4. Repeat steps 1 through 3 two more times. 5. Within 1 to 4 seconds, turn the ignition on (fourth time). 6. Within 1 to 4 seconds, press the lock or unlock button. 7. The door lock actuators should cycle. 8. Press the lock or unlock button a second time within 1 to 4 seconds to store the code. 9. For additional transmitters, repeat steps 6, 7, and 8. 10. Turn the ignition off and remove the key to exit programming mode.
BMW All models with transmitter in key head	Up to four transmitters can be programmed. All transmitters to be programmed must be programmed at the same time. This procedure erases all learned transmitters.	1. Use the vehicle key to unlock the central locking system. 2. Enter the vehicle and close all doors. 3. Put the key in the ignition and switch the ignition switch to position 1 and then back to off, within 5 seconds. 4. Press and hold key button 2 (arrow button). 5. While holding button 2, press button 1 (BMW logo) three times within 10 seconds. 6. Release button 2. 7. The locks will cycle to confirm programming. 8. Repeat steps 4 through 7 within 30 seconds for any additional transmitters. 9. After 30 seconds with no button pressed the programming mode will exit.
Buick Rendezvous Lucerne LaCrosse **Chevrolet** Blazer Impala Monte Carlo Uplander **Pontiac** Grand Prix Montana **Saturn** Relay	A scan tool is required. A total of four transmitters can be learned. All transmitters to be programmed must be programmed at the same time. Activating program mode erases previously learned codes.	1. Install a scan tool and access the BCM Special Functions, Lift Gate Module (LGM), or Module Setup; Program Key Fobs menu. 2. Press the start key on the scan tool. 3. Press and hold both the lock and unlock buttons on the first transmitter. Within 5 to 10 seconds the scan tool will report that the transmitter is programmed. 4. Repeat step 3 to program up to four transmitters. 5. Turn off and remove the scan tool to exit programming mode.
Buick Rainier **Cadillac** Escalade **Chevrolet** C/K Trucks Suburban Tahoe Trailblazer **Saab** 9-7 (some)	Fobs can also be programmed with a scan tool. All fobs to be used must be programmed at the same time. The first fob learned will be fob 1 and the second that is learned will be fob 2.	1. Enter the vehicle and close all the doors. 2. Insert the key into the ignition lock. 3. Press and hold the door unlock switch, then turn the ignition on, off, then release the unlock switch. 4. The door locks will cycle one time to confirm programming mode. 5. Press and hold the lock and unlock buttons on the key fob for about 15 seconds. 6. The locks will cycle once when the fob has been learned. 7. Repeat steps 5 and 6 to program any additional fobs. 8. Turn the ignition key to run, to exit the programming mode.

CHART 59–1 ***(CONTINUED)***

Remote keyless programming steps for popular vehicles. Procedures may also apply to similar vehicles by the same manufacturer. Always refer to service information for specific vehicles.

MAKE/MODEL	NOTES	PROCEDURE
Cadillac CTS SRX	All programmed key fobs will be erased. All transmitters to be programmed must be relearned during this procedure. Up to four fobs can be programmed. The first to be learned will be fob 1 and the second to be learned will be fob 2.	1. Install the scan tool and turn the ignition on. 2. Navigate to the Body, RFA (or RCDLR), Special Functions; Program Key Fobs menu. 3. Follow the directions on the scan tool to program the transmitters.
Cadillac Deville Seville **Pontiac** Bonneville Grand Am	Up to four transmitters can be programmed. All fobs to be used must be programmed at the same time. The first fob learned will be fob 1 and the second that is learned will be fob 2.	1. Install a scan tool and turn on the ignition. 2. Navigate to the Remote Function Actuator (RFA) module: Special function, Program Key Fobs menu to activate program mode. 3. The doors will lock and unlock to indicate programming mode. 4. Press and hold the lock and unlock buttons on the fob. The door locks will cycle to indicate the fob has been learned. 5. Repeat step 4 for any additional fobs. 6. To exit programming mode, turn off and remove the scan tool.
Cadillac STS XLR **Chevrolet** Corvette	A scan tool can also be used to program key fobs. This procedure will take 30 minutes to complete. All programmed key fobs will be erased. All transmitters to be programmed must be relearned during this procedure. Up to four fobs can be programmed. The first to be learned will be fob 1 and the second to be learned will be fob 2.	1. Start with the vehicle off. 2. Place the fob to be learned in the console pocket with the buttons facing forward. 3. Insert the vehicle key into the driver's door lock cylinder and cycle the key five times within 5 seconds. The DIC will display "OFF/ACC TO LEARN." 4. Press the OFF/ACC part of the ignition button. 5. The DIC will display "WAIT 10 MINUTES," then count down to zero, 1 minute at a time. The display will change to "OFF/ACC TO LEARN." 6. Repeat steps 4 and 5 two more times for a total of 30 minutes. 7. When the DIC displays "OFF/ACC TO LEARN" for the fourth time, press the OFF/ACC button again; the DIC will display "READY FOR FOB 1." 8. When fob 1 has been learned, a beep will be heard and the DIC will display "READY FOR FOB 2." 9. Remove fob 1 from the pocket and insert fob 2. A beep will be heard when that fob has been learned. 10. Repeat steps 8 and 9 for additional fobs. 11. To exit programming, press the OFF/ACC portion of the ignition button.
Chevrolet Cavalier Equinox Malibu SSR S/T Trucks **Saab** 9–7 (some models) **Saturn** Vue	A scan tool is required. Up to four transmitters can be programmed. On vehicles with personalization features, the transmitters are numbered 1 and 2. The first transmitter programmed will become driver 1 and the second will become driver 2.	1. Install the scan tool and navigate to the BCM or RFA menu, Special Functions; select Program Key Fobs. 2. Select Add/Replace Key Fob to program a new or additional fob. 3. Select Clear Memory and Program All Fobs option to replace all fobs or to recode driver 1 and driver 2 fobs. 4. Follow the scan tool instructions to complete the programming.
Chevrolet Venture van GM "U" vans	All fobs to be used must be programmed at the same time. Up to four transmitters can be programmed. If the BCM displays DTCs in step 5, they may have to be resolved before programming can continue.	1. With the ignition key out of the ignition, remove the BCM PRGRM fuse from the passenger side fuse block. 2. Enter the vehicle and close all doors. 3. Insert the key and turn the ignition to ACC. 4. The seat belt indicator and chime will activate two, three, or four times, depending on the type of BCM in the vehicle. 5. Turn the key off and then back to ACC within 1 second. If the BCM has any stored DTCs, they will be displayed by the chime and belt indicator at this time. 6. Open and close any door. The chime will sound to indicate programming mode. 7. Press and hold the fob lock and unlock buttons for about 14 seconds. The BCM will sound the chime when the fob has been learned. 8. Repeat step 7 for up to four total transmitters. 9. After programming, remove the ignition key and replace the BCM PRGRM fuse.

CHART 59–1

Remote keyless programming steps for popular vehicles. Procedures may also apply to similar vehicles by the same manufacturer. Always refer to service information for specific vehicles.

MAKE/MODEL	NOTES	PROCEDURE
Chrysler PT Cruiser Concorde	A scan tool is required if there are no functioning transmitters. Maximum of four transmitters can be programmed. Programming mode will exit after 30 seconds.	1. Turn ignition to run and wait until the chimes stop or fasten seat belt to cancel chimes. 2. Using any original working transmitter, press and hold the unlock button for 4 to 10 seconds. 3. While holding the unlock button, press the panic button for 1 second. Chime will sound to indicate programming mode is ready. 4. Press and release any button on the transmitters to be programmed. All transmitters should be programmed at this time, including previously programmed transmitters. A chime will sound after each programming success. 5. Turn the ignition off to exit programming.
Chrysler Sebring Town and Country **Dodge** Pickup R1500 Stratus R/T Caravan Dakota Durango	Programming is by scan tool or by "customer learn" mode. If no functioning transmitter is available the scan tool must be used. Programming mode will cancel 60 seconds after the chimes stop in step 3. All programming must be completed within this time period.	CUSTOMER LEARN MODE 1. Turn ignition to run and wait until the chimes stop or fasten seat belt to cancel chimes. 2. Using any original working transmitter, press and hold the unlock button for 4 to 10 seconds. 3. While holding the unlock button, press the panic button for 1 second. Chime will sound for 3 seconds to indicate programming mode is ready. 4. Press lock and unlock buttons together for 1 second and release.
Jeep Liberty	Up to four transmitters can be stored.	1. Press and release any button on the same transmitter. If the code is successfully learned, the chime will sound. 2. To program additional transmitters, repeat steps 4 and 5. 3. Turn ignition off.
Ford Focus	Maximum of four transmitters can be programmed. All transmitters must be programmed at the same time. Programming mode will exit if: • The engine is started. • The 10 second time expires. • Four transmitters are programmed.	1. Enter vehicle. Close all doors. 2. Turn ignition switch from ACC to run, four times within 6 seconds. 3. Turn ignition switch to off. 4. Chime will sound to indicate ready to program. 5. Within 10 seconds press any button on the transmitter. A chime will indicate code accepted. 6. To program additional transmitters repeat step 5.
Ford F150 Pickup Explorer Taurus Escape Expedition Excursion Ranger **Lincoln** Navigator **Mazda** B2300 **Mercury** Mountaineer Mariner	All transmitters must be programmed at the same time. RKE transmitters can also be programmed using a scan tool. Programming mode will exit if: • The key is turned off. • The 20 second time expires. • The maximum number of transmitters are programmed (depends on vehicle).	1. Electrically unlock the doors using the RKE transmitter of door lock switch. 2. Turn the key from off to run, eight times within 10 seconds, ending with the key on. The module will lock and unlock the doors, indicating program mode. 3. Within 20 seconds press any button on the transmitter. The locks will cycle to indicate the transmitter has been learned. 4. Repeat step 3 for any additional RKE transmitters. 5. Turn the key off to exit the programming mode.

CHART 59–1 ***(CONTINUED)***

Continued

MAKE/MODEL	NOTES	PROCEDURE
Infiniti G20 G35 FX35 Q45	Key fob codes can be checked and changed using a scan tool. If step 2 is done too fast, the system will not enter programming mode. Up to five key fobs can be registered. If more than five are input, the oldest ID code will be overwritten. It is possible to enter the same key code into all five memories. This can be used to erase the ID code of a fob that has been lost, if needed.	1. Enter the vehicle and close all doors. 2. Insert and then completely remove key from the ignition cylinder more than six times within 10 seconds. Hazard warning lamps will flash twice to indicate programming mode is active. 3. Insert the key and turn the ignition to ACC. 4. Press any key on the fob once. The hazard warning lamps will flash twice to indicate that the code is stored. 5. To end programming mode open the driver's door. If programming additional fobs proceed to step 6 (don't open the driver's door). 6. To enter an additional code unlock and then lock the driver's door using the window main switch. 7. Press any button on the additional fob. The hazard warning lamps will flash twice to indicate the code is learned. 8. To enter another key fob code repeat steps 6 and 7. 9. Open the driver's door to end programming mode.
Lincoln Town Car Continental Navigator **Mercury** Grand Marquis	All RKE transmitters must be programmed at the same time. RKE transmitters can also be programmed using a scan tool. Additional transmitters must be programmed within 7 seconds or the process will have to be repeated from step 1. Wait at least 20 seconds after exiting programming mode to test the RKE transmitters.	1. Turn the key from off to run, eight times (four times for early systems) within 10 seconds, ending with the key on. The module will lock and unlock the doors, indicating program mode. 2. Press any button on the transmitter. Doors will lock and unlock to confirm programming success. 3. To program additional repeat step 2 within 7 seconds. 4. Wait 7 seconds or turn the key off to exit programming mode.
Mazda 5 6	Start with the key out and all doors, trunk lid, and lift gate closed. A total of three transmitters can be programmed. Previously programmed transmitters may be erased during this procedure. If possible, program all desired transmitters at the same time.	1. Open the driver's side door. 2. Put the key in the ignition lock and turn the ignition to on and back to lock, three times (ending in the lock position with the key in the ignition). 3. Close and then open the driver's door three times, ending with the door open. The door locks will lock and unlock. 4. Push the unlock button on the transmitter twice. Door locks will lock and unlock to verify programming is okay. 5. Repeat step 4 for any additional transmitter to be programmed. 6. When the last transmitter to be programmed has been learned, push the unlock button twice on that transmitter to exit programming mode.
Mazda 626 Millenia Protégé	Start with the key out and all doors, trunk lid, and lift gate closed. A total of three transmitters can be programmed. Previously programmed transmitters may be erased during this procedure. If possible, program all desired transmitters at the same time. Protégé will cycle locks instead of sounding a buzzer.	1. Open the driver's side door. 2. Put the key in the ignition lock and turn the ignition to on and back to lock, three times, then remove the key. 3. Close and then open the driver's door three times, ending with the door open. A buzzer will sound from the CPU. 4. Push any button on the transmitter twice. Buzzer will sound once to verify programming is okay. 5. Repeat step 4 for any additional transmitter to be programmed. 6. When the last transmitter to be programmed has been learned, push any button twice on that transmitter. The buzzer will sound twice to exit programming mode.

CHART 59–1

Remote keyless programming steps for popular vehicles. Procedures may also apply to similar vehicles by the same manufacturer. Always refer to service information for specific vehicles.

MAKE/MODEL	NOTES	PROCEDURE
Nissan Altima Armada Frontier Maxima Murano Titan	Key fob codes can also be checked and changed using a scan tool. If step 2 is done too fast, the system will not enter programming mode. Up to five key fobs can be registered. If more than five are input, the oldest ID code will be overwritten. It is possible to enter the same key code into all five memories. This can be used to erase the ID code of a fob that has been lost, if needed.	1. Enter the vehicle and close all doors. 2. Insert and then completely remove key from the ignition cylinder more than six times within 10 seconds. Hazard warning lamps will flash twice to indicate programming mode is active. 3. Insert the key and turn the ignition to ACC. 4. Press any key on the fob once. The hazard warning lamps will flash twice to indicate that the code is stored. 5. To end programming mode, open the driver's door. If programming additional fobs proceed to step 6 (don't open the driver's door). 6. To enter an additional code unlock and then lock the driver's door using the window main switch. 7. Press any button on the additional fob. The hazard warning lamps will flash twice to indicate the code is learned. 8. To enter another key fob code repeat steps 6 and 7. 9. Open the driver's door to end programming mode.
Pontiac Vibe **Scion** xB **Toyota** Camry Corolla	Up to four transmitters can be programmed. If more than four transmitters are programmed, the oldest transmitter code will be overwritten. There are four programming modes: • Add mode: Used to program additional transmitters • Rewrite mode: Erases all previously programmed transmitters • Confirmation mode: Indicates how many transmitters are already programmed • Prohibition mode: Erases all learned codes and disables the wireless entry system In confirmation mode, if no codes are stored the door locks will cycle five times. Open any door to exit the programming mode.	1. Enter the vehicle, key out of ignition, close all doors except the driver's door. 2. Insert and remove the key from the ignition twice within 5 seconds. 3. Close and open the driver's door twice within 40 seconds and then insert the key and remove it. 4. Close and open the driver's door twice again, then insert the ignition key and close the door. 5. Turn the key from lock to on and back to lock to select the programming mode: • One time for add mode (go to step 6) • Two times for rewrite mode (go to step 6) • Three times for confirmation mode (go to step 10) • Five times for prohibition mode (see step 11) 6. Remove the key from the ignition. 7. The doors will lock-unlock once for add mode or twice for rewrite mode. 8. To program a transmitter, press lock and unlock buttons for 1.5 seconds and release; then within 3 seconds press either button for more than 1 second to confirm programming: • One lock-unlock cycle indicates okay. • Two lock-unlock cycles indicates not okay; repeat this step. 9. Repeat step 8 to program additional transmitters. 10. In confirmation mode the number of lock-unlock cycles will indicate the number of codes already stored and programming mode will exit. Example: Two cycles indicates two codes are stored. 11. If prohibition mode is selected the locks will cycle five times and programming mode will exit.
Pontiac G6 **Saturn** Ion L300	A scan tool is used to program key fobs. Up to four transmitters can be programmed. If any key fob is programmed, all fobs must be programmed at the same time. On vehicles with personalization features, the transmitters are numbered 1 and 2. The first transmitter programmed will become driver 1 and the second will become driver 2.	1. Install the scan tool and navigate to the Program Key Fobs menu. 2. Select the number of fobs to be programmed. 3. Press and hold the lock and unlock buttons on the first fob to be programmed. The locks should cycle to indicate okay. NOTE: This fob becomes driver 1 key fob. 4. Repeat step 3 for the second fob. This fob becomes driver 2 key fob. 5. Repeat step 3 for any other key fobs to be programmed. 6. Turn off and remove the scan tool to exit programming.

CHART 59–1 ***(CONTINUED)***

Continued

MAKE/MODEL	NOTES	PROCEDURE
Saab 9-2	Up to four transmitters can be programmed.	1. Sit in the driver's seat and close all doors. 2. Open and close the driver's door. 3. Turn the ignition switch from on to lock, 10 times within 15 seconds. The horn will chirp to indicate programming mode. 4. Open and close the driver's door. 5. Press any button on the fob to be programmed. 6. The horn will chirp two times to indicate that the transmitter has been learned. 7. Repeat steps 4, 5, and 6 for any additional transmitters. 8. To exit from programming mode remove the key from the ignition. The horn should chirp three times to confirm.
Subaru Forester Impreza Legacy Outback Tribeca	A scan tool is used to program RKE codes. Up to four RKE transmitters can be registered. The eight-digit code is on the plastic bag of a new transmitter on the circuit board inside the transmitter.	1. Install the scan tool and navigate to the keyless transmitter ID registration menu. 2. Input the transmitter eight-digit ID number into the scan tool. 3. When the number is correct, press yes. 4. The scan tool will display "ID registration done" when the ID is programmed. 5. Follow the scan tool menus to program additional transmitters.
Toyota Tundra Sequoia **Lexus** GS 430 RX 300	Up to four transmitters can be programmed. If more than four transmitters are programmed, the oldest transmitter code will be overwritten. There are four programming modes: • Add mode: Used to program additional transmitters • Rewrite mode: Erases all previously programmed transmitters • Confirmation mode: Indicates how many transmitters are already programmed • Prohibition mode: Erases all learned codes and disables the wireless entry system In confirmation mode, if no codes are stored the door locks will cycle five times. Open any door to exit the programming mode.	1. Enter the vehicle, key out of ignition, close all doors except the driver's door. 2. Insert and remove the key from the ignition key cylinder. 3. Use the driver's door lock control switch to lock and unlock the doors five times, at about 1 second intervals. 4. Close and open the driver's door. 5. Use the driver's door lock control switch to lock and unlock the doors five times, at about 1 second intervals. 6. Insert the ignition key. 7. Turn the key from lock to on and back to lock to select the programming mode: • One time for add mode (go to step 10) • Two times for rewrite mode (go to step 10) • Three times for confirmation mode (go to step 12) • Five times for prohibition mode (see step 13) 8. Remove the key from the ignition. 9. The doors will lock-unlock once, twice, three times of five times to confirm the mode. 10. To program a transmitter press lock and unlock buttons for 1.5 seconds and release; then within 3 seconds press either button for more than 1 second to confirm programming: One lock-unlock cycle indicates okay. Two lock-unlock cycles indicates not okay; repeat this step. 11. Repeat step 10 to program additional transmitters. 12. In confirmation mode the number of lock-unlock cycles will indicate the number of codes already stored and programming mode will exit. Example: Two cycles indicates two codes are stored. 13. If prohibition mode is selected the locks will cycle five times and programming mode will exit.

CHART 59–1

Remote keyless programming steps for popular vehicles. Procedures may also apply to similar vehicles by the same manufacturer. Always refer to service information for specific vehicles.

ANTITHEFT SYSTEMS

PARTS AND OPERATION Antitheft devices flash lights or sound an alarm if the vehicle is broken into or vandalized. In addition to the alarm, some systems prevent the engine from starting by disabling the starter, ignition, or fuel system once the antitheft device is activated. Others permit the engine to start, but then disable it after several seconds. Switches in the doorjambs, trunk, and hood provide an input signal to the control module should an undesirable entry occur on a typical system. Some antitheft systems are more complex and also have electronic sensors that trigger the alarm if there is a change in battery current draw, a violent vehicle motion, or if glass is broken. These sensors also provide an input signal to the control module, which may be a separate antitheft

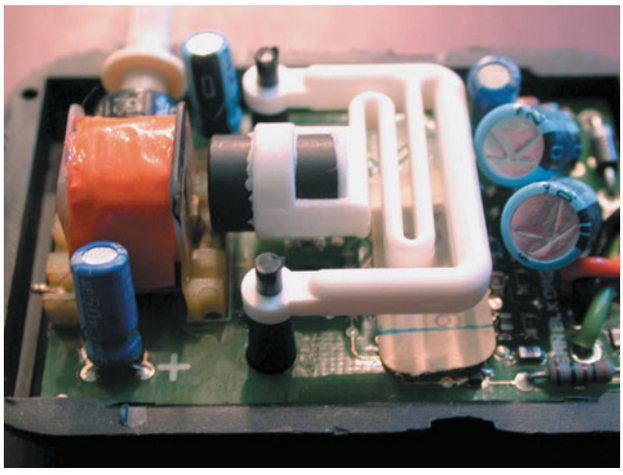


FIGURE 59–28 A shock sensor used in alarm and antitheft systems. If the vehicle is moved, the magnet will move relative to the coil, inducing a small voltage that will trigger the alarm.

unit or incorporated into the PCM or BCM. ● **SEE FIGURE 59–28** on page 360 for an example of a shock sensor used in an antitheft alarm system.

ANTITHEFT SYSTEM DIAGNOSIS

Most factory-installed antitheft systems are integrated with several other circuits to form a complex, multiple-circuit system. The major steps are as follows:

1. It is essential to have accurate diagrams, specifications, and test procedures for the specific model being serviced.
2. The easiest way to reduce circuit complexity is to use the wiring diagram to break the entire system into its subcircuits, then check only those related to the problem.
3. If any step indicates that a subcircuit is not complete, check the power source, ground, components, and wiring in that subcircuit.

Many systems use a computer chip in the plastic part of the key. Most systems are electronically regulated and have a self-diagnostic program. This self-diagnostic program is generally accessed and activated using a scan tool. Diagnostic and test procedures are similar as for any of the other electronic control systems used on the vehicle.

ANTITHEFT SYSTEM TESTING AND SERVICE

Before performing any diagnostic checks, make sure that all of the following electrical devices function correctly.

- Parking and low-beam headlights
- Dome and courtesy lights
- Horn
- Electric door locks

Circuit information from these devices often provides basic inputs to the control module. If a problem is detected in any of these circuits, such as a missing signal or a signal that is out of range, the control module disables the antitheft system and may record a diagnostic trouble code (DTC).

If all of the previously mentioned devices are operational, check all the circuits leading to the antitheft control module. Make

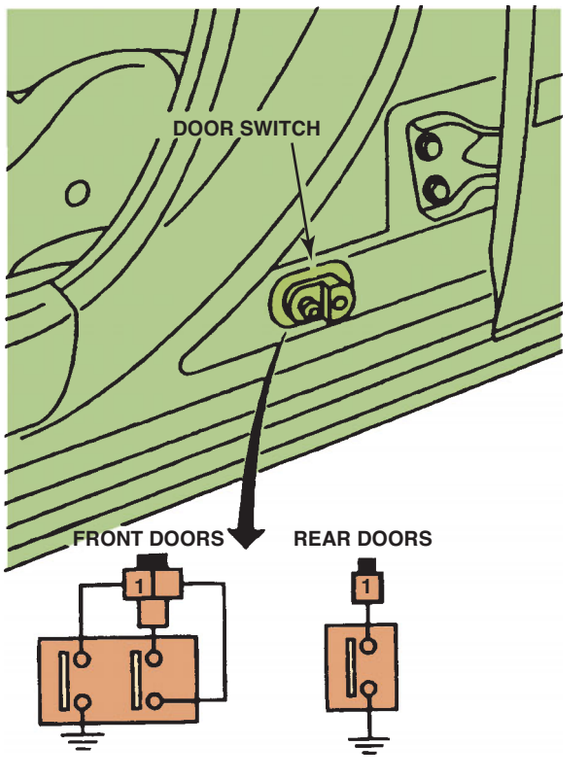


FIGURE 59–29 Door switches, which complete the ground circuit with the door open, are a common source of high resistance.



FIGURE 59–30 A special tool is needed to diagnose a General Motors VATS security system and special keys that contain a resistor pellet.

sure all switches are in their normal or off positions. Doorjamb switches complete the ground circuit when a door is opened. ● **SEE FIGURE 59–29.**

Frequently, corrosion that builds up on the switch contacts prevents the switch from operating properly. Conduct voltage drop tests to isolate faulty components and circuit problems. Repair as needed and retest to confirm that the system is operational. Follow procedures from the manufacturer to clear DTC records, and then run the self-diagnostic program to verify repairs. Some system diagnostic procedures specify the use of special testers. ● **SEE FIGURE 59–30.**

● **SEE CHART 59–2** for programming procedures for selected vehicles.

MAKE/MODEL	NOTES	PROCEDURES
Chrysler Pacifica Town and Country PT Cruiser Sebring 300 Some other models **Dodge** Caravan Durango Magnum Neon Pickup Stratus **Jeep** Liberty Grand Cherokee Some other models	Programming is by scan tool or by "customer learn" mode. Customer learn mode requires at least two functioning Sentry keys. If no functioning Sentry keys are available, the scan tool and the vehicle PIN number are required for programming. Both the immobilizer and RKE are programmed with this procedure. Only a blank key transponder can be programmed. Once programmed, the key cannot be used in another vehicle. The customer learn mode will exit after each key is programmed. The complete procedure must be completed for each key to be programmed. A total of eight keys can be programmed by the Sentry Key Remote Entry Module (four on some models).	CUSTOMER LEARN MODE 1. Using a blank Sentry key, cut the key to match the lock cylinder code. 2. Insert one of the two valid keys into the ignition and turn the ignition on. 3. After 3 seconds, but before 15 seconds expire, turn off the ignition and remove the key. 4. Within 15 seconds insert the second valid key and turn the ignition on. 5. Within 10 seconds a chime will sound and/or the indicator lamp will flash, indicating customer learn mode is active. 6. Within 60 seconds turn the ignition off, insert the blank Sentry key, and turn the ignition on. 7. After about 10 seconds a single chime will sound and the indicator lamp will stay on solid for about 3 seconds; this indicates the key has been programmed.
Ford Taurus Some other models **Lincoln** Some models **Mercury** Grand Marquis Milan Montego	This procedure requires two or more programmed keys. If two programmed keys are not available a scan tool must be used. Maximum of eight keys can be programmed. Repeat the complete procedure for each key to be learned. If the programming is not successful the antitheft indicator will flash and the vehicle will not start. Leave the key on for 30 seconds and then retry the procedure.	1. Using the first programmed key, turn the ignition from off to run. Leave the switch in run for at least 3 seconds but not more than 10 seconds. 2. Turn the switch to off. Within 10 seconds repeat step 1 with the second programmed key. 3. Turn the ignition switch off. 4. Within 20 seconds, insert the un-programmed key and turn the ignition switch from off to run. 5. After 3 seconds, attempt to start the vehicle. If the programming is successful the vehicle will start and the antitheft indicator will light for 3 seconds and go out.
Ford Crown Victoria Some other models	This procedure requires two or more programmed keys. If two programmed keys are not available a scan tool must be used. Maximum of eight keys can be programmed. Repeat the complete procedure for each key to be learned. If the programming is not successful the antitheft indicator will flash and the vehicle will not start. Leave the key on for 30 seconds and then retry the procedure.	1. Using the first programmed key, turn the ignition from off to run. Leave the switch in run for 1 second. 2. Turn the switch to off. Within 5 seconds repeat step 1 with the second programmed key. 3. Turn the ignition switch off. 4. Within 10 seconds, insert the un-programmed key and turn the ignition switch from off to run. 5. After 1 second, attempt to start the vehicle. If the programming is successful the vehicle will start and the antitheft indicator will light for 3 seconds and go out.
General Motors Passkey Passkey II (except vehicles with BCM)	The Passkey decoder will learn the first pellet read when the decoder module is first installed. This learned value cannot be changed. A Passkey Interrogator special tool is needed to read key pellet resistance when replacing keys. The tool will read out a code number related to the pellet resistance.	NEW DECODER MODULE 1. Install the new decoder module. 2. Insert the key and start the vehicle to program the pellet code into the new module. DUPLICATE KEY 1. Use the Interrogator tool to read the existing key code. 2. Obtain a key with the matching pellet code and cut the key to match the original key.

CHART 59–2

Immobilizer or vehicle theft deterrent key learn procedures for some popular vehicles.

MAKE/MODEL	NOTES	PROCEDURES
	PELLET CODE — RESISTANCE 1 — 402 2 — 523 3 — 681 4 — 887 5 — 1,130 6 — 1,470 7 — 1,870 8 — 2,370 9 — 3,010 10 — 3,740 11 — 4,750 12 — 6,040 13 — 7,500 14 — 9,530 15 — 11,800	LOST KEY 1. The Interrogator tool must be used to determine the stored code. 2. Cut a blank key so that the ignition can be turned. 3. Access the lock cylinder 2 wire connector and connect it to the Interrogator. 4. Alternately select each of the 15 code positions on the Interrogator until the vehicle starts. This is then the correct pellet code. 5. Obtain the correct coded key and cut it to fit.
General Motors Passkey II (vehicles with BCM)	On vehicles with a body control module (BCM) the Passkey II pellet code is stored in the BCM. The BCM can learn the pellet code of a replacement key using a scan tool or this procedure. Make sure that the battery is fully charged. If the learning procedure is not successful check the system for codes and repair.	1. Insert the key to be learned and turn the ignition on. Leave the switch on for 11 minutes. The security lamp will be on or flashing during this time. 2. When the security lamp goes off turn the ignition off for 30 seconds. 3. Repeat step 1 two more times. 4. Turn the ignition off for 30 seconds. 5. Attempt to start the vehicle. The vehicle should start and run if the learn is successful.
General Motors Passkey III Passkey III+	Quick-Learn requires at least one programmed master (black) key. Keys can be learned with a scan tool. If no programmed master key is available the 30 minute Auto Learn procedure must be used. Auto Learn procedure will erase all learned keys. Make sure that the battery is fully charged. On vehicles with a driver information center (DIC) a "STARTING DISABLED DUE TO THEFT" message will display during the 10 minute timer.	QUICK LEARN 1. Insert a programmed master key and turn on the ignition. 2. Turn the ignition off and remove the key. 3. Within 10 seconds insert the key to be learned and turn the ignition on. 4. The key is now programmed. 30 MINUTE AUTO LEARN 1. Insert the new master key and turn on the ignition. The security lamp should be on and then turn it off after 10 minutes. 2. Turn the ignition off for 5 seconds. 3. Repeat steps 1 and 2 two more times (30 minutes total). 4. From the off position turn on and start the vehicle. 5. The vehicle should start and run, indicating the key has been learned.
General Motors Passlock (early systems)	Passlock systems do not have coded keys. Replacement or new keys do not have to be learned. Early Passlock systems pass an "R" code to the instrument cluster and then the IPC sends a password on to the PCM. Perform this procedure if replacing the instrument cluster, lock cylinder, or PCM.	1. After parts are installed, attempt to start the vehicle. 2. The vehicle should start and stall. 3. Leave the key on and wait until the flashing theft lamp stays on steady. 4. Attempt to start the vehicle again. It should start and continue to run. 5. The theft lamp should flash for 10 seconds and then go out to indicate the password has been learned.
General Motors Passlock (later models)	Replacement or additional keys do not have to be learned. Programming is necessary if the Passlock sensor, BCM, or PCM has been replaced.	1. Turn the ignition on and attempt to start the vehicle. 2. The vehicle will not start. Release the key to on. Wait about 10 minutes for the security lamp to go off. 3. Turn off the ignition for 5 seconds.

CHART 59–2

(*CONTINUED*)

Continued

MAKE/MODEL	NOTES	PROCEDURES
	A scan tool can also be used to program the Passlock system. ● **SEE FIGURE 59–31.**	4. Repeat steps 1 through 3 two more times. 5. For a fourth time turn the key on and start the vehicle. The vehicle should start and run, indicating that the lock code has been learned.
Honda	A programmed key, scan tool, and password are required to program keys.	1. Connect the scan tool and navigate to the ADD and DELETE KEYS menu. 2. Follow the instructions on the scan tool to add or delete keys as needed.
Hyundai	A scan tool can be used to program keys. A special ID key is needed to program new or additional keys.	1. Using the ID key, turn the ignition on then off. 2. Using the key to be programmed, turn the ignition on then off. This will program the key. 3. Repeat step 2 for any additional keys.
Toyota Camry Land Cruiser Some other earlier models	Up to seven master (black) keys can be learned. An already learned master key must be used to initiate the procedure. Keys can also be programmed with a scan tool.	1. Insert a programmed master key into the ignition switch. 2. Within 15 seconds, press and release the accelerator pedal five times. 3. Within 20 seconds, press and release the brake pedal six times. 4. Remove the master key. 5. Within 10 seconds, insert the key to be programmed into the lock cylinder and press and release the accelerator pedal one time. 6. The security indicator should flash for about 1 minute and then go out to indicate that the key has been learned. 7. To program additional keys repeat steps 5 and 6 within 10 seconds.
Toyota Corolla Matrix Tacoma Sienna RAV4 Some other late models **Lexus** LS430 Some other models	Up to five keys can be learned. A scan tool should be used to register keys.	1. Insert a programmed master key into the ignition and turn the ignition on. 2. Install the scan tool and navigate to the IMMOBILIZER, TRANSP CODE REG. screen. Follow the instructions on the scan tool. 3. The security indicator will turn on. Within 20 seconds, remove the master key. 4. Within 10 seconds, insert the new key to be programmed. 5. The security indicator will blink for 60 seconds and then go off when the key is learned.

CHART 59–2

Immobilizer or vehicle theft deterrent key learn procedures for some popular vehicles.

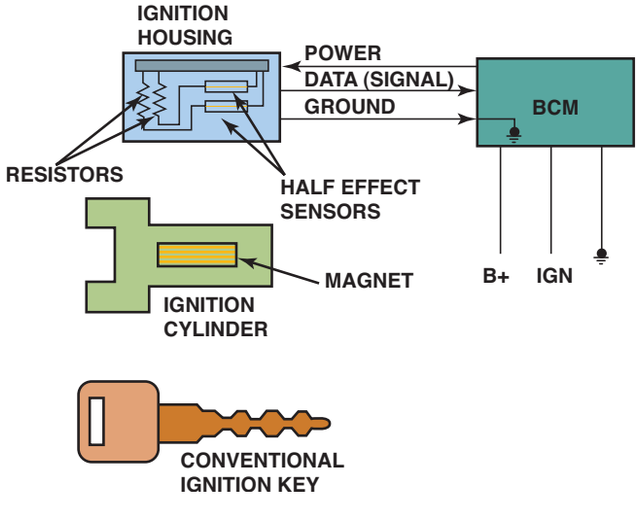


FIGURE 59–31 The Passlock series of General Motors security systems uses a conventional key. The magnet is located in the ignition lock cylinder and triggers the Hall-effect sensors.

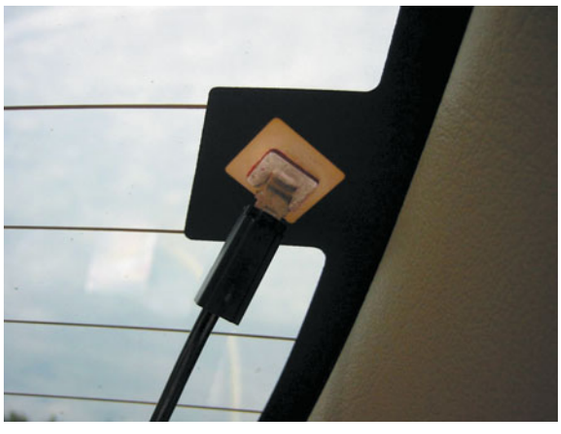


FIGURE 59–32 Corrosion or faults at the junction between the wiring and the rear window electrical grid are the source of many rear window defogger problems.

ELECTRICAL ACCESSORY SYMPTOM GUIDE

Cruise Control Problem	Possible Causes and/or Solutions
Cruise (speed) control is inoperative.	1. Blown fuse 2. Defective or misadjusted electrical or vacuum safety switch near the brake pedal arm 3. Lack of engine vacuum to servo or transducer 4. Defective transducer; defective speed control switch
Cruise (speed) control speed is incorrect or variable.	1. Misadjusted activation cable 2. Defective or pinched vacuum hose 3. Misadjustment of transducer

Power Windows Problem	Possible Causes and/or Solutions
Power windows are inoperative.	1. Defective (blown) fuse (circuit breaker) 2. Defective relay (if used) 3. Poor ground for master control switch 4. Poor connections at switch(es) or motor(s) 5. Open circuit (usually near the master control switch) 6. Defective lockout switch
One power window is inoperative.	1. Defective motor; defective or open control switch 2. Open or loose wiring to the switch or the motor
Only one power window can be operated from the master switch.	1. Poor connection or open circuit in the control wire(s)

Power Seats Problem	Possible Causes and/or Solutions
Power seats are inoperative, no click or noise.	1. Defective circuit breaker 2. Poor ground at the switch or relay (if used) 3. Open in the wiring between the switch and relay (if used); defective switch 4. Defective solenoid(s) or wiring 5. Defective door switch
Power seats are inoperative, click is heard.	1. "Flex" in the cables from the motor(s) to check for motor operation (If flex is felt, the motor is trying to operate the gear nut or the screw jack.) 2. Binding or obstruction 3. Defective motor (The click is generally the relay sound.) 4. Defective solenoid(s) or wiring to the solenoid(s)
All power seat functions are operative except one.	1. Defective motor 2. Defective solenoid or wiring to the solenoid

Electric Power Door Lock Problem	Possible Causes and/or Solutions
Power door locks are inoperative.	1. Defective circuit breaker, fuse, or wiring to the switch or relay (if used) 2. Defective relay (if used); defective switch 3. Defective door lock solenoid or ground for solenoid (if solenoid operated) 4. Open in the wiring to the door lock solenoid or the motor 5. Mechanical obstruction of the door lock mechanism
Only one door lock is inoperative.	1. Defective switch; poor ground on the solenoid (if solenoid operated) 2. Defective door lock solenoid or motor; poor electrical connection at the motor or solenoid

Rear Window Defogger Problem	Possible Causes and/or Solutions
Rear window defogger is inoperative.	1. Proper operation by performing breath test and/or voltmeter (Check at the power side of the rear window grid.); defective relay or timer assembly 2. Defective switch 3. Open ground connection at the rear window grid (● **SEE FIGURE 59–32.**) **NOTE: If there is an open circuit (power side or ground side), the dash indicator light will still operate in most cases.**
Rear window defogger cleans only a portion of the rear window.	1. Broken grid wire(s) or poor electrical connections at either the power side or the ground side of the wire grid

DOOR PANEL REMOVAL



1 Looking at the door panel there appears to be no visible fasteners.



2 Gently prying at the edge of the light shows that it snaps in place and can be easily removed.



3 Under the red “door open” warning light is a fastener.



4 Another screw is found under the armrest.



5 A screw is removed from the bezel around the interior door handle.



6 The electric control panel is held in by clips.



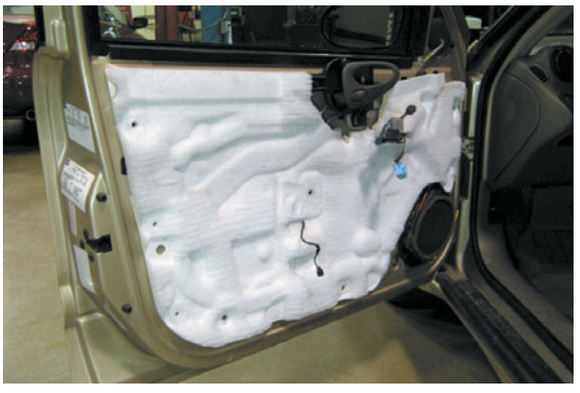
7 Another screw is found after the control panel is removed.



8 The panel beside the outside mirror is removed by gentle prying.



9 A gentle tug and the door panel is removed.



10 The sound-deadening material also acts as a moisture barrier and would need to be removed to gain access to the components inside the door.



11 Carefully inspect the door panel clips before reinstalling the door panel.



12 Align and press the door panel clips into the openings and reinstall all of the fasteners and components.

REVIEW QUESTIONS

1. How do power door locks on a four-door vehicle function with only one ground wire connection?
2. How does a rear window defogger regulate how much current flows through the grids based on temperature?
3. What is the usual procedure to follow to resynchronize a remote keyless entry transmitter?
4. How do heated and cooled seats operate?

CHAPTER QUIZ

1. The owner of a vehicle equipped with cruise control complains that the cruise control often stops working when driving over rough or bumpy pavement. Technician A says the brake switch may be out of adjustment. Technician B says a defective servo unit is the most likely cause. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
2. Technician A says that the cruise control on a vehicle that uses an electronic throttle control (ETC) system uses a servo to move the throttle. Technician B says that the cruise control on a vehicle with ETC uses the APP sensor to set the speed. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
3. All power windows fail to operate from the independent switches but all power windows operate from the master switch. Technician A says the window lockout switch may be on. Technician B says the power window relay could be defective. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
4. Technician A says that a defective ground connection at the master control switch (driver's side) could cause the failure of all power windows. Technician B says that if *one* control wire is disconnected, all windows will fail to operate. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
5. A typical radar cruise control system uses _____.
   a. Long-range radar (LRR)
   b. Short-range radar (SRR)
   c. Electronic throttle control system to control vehicle speed
   d. All of the above
6. When checking the operation of a rear window defogger with a voltmeter, _____.
   a. The voltmeter should be set to read AC volts
   b. The voltmeter should read close to battery voltage anywhere along the grid
   c. Voltage should be available anytime at the power side of the grid because the control circuit just completes the ground side of the heater grid circuit
   d. The voltmeter should indicate decreasing voltage when the grid is tested across the width of the glass
7. PM motors used in power windows, mirrors, and seats can be reversed by _____.
   a. Sending current to a reversed field coil
   b. Reversing the polarity of the current to the motor
   c. Using a reverse relay circuit
   d. Using a relay and a two-way clutch
8. If only one power door lock is inoperative, a possible cause is a _____.
   a. Poor ground connection at the power door lock relay
   b. Defective door lock motor (or solenoid)
   c. Defective (open) circuit breaker for the power circuit
   d. Defective (open) fuse for the control circuit
9. A keyless remote control stops working. Technician A says the battery in the remote could be dead. Technician B says that the key fob may have to be resynchronized. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
10. Two technicians are discussing antitheft systems. Technician A says that some systems require a special key. Technician B says that some systems use a computer chip in the key. Which technician is correct?
    a. Technician A only **c.** Both Technicians A and B
    b. Technician B only **d.** Neither Technician A nor B

chapter 60

AIRBAG AND PRETENSIONER CIRCUITS

OBJECTIVES: After studying Chapter 60, the reader will be able to: • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "H" (Accessories Diagnosis and Repair). • List the appropriate safety precautions to be followed when working with airbag systems. • Describe the procedures to diagnose and repair common faults in airbag systems. • Explain how the passenger presence system works.

KEY TERMS: Airbag 687 • Arming sensor 689 • Clockspring 691 • Deceleration sensor 690 • Dual-stage airbags 691 • EDR 697 • Integral sensor 690 • Knee airbags 694 • Occupant detection systems (ODS) 695 • Passenger presence system (PPS) 695 • Pretensioners 687 • SAR 688 • Side airbags 696 • SIR 688 • Squib 689 • SRS 688

SAFETY BELTS AND RETRACTORS

SAFETY BELTS

Safety belts are used to keep the driver and passengers secured to the vehicle in the event of a collision. Most safety belts include three-point support and are constructed of nylon webbing about 2 in. (5 cm) wide. The three support points include two points on either side of the seat for the belt over the lap and one crossing over the upper torso, which is attached to the "B" pillar or seat back. Every crash consists of three types of collisions.

Collision 1: The vehicle strikes another vehicle or object.

Collision 2: The driver and/or passengers hit objects inside the vehicle if unbelted.

Collision 3: The internal organs of the body hit other organs or bones, which causes internal injuries.

If a safety belt is being worn, the belt stretches, absorbing a lot of the impact, thereby preventing collision with other objects in the vehicle and reducing internal injuries. ● **SEE FIGURE 60–1**.

BELT RETRACTORS

Safety belts are also equipped with one of the following types of retractors.

- Nonlocking retractors, which are used primarily on recoiling
- Emergency locking retractors, which lock the position of the safety belt in the event of a collision or rollover
- Emergency and web speed-sensitive retractors, which allow freedom of movement for the driver and passenger but lock if the vehicle is accelerating too fast or if the vehicle is decelerating too fast.

● **SEE FIGURE 60–2** for an example of an inertia-type seat belt locking mechanism.

SAFETY BELT LIGHTS AND CHIMES

All late-model vehicles are equipped with a safety belt warning light on the dash and a chime that sounds if the belt is not fastened. ● **SEE FIGURE 60–3**.

Some vehicles will intermittently flash the reminder light and sound a chime until the driver and sometimes the front passenger fasten their safety belts.

PRETENSIONERS

A **pretensioner** is an explosive (pyrotechnic) device that is part of the seat belt retractor assembly and tightens the seat belt as the airbag is being deployed. The purpose of the pretensioning device is to force the occupant back into position against the seat back and to remove any slack in the seat belt. ● **SEE FIGURE 60–4**.

CAUTION: The seat belt pretensioner assemblies must be replaced in the event of an airbag deployment. Always follow the vehicle manufacturer's recommended service procedure. Pretensioners are explosive devices that could be ignited if voltage is applied to the terminals. Do not use a jumper wire or powered test light around the wiring near the seat belt latch wiring. Always follow the vehicle manufacturer's recommended test procedures.

FRONT AIRBAGS

PURPOSE AND FUNCTION

Airbag passive restraints are designed to cushion the driver (or passenger, if the passenger side is so equipped) during a frontal collision. The system consists of one

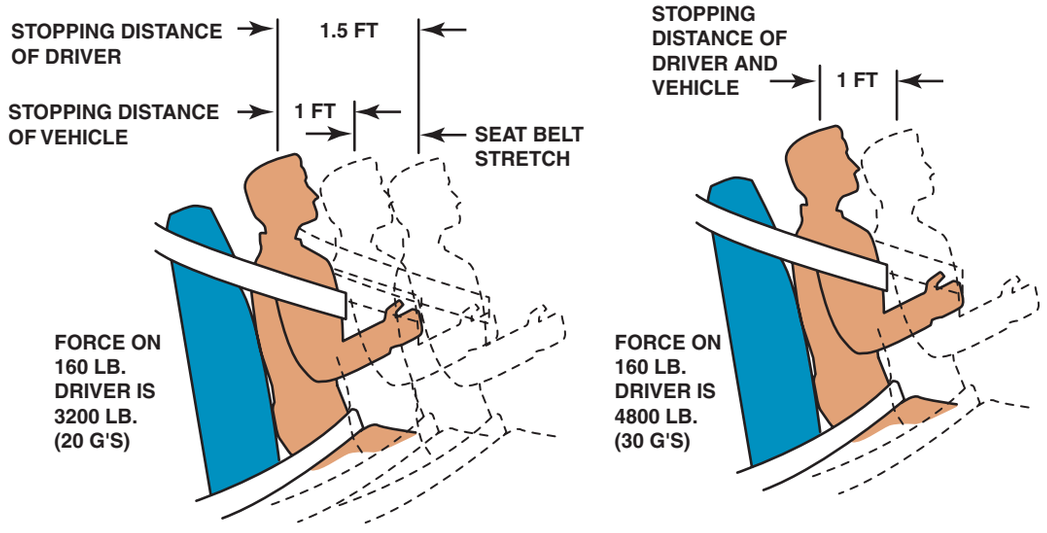


FIGURE 60–1 (a) Safety belts are the primary restraint system. (b) During a collision the stretching of the safety belt slows the impact to help reduce bodily injury.

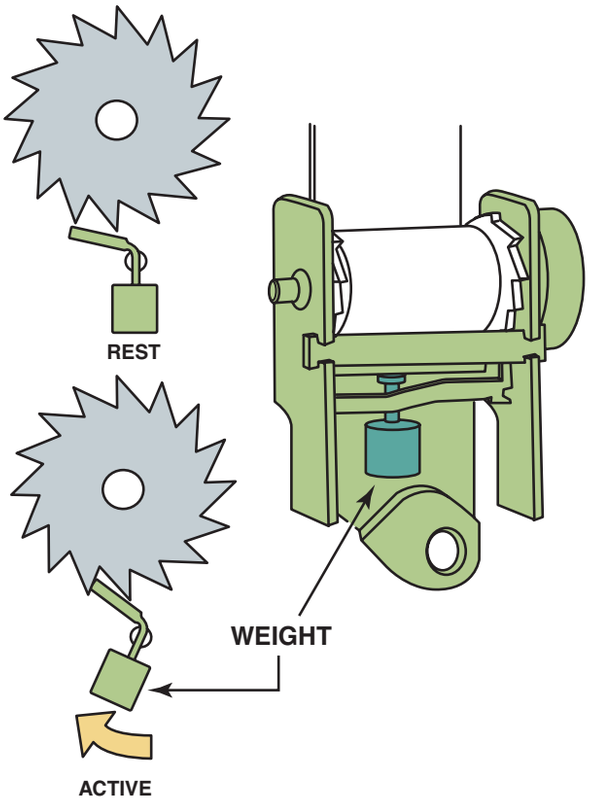


FIGURE 60–2 Most safety belts have an inertia-type mechanism that locks the belt in the event of rapid movement.



FIGURE 60–3 A typical safety belt warning light.

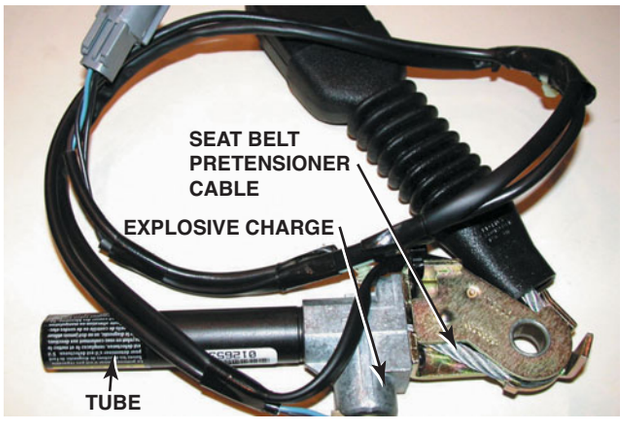


FIGURE 60–4 A small explosive charge in the pretensioner forces the end of the seat belt down the tube, which removes any slack in the seat belt.

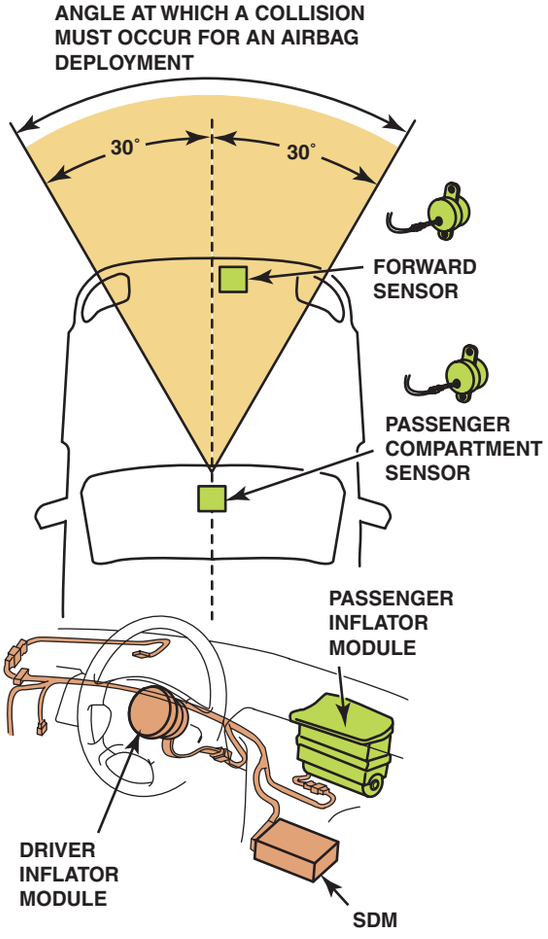


FIGURE 60–5 A typical airbag system showing many of the components. The SDM is the "sensing and diagnostic module" and includes the arming sensor as well as the electronics that keep checking the circuits for continuity and the capacitors that are discharged to deploy the air bags.

or more nylon bags folded up in compartments located in the steering wheel, dashboard, interior panels, or side pillars of the vehicle. During a crash of sufficient force, pressurized gas instantly fills the airbag and then deploys out of the storage compartment to protect the occupant from serious injury. These airbag systems may be known by many different names, including the following:

1. **Supplemental restraint system (SRS)**
2. **Supplemental inflatable restraints (SIR)**
3. **Supplemental air restraints (SAR)**

Most airbags are designed to supplement the safety belts in the event of a collision, and front airbags are meant to be deployed only in the event of a frontal impact within 30 degrees of center. Front (driver and passenger side) airbag systems are *not* designed to inflate during side or rear impact. The force required to deploy a typical airbag is approximately equal to the force of a vehicle hitting a wall at over 10 mph (16 km/hr).

The force required to trigger the sensors within the system prevents accidental deployment if curbs are hit or the brakes are rapidly applied. The system requires a substantial force to deploy the airbag to help prevent accidental inflation.

PARTS INVOLVED

● **SEE FIGURE 60–5** for an overall view of the parts included in a typical airbag system.

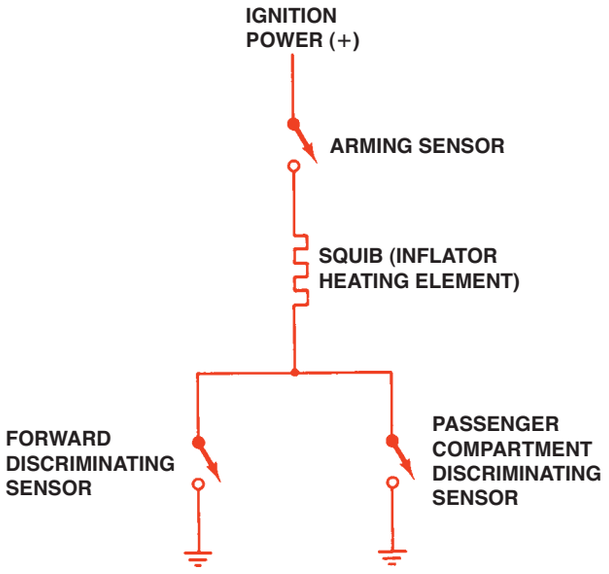


FIGURE 60–6 A simplified airbag deployment circuit. Note that both the arming sensor and at least one of the discriminating sensors must be activated at the same time. The arming sensor provides the power, and either one of the discriminating sensors can provide the ground for the circuit.

The parts include:

1. Sensors
2. Airbag (inflator) module
3. Clockspring wire coil in the steering column
4. Control module
5. Wiring and connectors

OPERATION

To cause inflation, the following events must occur.

- To cause a deployment of the airbag, two sensors must be triggered at the same time. The **arming sensor** is used to provide electrical power, and a *forward* or *discriminating sensor* is used to provide the ground connection.
- The arming sensor provides the electrical power to the airbag heating unit, called a **squib,** inside the inflator module.
- The squib uses electrical power and converts it into heat for ignition of the propellant used to inflate the airbag.
- Before the airbag can inflate, however, the squib circuit also must have a ground provided by the forward or the discriminating sensor. In other words, two sensors (arming and forward sensors) *must* be triggered *at the same time* before the airbag will be deployed. ● **SEE FIGURE 60–6**.

TYPES OF AIRBAG INFLATORS

There are two different types of inflators used in airbags.

1. **Solid fuel.** This type uses sodium azide pellets and, when ignited, generates a large quantity of nitrogen gas that quickly inflates the airbag. This was the first type used and is still commonly used in driver and passenger side airbag inflator modules. ● **SEE FIGURE 60–7**. The squib is the electrical heating element used to ignite the gas-generating material, usually sodium azide. It requires about 2 A of current to heat the heating element and ignite the inflator.
2. **Compressed gas.** Commonly used in passenger side airbags and roof-mounted systems, the compressed gas system uses a canister filled with argon gas, plus a small percentage of helium at 3,000 psi (435 kPa). A small igniter ruptures a burst disc to release the gas when energized. The compressed gas inflators are long cylinders that can be installed inside the instrument panel, seat back, door panel, or along any side rail or pillar of the vehicle. ● **SEE FIGURE 60–8**.



FIGURE 60–7 The inflator module is being removed from the airbag housing. The squib, inside the inflator module, is the heating element that ignites the pyrotechnic gas generator that rapidly produces nitrogen gas to fill the airbag.

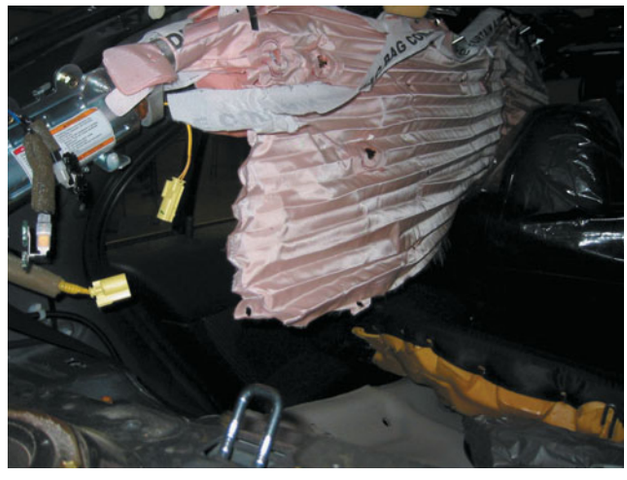


FIGURE 60–8 This shows a deployed side curtain airbag on a training vehicle.

Once the inflator is ignited, the nylon bag quickly inflates (in about 30 ms or 0.030 second) with nitrogen gas generated by the inflator. During an actual frontal collision accident, the driver is being thrown forward by the driver's own momentum toward the steering wheel. The strong nylon bag inflates at the same time. Personal injury is reduced by the spreading of the stopping force over the entire upper-body region. The normal collapsible steering column remains in operation and collapses in a collision when equipped with an airbag system. The bag is equipped with two large side vents that allow the bag to deflate immediately after inflation, once the bag has cushioned the occupant in a collision.

TIMELINE FOR AIRBAG DEPLOYMENT

Following are the times necessary for an airbag deployment in milliseconds (each millisecond is equal to 0.001 second or 1/1,000 of a second).

1. Collision occurs: 0.0 ms
2. Sensors detect collision: 16 ms (0.016 second)
3. Airbag is deployed and seam cover rips: 40 ms (0.040 second)

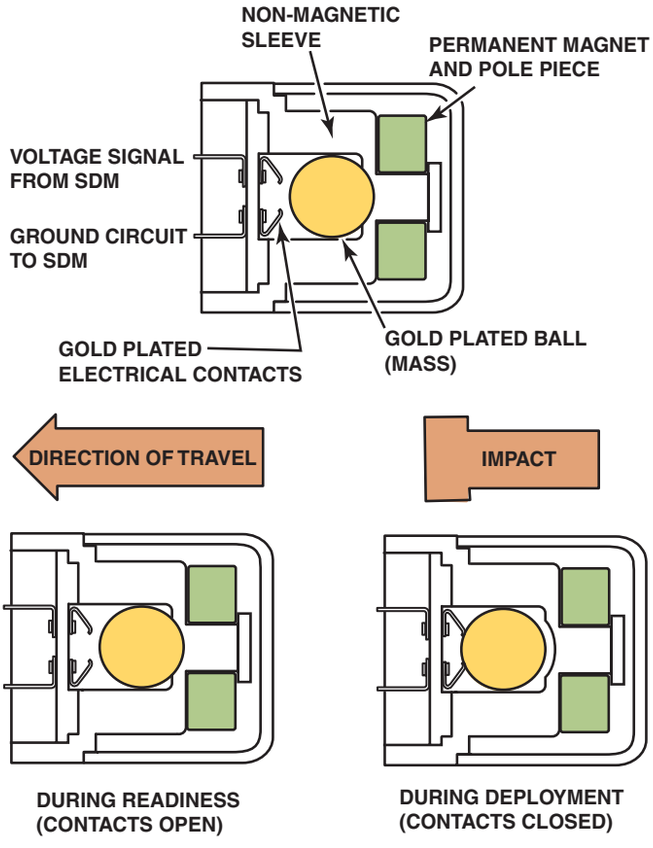


FIGURE 60–9 An airbag magnetic sensor.

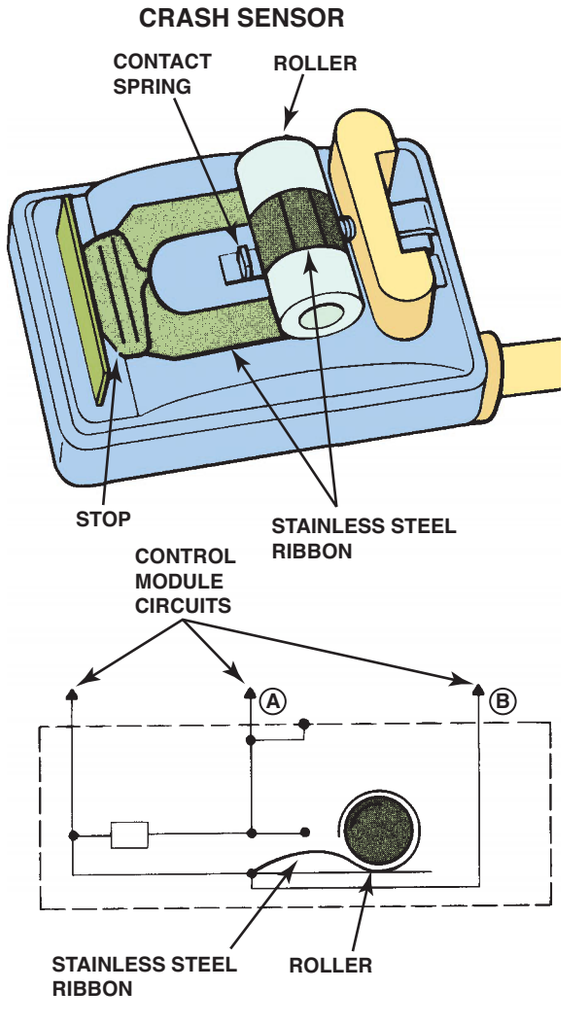


FIGURE 60–10 Some vehicles use a ribbon-type crash sensor.

4. Airbag is fully inflated: 100 ms (0.100 second)
5. Airbag deflated: 250 ms (0.250 second)

In other words, an airbag deployment occurs and is over in about a quarter of a second.

SENSOR OPERATION All three sensors are basically switches that complete an electrical circuit when activated. The sensors are similar in construction and operation, and the *location* of the sensor determines its name. All airbag sensors are rigidly mounted to the vehicle and *must* be mounted with the arrow pointing toward the front of the vehicle to ensure that the sensor can detect rapid forward deceleration.

There are three basic styles (designs) of airbag sensors.

1. **Magnetically retained gold-plated ball sensor.** This sensor uses a permanent magnet to hold a gold-plated steel ball away from two gold-plated electrical contacts. ● **SEE FIGURE 60–9**.

   If the vehicle (and the sensor) stops rapidly enough, the steel ball is released from the magnet because the inertia force of the crash was sufficient to overcome the magnetic pull on the ball and then makes contact with the two gold-plated electrodes. The steel ball only remains in contact with the electrodes for a relatively short time because the steel ball is drawn back into contact with the magnet.

2. **Rolled up stainless-steel ribbon-type sensor.** This sensor is housed in an airtight package with nitrogen gas inside to prevent harmful corrosion of the sensor parts. If the vehicle (and the sensor) stops rapidly, the stainless-steel roll "unrolls" and contacts the two gold-plated contacts. Once the force is stopped, the stainless-steel roll will roll back into its original shape. ● **SEE FIGURE 60–10**.

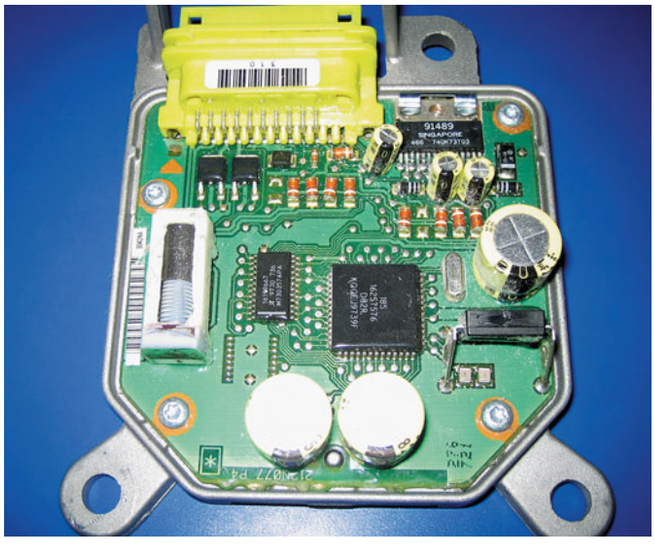


FIGURE 60–11 A sensing and diagnostic module that includes an accelerometer.

3. **Integral sensor.** Some vehicles use electronic **deceleration sensors** built into the inflator module, called **integral sensors.** For example, General Motors uses the term *sensing and diagnostic module* (*SDM*) to describe their integrated sensor/module assembly. These units contain an accelerometer-type sensor which measures the rate of deceleration and, through computer logic, determines if the airbags should be deployed. ● **SEE FIGURE 60–11**.

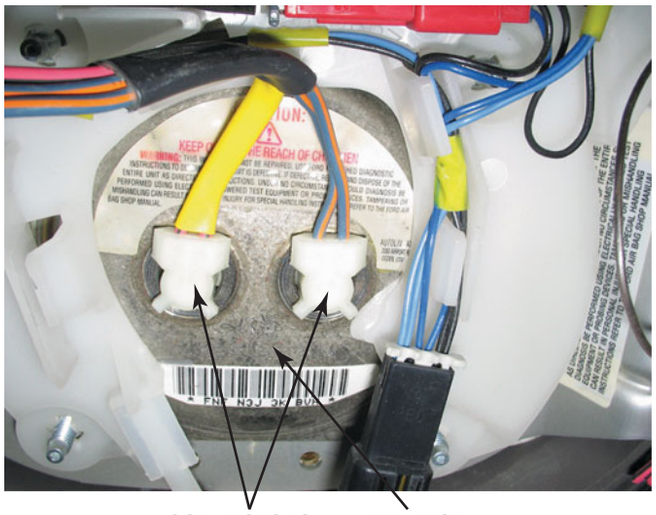


FIGURE 60–12 A driver's side airbag showing two inflator connectors. One is for the lower force inflator and the other is for the higher force inflator. Either can be ignited or both at the same time if the deceleration sensor detects a severe impact.

TWO-STAGE AIRBAGS Two-stage airbags, often called advanced airbags or smart airbags, use an accelerometer-type of sensor to detect force of the impact. This type of sensor measures the actual amount of deceleration rate of the vehicle and is used to determine whether one or both elements of a two-stage airbag should be deployed.

- **Low-stage deployment.** This lower force deployment is used if the accelerometer detects a low-speed crash.
- **High-stage deployment.** This stage is used if the accelerometer detects a higher speed crash or a more rapid deceleration rate.
- **Both low- and high-stage deployment.** Under severe high-speed crashes, both stages can be deployed.

● **SEE FIGURE 60–12.**

WIRING Wiring and connectors are very important for proper identification and long life. Airbag-related circuits have the following features.

- All electrical wiring and conduit for airbags are colored yellow.
- To ensure proper electrical connection to the inflator module in the steering wheel, a coil assembly is used in the steering column. This coil is a ribbon of copper wires that operates much like a window shade when the steering wheel is rotated. As the steering wheel is rotated, this coil, usually called a **clockspring,** prevents the lack of continuity between the sensors and the inflator assembly that might result from a horn-ring type of sliding conductor.
- Inside the yellow plastic airbag connectors are gold-plated terminals which are used to prevent corrosion.

● **SEE FIGURE 60–13.**

Most airbag systems also contain a diagnostic unit that often includes an auxiliary power supply, which is used to provide the current to inflate the airbag if the battery is disconnected from the vehicle during a collision. This auxiliary power supply normally uses capacitors that are discharged through the squib of the inflation module. When the ignition is turned off these capacitors are discharged. Therefore, after a few minutes an airbag system will not deploy if the vehicle is hit while parked.

SAFETY TIP

Dual-Stage Airbag Caution

Many vehicles are equipped with **dual-stage airbags** (two-stage airbags) that actually contain two separate inflators, one for less severe crashes and one for higher speed collisions. These systems are sometimes called *smart airbag systems* because the accelerometer-type sensor used can detect how severe the impact is and deploy one or both stages. If one stage is deployed, the other stage is still active and could be accidentally deployed. A service technician cannot tell by looking at the airbag whether both stages have deployed. Always handle a deployed airbag as if it has not been deployed and take all precautions necessary to keep any voltage source from getting close to the inflator module terminals.

TECH TIP

Pocket the Ignition Key to Be Safe

When replacing any steering gear such as a rack-and-pinion steering unit, be sure that no one accidentally turns the steering wheel. If the steering wheel is turned without being connected to the steering gear, the airbag wire coil (clockspring) can become off center. This can cause the wiring to break when the steering wheel is rotated after the steering gear has been replaced. To help prevent this from occurring, simply remove the ignition key from the ignition and keep it in your pocket while servicing the steering gear.

AIRBAG DIAGNOSIS TOOLS AND EQUIPMENT

SELF-TEST PROCEDURE The electrical portion of airbag systems is constantly checked by the circuits within the airbag-energizing power unit or through the airbag controller. The electrical airbag components are monitored by applying a small-signal voltage from the airbag controller through the various sensors and components. Each component and sensor uses a resistor in parallel with the load or open sensor switch for use by the diagnostic signals. If continuity exists, the testing circuits will measure a small voltage drop. If an open or short circuit occurs, a dash warning light is lighted and a possible diagnostic trouble code (DTC) is stored. Follow exact manufacturer's recommended procedures for accessing and erasing airbag diagnostic trouble codes.

Diagnosis and service of airbag systems usually require some or all of the following items.

- Digital multimeter (DMM)
- Airbag simulator, often called a load tool
- Scan tool
- Shorting bar or shorting connector(s)
- Airbag system tester

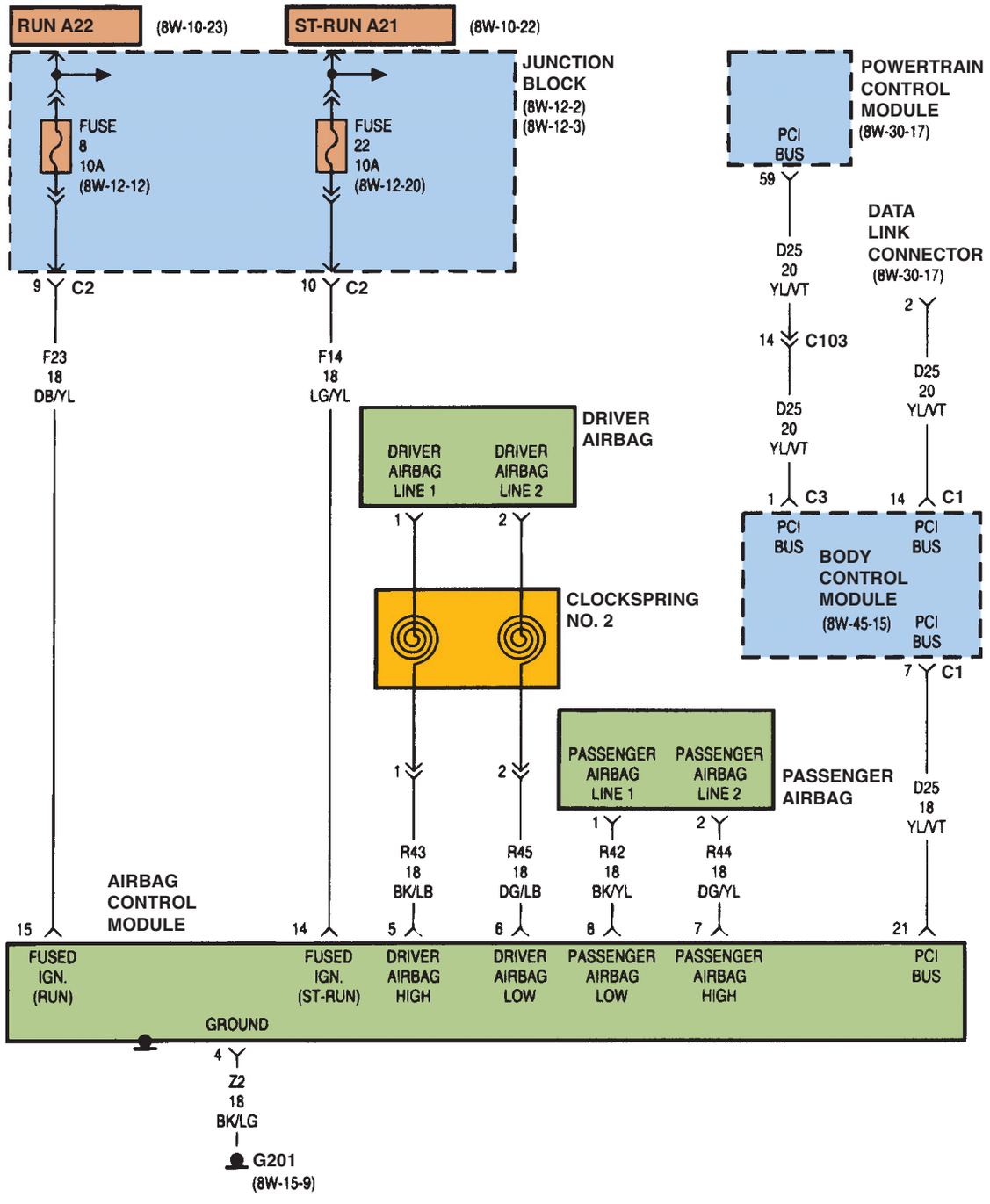


FIGURE 60–13 The airbag control module is linked to the powertrain control module (PCM) and the body control module (BCM) on this Chrysler system. Notice the airbag wire connecting the module to the airbag through the clockspring. Both power, labeled "driver airbag high" and ground, labeled "driver airbag low" are conducted through the clockspring.

- Vehicle-specific test harness
- Special wire repair tools or connectors, such as crimp-and-seal weatherproof connectors

● **SEE FIGURE 60–14.**

CAUTION: Most vehicle manufacturers specify that the negative battery terminal be removed when testing or working around airbags. Be aware that a memory saver device used to keep the computer and radio memory alive can supply enough electrical power to deploy an airbag.

PRECAUTIONS Take the following precautions when working with or around airbags.

1. Always follow all precautions and warning stickers on vehicles equipped with airbags.
2. Maintain a safe working distance from all airbags to help prevent the possibility of personal injury in the unlikely event of an unintentional airbag deployment.
   - Side impact airbag: 5 in. (13 cm) distance
   - Driver front airbag: 10 in. (25 cm) distance
   - Passenger front airbag: 20 in. (50 cm) distance
3. In the event of a collision in which the bag(s) is deployed, the inflator module *and* all sensors usually must be replaced to ensure proper future operation of the system.
4. Avoid using a self-powered test light around the yellow airbag wiring. Even though it is highly unlikely, a self-powered test light



FIGURE 60–14 An airbag diagnostic tester. Included in the plastic box are electrical connectors and a load tool that substitutes for the inflator module during troubleshooting.

could provide the necessary current to accidentally set off the inflator module and cause an airbag deployment.

5. Use care when handling the inflator module section when it is removed from the steering wheel. Always hold the inflator away from your body.
6. If handling a deployed inflator module, always wear gloves and safety glasses to avoid the possibility of skin irritation from the sodium hydroxide dust, which is used as a lubricant on the bag(s), that remains after deployment.
7. Never jar or strike a sensor. The contacts inside the sensor may be damaged, preventing the proper operation of the airbag system in the event of a collision.
8. When mounting a sensor in a vehicle, make certain that the arrow on the sensor is pointing toward the front of the vehicle. Also be certain that the sensor is securely mounted.

AIRBAG SYSTEM SERVICE

DIS-ARMING The airbags should be dis-armed, (temporarily disconnected), whenever performing service work on any of the follow locations.

- Steering wheel
- Dash or instrument panel
- Glove box (instrument panel storage compartment)

Check service information for the exact procedure, which usually includes the following steps.

STEP 1 Disconnect the negative battery cable.

STEP 2 Remove the airbag fuse (has a yellow cover).

STEP 3 Disconnect the yellow electrical connector located at the base of the steering column to disable the driver's side airbag.

STEP 4 Disconnect the yellow electrical connector for the passenger side airbag.

This procedure is called "disabling air bags" in most service information. Always follow the vehicle manufacturer's specified procedures.

? FREQUENTLY ASKED QUESTION

What Are Smart Airbags?

Smart airbags use the information from sensors to determine the level of deployment. Sensors used include:

- **Vehicle speed (VS) sensors.** This type of sensor has a major effect on the intensity of a collision. The higher the speed is, the greater the amount of impact force.
- **Seat belt fastened switch.** If the seat belt is fastened, as determined by the seat belt buckle switch, the airbag system will deploy accordingly. If the driver or passenger is not wearing a seat belt, the airbag system will deploy with greater force compared to when the seat belt is being worn.
- **Passenger seat sensor.** The sensor in the seat on the passenger's side determines the force of deployment. If there is not a passenger detected, the passenger side airbag will not deploy on the vehicle equipped with a passenger seat sensor system.

? FREQUENTLY ASKED QUESTION

Why Change Knee Bolsters If Switching to Larger Wheels?

Larger wheels and tires can be installed on vehicles, but the powertrain control module (PCM) needs to be reprogrammed so the speedometer and other systems that are affected by a change in wheel/tire size can work effectively. When 20 in. wheels are installed on General Motors trucks or sport utility vehicles (SUVs), GM specifies that replacement knee bolsters be installed. Knee bolsters are the padded area located on the lower part of the dash where a driver or passenger's knees would hit in the event of a front collision. The reason for the need to replace the knee bolsters is to maintain the crash testing results. The larger 20 in. wheels would tend to be forced farther into the passenger compartment in the event of a front-end collision. Therefore to maintain the frontal crash rating standard, the larger knee bolsters are required.

WARNING: Failure to perform the specified changes when changing wheels and tires could result in the vehicle not being able to provide occupant protection as designed by the crash test star rating that the vehicle originally achieved.

DIAGNOSTIC AND SERVICE PROCEDURE Airbag system components and their location in the vehicle vary according to system design, but the basic principles of testing are the same as for other electrical circuits. Use service information to determine how the circuit is designed and the correct sequence of tests to be followed.

- Some airbag systems require the use of special testers. The built-in safety circuits of such testers prevent accidental deployment of the airbag.
- If such a tester is not available, follow the recommended alternative test procedures specified by the manufacturer.

- Access the self-diagnostic system and check for diagnostic trouble code (DTC) records.
- The scan tool is needed to access the data stream on most systems.

SELF-DIAGNOSIS All airbag systems can detect system electrical faults, and if found will disable the system and notify the driver through an airbag warning lamp in the instrument cluster. Depending on circuit design, a system fault may cause the warning lamp to fail to illuminate, remain lit continuously, or flash. Some systems use a tone generator that produces an audible warning when a system fault occurs or if the warning lamp is inoperative.

The warning lamp should illuminate with the ignition key on and engine off as a bulb check. If not, the diagnostic module is likely disabling the system. If the airbag warning light remains on, the airbags may or may not be disabled, depending on the specific vehicle and the fault detected. Some warning lamp circuits have a timer that extinguishes the lamp after a few seconds. The airbag system generally does not require service unless there is a failed component. However, a steering wheel–mounted airbag module is routinely removed and replaced in order to service switches and other column-mounted devices.

KNEE AIRBAGS Some vehicles are equipped with **knee airbags** usually on the driver's side. Use caution if working under the dash and always follow the vehicle manufacturer's specified service procedures.

DRIVER SIDE AIRBAG MODULE REPLACEMENT

For the specific model being serviced, carefully follow the procedures provided by the vehicle manufacturer to disable and remove the airbag module. Failure to do so may result in serious injury and extensive damage to the vehicle. Replacing a discharged airbag is costly. The following procedure reviews the basic steps for removing an airbag module. Do not substitute these general instructions for the specific procedure recommended by the manufacturer.

1. Turn the steering wheel until the front wheels are positioned straight ahead. Some components on the steering column are removed only when the front wheels are straight.
2. Switch the ignition off and disconnect the negative battery cable, which cuts power to the airbag module.
3. Once the battery is disconnected, wait as long as recommended by the manufacturer before continuing. When in doubt, wait at least 10 minutes to make sure the capacitor is completely discharged.
4. Loosen and remove the nuts or screws that hold the airbag module in place. On some vehicles, these fasteners are located on the back of the steering wheel. On other vehicles, they are located on each side of the steering wheel. The fasteners may be concealed with plastic finishing covers that must be pried off with a small screwdriver to access them.
5. Carefully lift the airbag module from the steering wheel and disconnect the electrical connector. Connector location varies: Some are below the steering wheel behind a plastic trim cover; others are at the top of the column under the module. ● **SEE FIGURES 60–15 AND 60–16.**

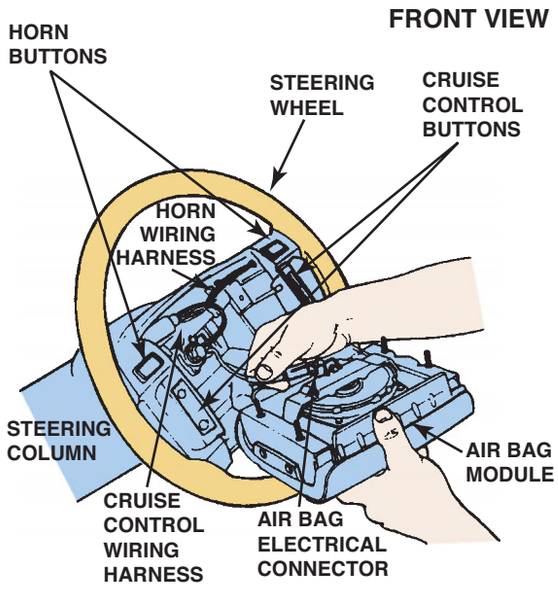


FIGURE 60–15 After disconnecting the battery and the yellow connector at the base of the steering column, the airbag inflator module can be removed from the steering wheel and the yellow airbag electrical connector at the inflator module disconnected.

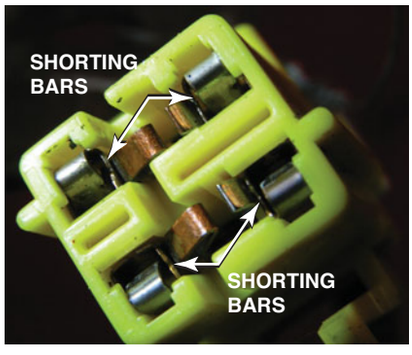


FIGURE 60–16 Shorting bars are used in most airbag connectors. These spring-loaded clips short across both terminals of an airbag connector when it is disconnected to help prevent accidental deployment of the airbag. If electrical power was applied to the terminals, the shorting bars would simply provide a low-resistance path to the other terminal and not allow current to flow past the connector. The mating part of the connector has a tapered piece that spreads apart the shorting bars when the connector is reconnected.

6. Store the module pad side up in a safe place where it will not be disturbed or damaged while the vehicle is being serviced. Do not attempt to disassemble the airbag module. If the airbag is defective, replace the entire assembly.

When installing the airbag module, make sure the clockspring is correctly positioned to ensure module-to-steering-column continuity. ● **SEE FIGURE 60–17.**

Always route the wiring exactly as it was before removal. Also, make sure the module seats completely into the steering wheel. Secure the assembly using new fasteners, if specified.

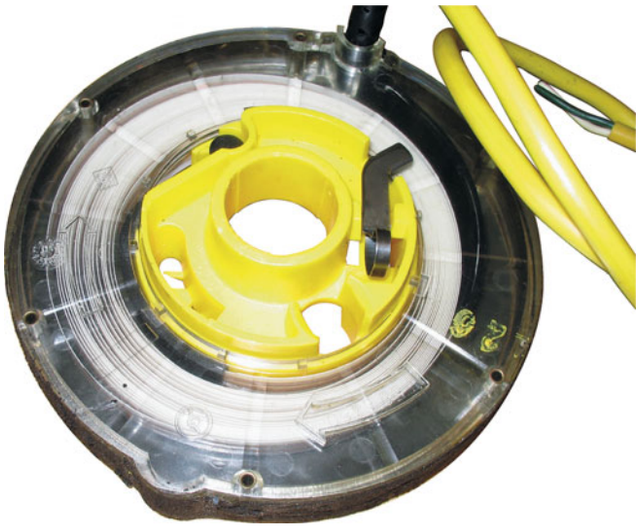


FIGURE 60–17 An airbag clockspring showing the flat conductor wire. It must be properly positioned to ensure proper operation.

SAFETY WHEN MANUALLY DEPLOYING AIRBAGS

Airbag modules cannot be disposed of unless they are deployed. Do the following to prevent injury when manually deploying an airbag.

- When possible, deploy the airbag outside of the vehicle. Follow the vehicle manufacturer's recommendations.
- Follow the vehicle manufacturer's procedures and equipment recommendations.
- Wear the proper hearing and eye protection.
- Deploy the airbag with the trim cover facing up.
- Stay at least 20 ft (6 m) from the airbag. (Use long jumper wires attached to the wiring and routed outside the vehicle to a battery.)
- Allow the airbag module to cool.

● **SEE FIGURE 60–18**.



FIGURE 60–18 An airbag being deployed as part of a demonstration in an automotive laboratory.

OCCUPANT DETECTION SYSTEMS

PURPOSE AND FUNCTION The U.S. Federal Motor Vehicle Safety Standard 208 (FMVSS) specifies that the passenger side airbag be disabled or deployed with reduced force under the following conditions. This system is referred to as an **occupant detection system (ODS)** or the **passenger presence system (PPS).**

- When there is no weight on the seat and no seat belt is fastened, the passenger side airbag will not deploy and the passenger airbag light should be off. ● **SEE FIGURE 60–19**.
- The passenger side airbag will be disabled and the disabled airbag light will be on if only 10 to 37 lb (4.5 to 17 kg) is on the passenger seat, which would generally represent a seated child.



FIGURE 60–19 A dash warning lamp will light if the passenger side airbag is off because no passenger was detected by the seat sensor.

- If 38 to 99 lb (17 to 45 kg) is detected on the passenger seat, which represents a child or small adult, the airbag will deploy at a decreased force.
- If 99 lb (45 kg) or more is detected on the passenger seat, the airbag will deploy at full force, depending on the severity of the crash, speed of the vehicle, and other factors which may result in the airbag deploying at a reduced force.

● **SEE FIGURE 60–20**.



FIGURE 60–20 The passenger side airbag "on" lamp will light if a passenger is detected on the passenger seat.



FIGURE 60–21 A gel-filled (bladder-type) occupant detection sensor showing the pressure sensor and wiring.

TYPE OF SEAT SENSOR

The passenger presence system (PPS) uses one of three types of sensors.

- **Gel-filled bladder sensor.** This type of occupant sensor uses a silicone-filled bag that has a pressure sensor attached. The weight of the passenger is measured by the pressure sensor, which sends a voltage signal to the module controlling the airbag deployment. A safety belt tension sensor is also used with a gel-filled bladder system to monitor the tension on the belt. The module then uses the information from both the bladder and the seat belt sensor to determine if a tightened belt may be used to restrain a child seat. ● **SEE FIGURE 60–21**.
- **Capacitive strip sensors.** This type of occupant sensor uses several flexible conductive metal strips under the seat cushion. These sensor strips transmit and receive a low-level electric field, which changes due to the weight of the front passenger seat occupant. The module determines the weight of the occupant based on the sensor values.
- **Force-sensing resistor sensors.** This type of occupant sensor uses resistors, which change their resistance based on the stress that is applied. These resistors are part of the seat structure, and the module can determine the weight of the occupant based on the change in the resistance of the sensors. ● **SEE FIGURE 60–22**.



FIGURE 60–22 A resistor-type occupant detection sensor. The weight of the passenger strains these resistors, which are attached to the seat, thereby signaling to the module the weight of the occupant.



FIGURE 60–23 A test weight is used to calibrate the occupant detection system on a Chrysler vehicle.

CAUTION: Because the resistors are part of the seat structure, it is very important that all seat fasteners be torqued to factory specifications to ensure proper operation of the occupant detection system. A *seat track position (STP) sensor* is used by the airbag controller to determine the position of the seat. If the seat is too close to the airbag, the controller may disable the airbag.

DIAGNOSING OCCUPANT DETECTION SYSTEMS

A fault in the system may cause the passenger side airbag light to turn on when there is no weight on the seat. A scan tool is often used to check or calibrate the seat, which must be empty, by commanding the module to rezero the seat sensor. Some systems, such as those on Chrysler vehicles, use a unit that has various weights along with a scan tool to calibrate and diagnose the occupant detection system. ● **SEE FIGURE 60–23**.

SEAT AND SIDE CURTAIN AIRBAGS

SEAT AIRBAGS

Side and/or *curtain airbags* use a variety of sensors to determine if they need to be deployed. **Side airbags** are mounted in one of two general locations.

- In the side bolster of the seat (● **SEE FIGURE 60–24**.)
- In the door panel

Most side airbag sensors use an electronic accelerometer to detect when to deploy the airbags, which are usually mounted to the



FIGURE 60–24 A typical seat (side) airbag that deploys from the side of the seat.

TECH TIP

Aggressive Driving and OnStar

If a vehicle equipped with the OnStar system is being driven aggressively and the electronic stability control system has to intercede to keep the vehicle under control, OnStar may call the vehicle to see if there has been an accident. The need for a call from OnStar usually will be determined if the accelerometer registers slightly over 1 g-force, which could be achieved while driving on a race track.

bottom of the left and right "B" pillars (where the front doors latch) behind a trim panel on the inside of the vehicle.

CAUTION: Avoid using a lockout tool (e.g., a "slim jim") in vehicles equipped with side airbags to help prevent damage to the components and wiring in the system.

SIDE CURTAIN AIRBAGS Side curtain airbags are usually deployed by a module based on input from many different sensors, including a lateral acceleration sensor and wheel speed sensors. For example, in one system used by Ford, the ABS controller commands that the brakes on one side of the vehicle be applied, using down pressure while monitoring the wheel speed sensors. If the wheels slow down with little brake pressure, the controller assumes that the vehicle could roll over, thereby deploying the side curtain airbags.

EVENT DATA RECORDERS

PARTS AND OPERATION As part of the airbag controller on many vehicles, the **event data recorder (EDR)** is used to record parameters just before and slightly after an airbag deployment. The following parameters are recorded.

- Vehicle speed
- Brake on/off
- Seat belt fastened
- G-forces as measured by the accelerometer

Unlike an airplane event data recorder, a vehicle unit is not a separate unit and does not record voice conversations and does not include all crash parameters. This means that additional crash data, such as skid marks and physical evidence at the crash site, will be needed to fully reconstruct the incident.

The EDR is embedded into the airbag controller and receives data from many sources and at varying sample rates. The data is constantly being stored in a memory buffer and not recorded into the EPROM unless an airbag deployment has been commanded. The combined data is known as an *event file.* The airbag is commanded on, based on input mainly from the accelerometer sensor. This sensor, usually built into the airbag controller, is located inside the vehicle. The accelerometer calculates the rate of change of the speed of the vehicle. This determines the acceleration rate and is used to predict if that rate is high enough to deploy the frontal airbags. The airbags will be deployed if the threshold g-value is exceeded. The passenger side airbag will also be deployed unless it is suppressed by either of the following:

- No passenger is detected.
- The passenger side airbag switch is off.

DATA EXTRACTION Data extraction from the event data recorder in the airbag controller can only be achieved using a piece of equipment known as the Crash Data Retrieval System, manufactured by Vetronics Corporation. This is the only authorized method for retrieving event files and only certain organizations are allowed access to the data. These groups or organizations include:

- Original equipment manufacturer's representatives
- National Highway Traffic Safety Administration
- Law enforcement agencies
- Accident reconstruction companies

Crash data retrieval must only be done by a trained crash data retrieval (CDR) technician or analyst. A technician undergoes specialized training and must pass an examination. An analyst must attend additional training beyond that of a technician to achieve CDR analyst certification.

REVIEW QUESTIONS

1. What are the safety precautions to follow when working around an airbag?
2. What sensor(s) must be triggered for an airbag deployment?
3. How should deployed inflation modules be handled?
4. What is the purpose of pretensioners?

CHAPTER QUIZ

1. A vehicle is being repaired after an airbag deployment. Technician A says that the inflator module should be handled as if it is still live. Technician B says rubber gloves should be worn to prevent skin irritation. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. A seat belt pretensioner is _____.
   a. A device that contains an explosive charge
   b. Used to remove slack from the seat belt in the event of a collision
   c. Used to force the occupant back into position against the seat back in the event of a collision
   d. All of the above
3. What conducts power and ground to the driver's side airbag?
   a. Twisted-pair wires
   b. Clockspring
   c. Carbon contact and brass surface plate on the steering column
   d. Magnetic reed switch
4. Two technicians are discussing dual-stage airbags. Technician A says that a deployed airbag is safe to handle regardless of which stage caused the deployment of the airbag. Technician B says that both stages ignite, but at different speeds depending on the speed of the vehicle. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
5. Where are shorting bars used?
   a. In pretensioners
   b. At the connectors for airbags
   c. In the crash sensors
   d. In the airbag controller
6. Technician A says that a deployed airbag can be repacked, reused, and reinstalled in the vehicle. Technician B says that a deployed airbag should be discarded and replaced with an entire new assembly. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. What color are the airbag electrical connectors and conduit?
   a. Blue
   b. Red
   c. Yellow
   d. Orange
8. Driver and/or passenger front airbags will only deploy if a collision occurs how many degrees from straight ahead?
   a. 10 degrees
   b. 30 degrees
   c. 60 degrees
   d. 90 degrees
9. How many sensors must be triggered at the same time to cause an airbag deployment?
   a. One
   b. Two
   c. Three
   d. Four
10. The electrical terminals used for airbag systems are unique because they are _____.
    a. Solid copper
    b. Tin-plated heavy-gauge steel
    c. Silver plated
    d. Gold plated

chapter 61

AUDIO SYSTEM OPERATION AND DIAGNOSIS

OBJECTIVES: **After studying Chapter 61, the reader will be able to:** • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "H" (Accessories Diagnosis and Repair). • Describe how AM and FM radio works. • Explain how to test speaker polarity. • Explain how to match speaker impedance. • Explain how crossovers work. • Describe how satellite radio works • Explain how Bluetooth systems work • Discuss voice recognition systems. • List causes and corrections of radio noise and interference.

KEY TERMS: Active crossover 705 • Alternator whine 708 • AM 699 • Bluetooth 707 • Crossover 704 • Decibels (dB) 704 • Floating ground system 704 • FM 699 • Frequency 699 • Ground plane 701 • Hertz 699 • High-pass filter 705 • Impedance 702 • Low-pass filter 705 • Modulation 699 • Powerline capacitor 705 • Radio choke 709 • Radio frequency (RF) 699 • RMS 706 • SDARS 707 • Skin effect 703 • Speakers 702 • Stiffening capacitor 705 • Subwoofer 704 • THD 706 • Tweeter 704 • Voice recognition 706 • Wavelength 699

AUDIO FUNDAMENTALS

INTRODUCTION The audio system of today's vehicles is a complex combination of antenna system, receiver, amplifier, and speakers all designed to provide living room–type music reproduction while the vehicle is traveling in city traffic or at highway speed.

Audio systems produce audible sounds and include:

- Radio (AM, FM, and satellite)
- Antenna systems that are used to capture electronic energy broadcast to radios
- Speaker systems
- Aftermarket enhancement devices that increase the sound energy output of an audio system
- Diagnosis of audio-related problems

Many audio-related problems can be addressed and repaired by a service technician.

TYPES OF ENERGY There are two types of energy that affect audio systems.

- **Electromagnetic energy or radio waves.** Antennas capture the radio waves which are then sent to the radio or receiver to be amplified.
- **Acoustical energy, usually called sound.** Radios and receivers amplify the radio wave signals and drive speakers which reproduce the original sound as transmitted by radio waves.

  ● **SEE FIGURE 61–1**.

TERMINOLOGY Radio waves travel at approximately the speed of light (186,282,000 miles per second) and are electromagnetic. Radio waves are measured in two ways, wavelength and frequency. A radio wave has a series of high points and low points. A **wavelength** is the time and distance between two consecutive points, either high or low. A wavelength is measured in meters. **Frequency,** also known as **radio frequency (RF),** is the number of times a particular waveform repeats itself in a given amount of time, and is measured in **hertz (Hz).** A signal with a frequency of 1 Hz is one radio wavelength per second. Radio frequencies are measured in kilohertz (kHz), thousands of wavelengths per second, and megahertz (MHz), millions of wavelengths per second. ● **SEE FIGURE 61–2**.

- The higher the frequency, the shorter the wavelength.
- The lower the frequency, the longer the wavelength.

A longer wavelength can travel a farther distance than a shorter wavelength. Therefore, lower frequencies provide better reception at farther distances.

- AM radio frequencies range from 530 to 1,710 kHz.
- FM radio frequencies range from 87.9 to 107.9 MHz.

MODULATION **Modulation** is the term used to describe when information is added to a constant frequency. The base radio frequency used for RF is called the *carrier wave.* A carrier is a radio wave that is changed to carry information. The two types of modulation are:

- **Amplitude modulation (AM)**
- **Frequency modulation (FM)**

AM waves are radio waves that have amplitude that can be varied, transmitted, and detected by a receiver. Amplitude is the height of the wave as graphed on an oscilloscope. ● **SEE FIGURE 61–3**.

FM waves are also radio waves that have a frequency that can be varied, transmitted, and detected by a receiver. This type of modulation changes the number of cycles per second, or frequency, to carry the information. ● **SEE FIGURE 61–4**.

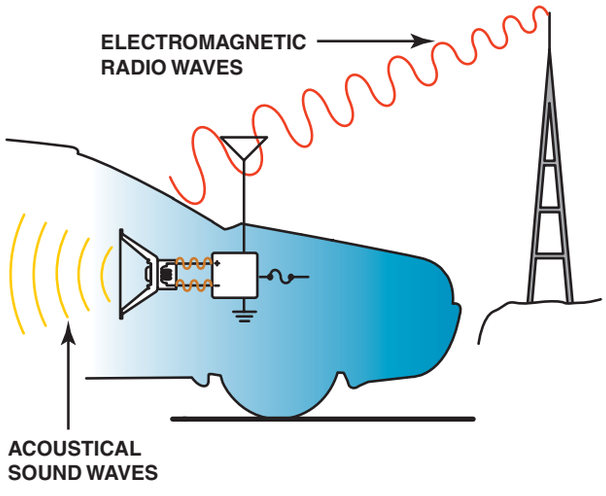


FIGURE 61–1 Audio systems use both electromagnetic radio waves and sound waves to reproduce sound inside the vehicle.

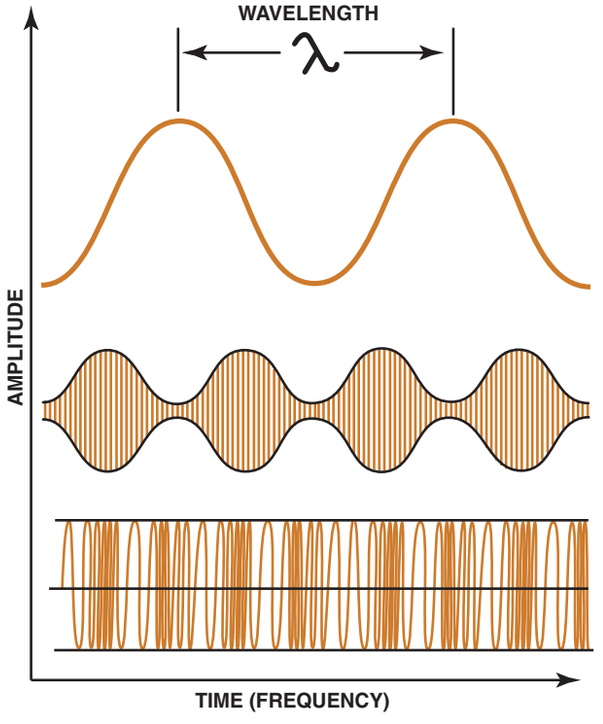


FIGURE 61–2 The relationship among wavelength, frequency, and amplitude.

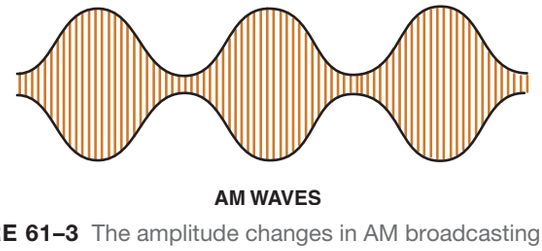


FIGURE 61–3 The amplitude changes in AM broadcasting.

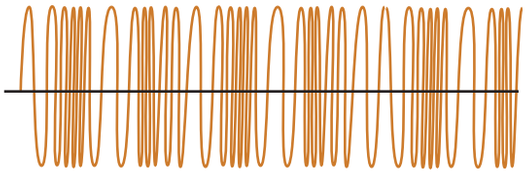


FIGURE 61–4 The frequency changes in FM broadcasting and the amplitude remains constant.

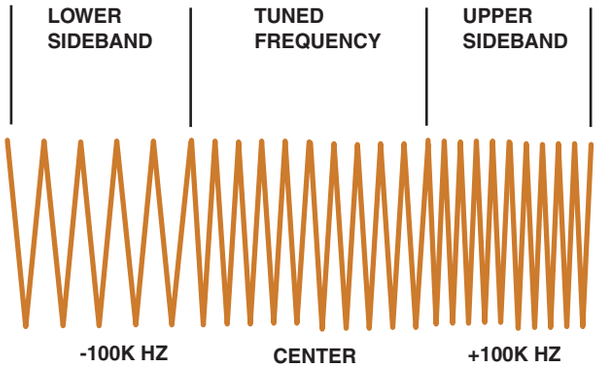


FIGURE 61–5 Using upper and lower sidebands allows stereo to be broadcast. The receiver separates the signals to provide left and right channels.

FREQUENTLY ASKED QUESTION

What Does a "Capture" Problem Mean?

A capture problem affects only FM reception and means that the receiver is playing more than one station if two stations are broadcasting at the same frequency. Most radios capture the stronger signal and block the weaker signal. However, if the stronger signal is weakened due to being blocked by buildings or mountains, the weaker signal will then be used. When this occurs, it will sound as if the radio is changing stations by itself. This is not a fault with the radio, but simply a rare occurrence with FM radio.

RADIO WAVE TRANSMISSION More than one signal can be carried by a radio wave. This process is called *sideband operation.* Sideband frequencies are measured in kilohertz. The amount of the signal above the assigned frequency is referred to as the upper sideband. The amount of the signal below the assigned frequency is called the lower sideband. This capability allows radio signals to carry stereo broadcasts. Stereo broadcasts use the upper sideband to carry one channel of the stereo signal, and the lower sideband to carry the other channel. When the signal is decoded by the radio, these two signals become the right and left channels. ● **SEE FIGURE 61–5**.

NOISE Because radio waves are a form of electromagnetic energy, other forms of energy can impact them. For example, a bolt of lightning generates broad radio-frequency bandwidths known as radio-frequency interference (RFI). RFI is one type of electromagnetic interference (EMI) and is the frequency that interferes with radio transmission.

AM CHARACTERISTICS AM radio reception can be achieved over long distances from the transmitter because the waves can bounce off the ionosphere, usually at night. Even during the day, the AM signals can be picked up some distance from the transmitter. AM radio reception depends on a good antenna. If there is a fault in the antenna circuit, AM reception is affected the most.

FM CHARACTERISTICS Because FM waves have a high RF and a short wavelength, they travel only a short distance. The waves cannot follow the shape of the earth but instead travel in a straight line from the transmitter to the receiver. FM waves will travel through the ionosphere and into space and do not reflect back to earth like AM waves.

MULTIPATH Multipath is caused by reflected, refracted, or line of sight signals reaching an antenna at different times. Multipath results from the radio receiving two signals to process on the same frequency. This causes an echo effect in the speakers. *Flutter,* or *picket fencing* as it is sometimes called, is caused by the blocking of part of the FM signal. This blocking causes a weakening of the signal resulting in only part of the signal getting to the antenna, causing an on-again off-again radio sound. Flutter also occurs when the transmitter and the receiving antenna are far apart.

The antenna receives the radio wave where it is converted into very weak fluctuating electrical current. This current travels along the antenna lead-in to the radio that amplifies the signal and sends the new signal to the speakers where it is converted into acoustical energy.

Most late-model radios and receivers use five input/output circuits.

1. **Power.** Usually a constant 12 volt feed to keep the internal clock alive
2. **Ground.** This is the lowest voltage in the circuit and connects indirectly to the negative terminal of the battery.
3. **Serial data.** Used to turn the unit on and off and provide other functions such as steering wheel control operation
4. **Antenna input.** From one or more antennas
5. **Speaker outputs.** These wires connect the receiver to the speakers or as an input to an amplifier.

ANTENNAS

TYPES OF ANTENNAS The typical radio electromagnetic energy from the broadcast antenna induces a signal in the antenna that is very small, only about 25 microvolts AC (0.000025 VAC) in strength. The radio contains amplifier circuits that increase the received signal strength into usable information.

For example, the five types of antennas used on vehicles include:

- **Slot antenna.** The slot antenna is concealed in the roof of some plastic body vehicles such as older General Motors plastic body vans. This antenna is surrounded by metal on a Mylar sheet.

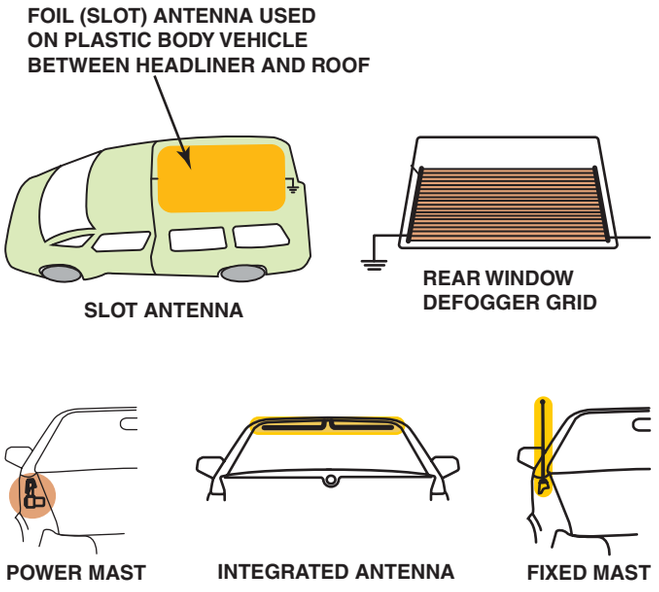


FIGURE 61–6 The five types of antennas used on General Motors vehicles include the slot antenna, fixed mast antenna, rear window defogger grid antenna, a powered mast antenna, and an integrated antenna.

- **Rear window defogger grid.** This type of system uses the heating wires to receive the signals and special circuitry to separate the RF from the DC heater circuit.
- **Powered mast.** These antennas are controlled by the radio. When the radio is turned on, the antenna is raised; when the radio is shut off, the antenna is retracted. The antenna system consists of an antenna mast and a drive motor controlled by the radio "on" signal through a relay.
- **Fixed mast antenna.** This antenna offers the best overall performance currently available. The mast is simply a vertical rod. Mast antennas are typically located on the fender or rear quarter panel of the vehicle.
- **Integrated antenna.** This type of antenna is sandwiched in the windshield and an appliqué on the rear window glass. The antenna in the rear window is the primary antenna and receives both AM and FM signals. The secondary antenna is located in the front windshield typically on the passenger side of the vehicle. This antenna receives only FM signals.

  ● **SEE FIGURE 61–6.**

ANTENNA DIAGNOSIS

ANTENNA HEIGHT The antenna collects all radio-frequency signals. An AM radio operates best with as long an antenna as possible, but FM reception is best when the antenna height is exactly 31 in. (79 cm). Most fixed-length antennas are, therefore, exactly this height. Even the horizontal section of a windshield antenna is 31 in. (79 cm) long.

A defective antenna will:

- Greatly affect AM radio reception
- May affect FM radio reception

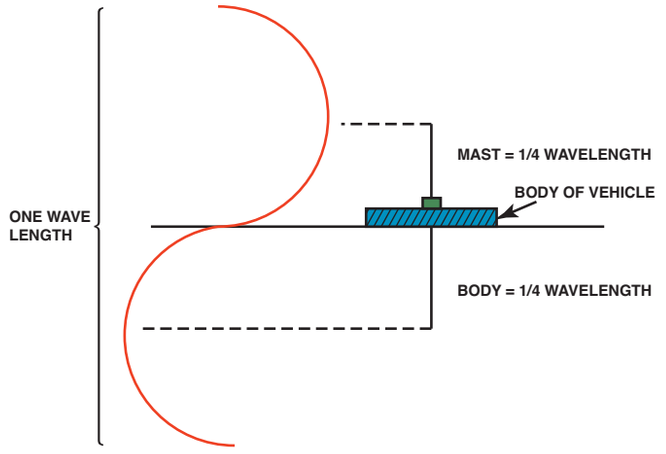


FIGURE 61–7 The ground plane is actually one-half of the antenna.

FREQUENTLY ASKED QUESTION

What Is a Ground Plane?

Antennas designed to pick up the electromagnetic energy that is broadcast through the air to the transmitting antenna are usually one-half wavelength high, and the other half of the wavelength is the **ground plane.** This one-half wavelength in the ground plane is literally underground.

For ideal reception, the receiving antenna should also be the same as the wavelength of the signal. Because this length is not practical, a design compromise uses the length of the antenna as one-fourth of the wavelength; in addition, the body of the vehicle itself is one-fourth of the wavelength. The body of the vehicle, therefore, becomes the ground plane. ● **SEE FIGURE 61–7.**

Any faulty condition in the ground plane circuit will cause the ground plane to lose effectiveness, such as:

- Loose or corroded battery cable terminals
- Acid buildup on battery cables
- Engine grounds with high resistance
- Loss of antenna or audio system grounds
- Defective alternator, causing an AC ripple exceeding 50 mV (0.050 V)

ANTENNA TESTING If the antenna or lead-in cable is broken (open), FM reception will be heard but may be weak, and there will be *no* AM reception. An ohmmeter should read infinity between the center antenna lead and the antenna case. For proper reception and lack of noise, the case of the antenna must be properly grounded to the vehicle body. ● **SEE FIGURE 61–8.**

POWER ANTENNA TESTING AND SERVICE Most power antennas use a circuit breaker and a relay to power a reversible, permanent magnet (PM) electric motor that moves a nylon cord attached to the antenna mast. Some vehicles have a dash-mounted control that can regulate antenna mast height and/or operation, whereas many operate automatically when the radio is turned on and off. The power antenna assembly is usually mounted between the outer and inner front fender or in the rear quarter panel. The unit contains the motor, a spool for the cord, and upper- and lower-limit

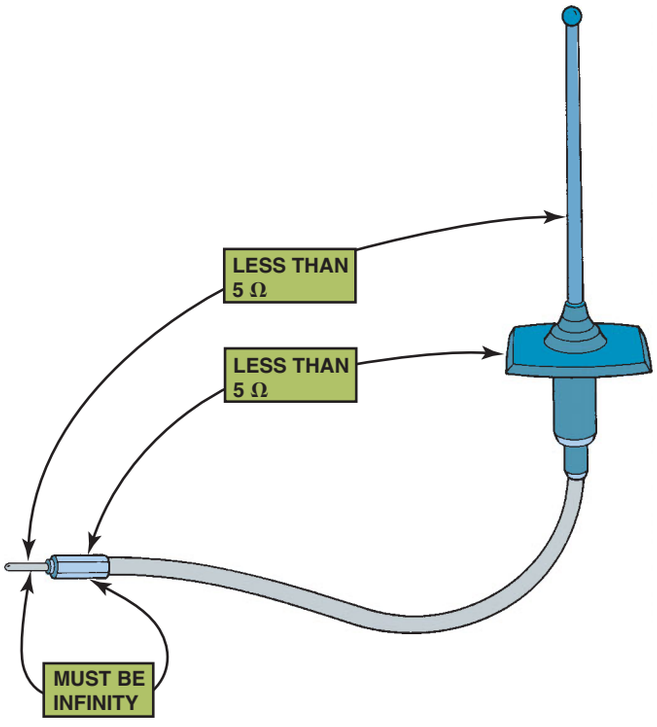


FIGURE 61–8 If all ohmmeter readings are satisfactory, the antenna is good.



FIGURE 61–9 Cutting a small hole in a fender cover helps to protect the vehicle when replacing or servicing an antenna.

TECH TIP

The Hole in the Fender Cover Trick

A common repair is to replace the mast of a power antenna. To help prevent the possibility of causing damage to the body or paint of the vehicle, cut a hole in a fender cover and place it over the antenna. ● **SEE FIGURE 61–9**.

If a wrench or tool slips during the removal or installation process, the body of the vehicle will be protected.

switches. The power antenna mast is tested in the same way as a fixed-mast antenna. (An infinity reading should be noted on an ohmmeter when the antenna is tested between the center antenna terminal and the housing or ground.) Except in the case of cleaning or mast replacement, most power antennas are either replaced as a unit or repaired by specialty shops. ● **SEE FIGURE 61–10**.

Making certain that the drain holes in the motor housing are not plugged with undercoating, leaves, or dirt can prevent many power antenna problems. All power antennas should be kept clean by wiping the mast with a soft cloth and lightly oiling with light oil such as WD-40 or similar.

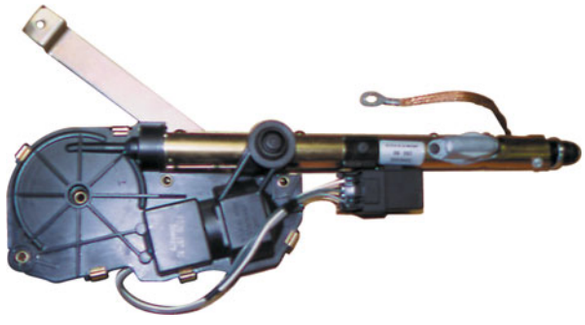


FIGURE 61–10 A typical power antenna assembly. Note the braided ground wire used to ensure that the antenna has a good ground plane.

SPEAKERS

PURPOSE AND FUNCTION The purpose of any **speaker** is to reproduce the original sound as accurately as possible. Speakers are also called *loudspeakers.* The human ear is capable of hearing sounds from a very low frequency of 20 Hz (cycles per seconds) to as high as 20,000 Hz. No one speaker is capable of reproducing sound over such a wide frequency range. ● **SEE FIGURE 61–11**.

Good-quality speakers are the key to a proper sounding radio or sound system. Replacement speakers should be securely mounted and wired according to the correct *polarity*. ● **SEE FIGURE 61–12**.

IMPEDANCE MATCHING All speakers used on the same radio or amplifier should have the same internal coil resistance, called **impedance.** If unequal-impedance speakers are used, sound quality may be reduced and serious damage to the radio may result. ● **SEE FIGURE 61–13**.

All speakers should have the same impedance. For example, if two 4 ohm speakers are being used for the rear and they are connected in parallel, the total impedance is 2 ohms.

$$R_T = \frac{4\Omega \text{ (impedance of each speaker)}}{2 \text{ (number of speakers in parallel)}} = 2 \text{ ohms}$$

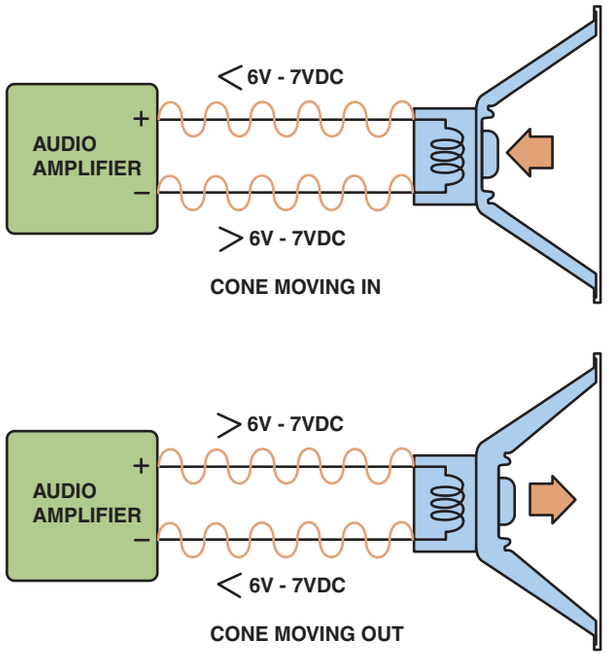


FIGURE 61–11 Between 6 and 7 volts is applied to each speaker terminal, and the audio amplifier then increases the voltage on one terminal and at the same time decreases the voltage on the other terminal causing the speaker cone to move. The moving cone then moves the air, causing sound.

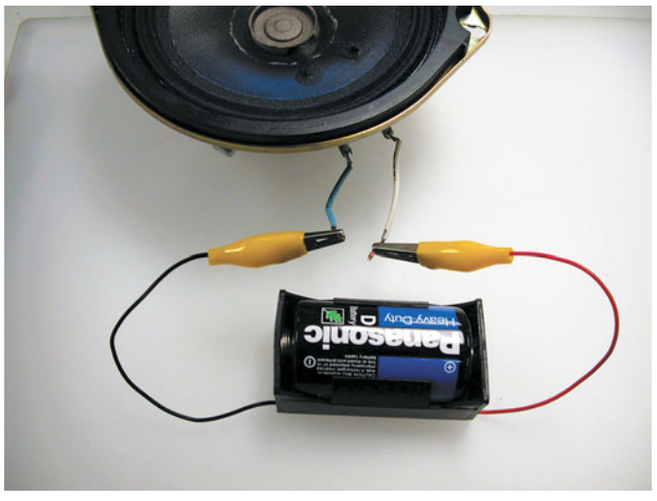


FIGURE 61–12 A typical automotive speaker with two terminals. The polarity of the speakers can be identified by looking at the wiring diagram in the service manual or by using a 1.5 volt battery to check. When the battery positive is applied to the positive terminal of the speaker, the cone will move outward. When the battery leads are reversed, the speaker cone will move inward.

The front speakers should also represent a 2 ohm load from the radio or amplifier. See the following example.

Two front speakers: each 2 ohms

Two rear speakers: each 8 ohms

Solution: Connect the front speakers in series (connect the positive [+] of one speaker to the negative [–] of the other) for a total impedance of 4 ohms (2 Ω + 2 Ω = 4 Ω). Connect the two rear speakers in parallel (connect the positive [+] of each speaker together and the negative [–] of each speaker together) for a total impedance of 4 ohms (8 Ω ÷ 2 = 4 Ω).

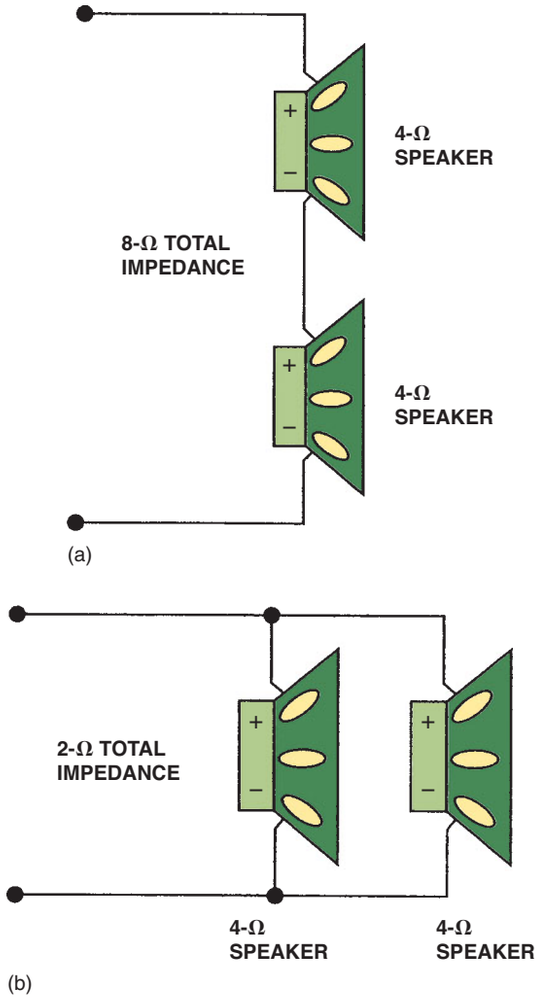


FIGURE 61–13 (a) Two 4 ohm speakers connected in series result in total impedance of 8 ohms. (b) Two 4 ohm speakers connected in parallel result in total impedance of 2 ohms.

TECH TIP

Skin Effect

When a high-frequency signal (AC voltage) is transmitted through a wire, the majority of it travels on the outside surface of the wire. This characteristic is called **skin effect.** The higher the frequency is, the closer to the outer surface the signal moves. To increase audio system output, most experts recommend the use of wire that has many strands of very fine wire to increase the surface area or the skin area of the conductor. Therefore, most aftermarket speaker wire is stranded with many small-diameter copper strands.

SPEAKER WIRING The wire used for speakers should be as large a wire (as low an AWG gauge number) as is practical in order to be assured that full power is reaching the speakers. Typical "speaker wire" is about 22 gauge (0.35 mm^2), yet tests conducted by audio engineers have concluded that increasing the wire gauge—up to 4 gauge (19 mm^2) or larger—greatly increases sound quality. All wiring connections should be soldered after making certain that all speaker connections have the correct polarity.

CAUTION: Be careful when installing additional audio equipment on a General Motors vehicle system that uses a two-wire speaker connection called a floating ground system. Other systems run only one power (hot) lead to each speaker and ground the other speaker lead to the body of the vehicle.

This arrangement helps prevent interference and static that could occur if these components were connected to a chassis (vehicle) ground. If the components are chassis grounded, there may be a difference in the voltage potential (voltage); this condition is called a *ground loop.*

CAUTION: Regardless of radio speaker connections used, *never* operate any radio without the speakers connected, or the speaker driver section of the radio may be damaged as a result of the open speaker circuit.

SPEAKER TYPES

INTRODUCTION No one speaker is capable of reproducing sound over such a wide frequency range. Therefore, speakers are available in three basic types.

1. Tweeters are for high-frequency ranges.
2. Midrange are for mid-frequency ranges.
3. Woofers and subwoofers are for low-frequency ranges.

WARNING

Hearing loss is possible if exposed to loud sounds. According to noise experts (audiologists), hearing protection should be used whenever the following occurs.

1. You must raise your voice to be heard by others next to you.
2. You cannot hear someone else speaking who is less than 3 ft (1 m) away.
3. You are operating power equipment, such as a lawnmower.

TWEETER A **tweeter** is a speaker designed to reproduce high-frequency sounds, usually between 4,000 and 20,000 Hz (4 and 20 kHz). Tweeters are very directional. This means that the human ear is most likely to be able to detect the location of the speaker while listening to music. This also means that a tweeter should be mounted in the vehicle where the sound can be directed in line of sight to the listener. Tweeters are usually mounted on the inside door near the top, windshield "A" pillar, or similar locations.

MIDRANGE A midrange speaker is designed and manufactured to be able to best reproduce sounds in the middle of the human hearing range, from 400 to 5,000 Hz. Most people are sensitive to the sound produced by these midrange speakers. These speakers are also directional in that the listener can usually locate the source of the sound.

SUBWOOFER A **subwoofer,** sometimes called a *woofer,* produces the lowest frequency of sounds, usually 125 Hz and lower. A *midbass* speaker may also be used to reproduce those frequencies between 100 and 500 Hz. Low-frequency sounds from these speakers are *not* directional. This means that the listener usually cannot detect the source of the sound from these speakers. The low-frequency sounds seem to be everywhere in the vehicle, so the location of the speakers is not as critical as with the higher frequency speakers.

The subwoofer can be placed almost anywhere in the vehicle. Most subwoofers are mounted in the rear of the vehicle where there is more room for the larger subwoofer speakers.

FREQUENTLY ASKED QUESTION

What Is a Bass Blocker?

A bass blocker is a capacitor and coil assembly that effectively blocks low frequencies. A bass blocker is normally used to block low frequencies being sent to the smaller front speakers. Using a bass blocker allows the smaller front speakers to more efficiently reproduce the midrange and high-range frequency sounds.

SPEAKER FREQUENCY RESPONSE Frequency response is how a speaker responds to a range of frequencies. A typical frequency response for a midrange speaker may be 500 to 4,000 Hz.

SOUND LEVELS

DECIBEL SCALE A **decibel (dB)** is a measure of sound power, and it is the faintest sound a human can hear in the midband frequencies. The dB scale is not linear (straight line) but logarithmic, meaning that a small change in the dB reading results in a large change in volume of noise. An increase of 10 dB in sound pressure is equal to doubling the perceived volume. Therefore, a small difference in dB rating means a big difference in the sound volume of the speaker.

EXAMPLES Some examples of decibel sound levels include:

- Quiet, faint — 30 dB: whisper, quiet library; 40 dB: quiet room
- Moderate — 50 dB: moderate range sound; 60 dB: normal conversation
- Loud — 70 dB: vacuum cleaner, city traffic; 80 dB: busy noisy traffic, vacuum cleaner
- Extremely loud — 90 dB: lawnmower, shop tools; 100 dB: chain saw, air drill
- Hearing loss possible — 110 dB: loud rock music

CROSSOVERS

DEFINITION A **crossover** is designed to separate the frequency of a sound and send a certain frequency range, such as low bass sounds, to a woofer designed to reproduce these low-frequency sounds. There are two types of crossovers: passive and active.

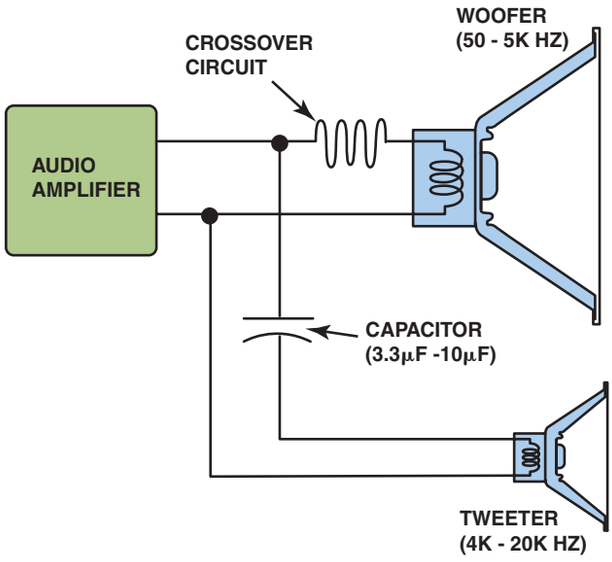


FIGURE 61–14 Crossovers are used in audio systems to send high-frequency sounds to the small (tweeter) speakers and low-frequency sounds to larger (woofer) speakers.



FIGURE 61–15 Two capacitors connected in parallel provide the necessary current flow to power large subwoofer speakers.

PASSIVE CROSSOVER A passive crossover does not use an external power source. Rather it uses a coil and a capacitor to block certain frequencies that a particular type of speaker cannot handle and allow just those frequencies that it can handle to be applied to the speaker. For example, a 6.6 millihenry coil and a 200 microfarad capacitor can effectively pass 100 Hz frequency sound to a large 10 in. subwoofer. This type of passive crossover is called a **low-pass filter,** because it passes (transfers) only the low-frequency sounds to the speaker and blocks all other frequencies. A **high-pass filter** is used to transfer higher frequency (over 100 Hz) to smaller speakers.

ACTIVE CROSSOVER **Active crossovers** use an external power source and produce superior performance. An active crossover is also called an *electronic crossover* or *crossover network.* These units include many powered filters and are considerably more expensive than passive crossovers. Two amplifiers are necessary to fully benefit from an active crossover. One amplifier is for the higher frequencies and midrange and the other amplifier is for the subwoofers. If you are on a budget and plan to use just one amplifier, then use passive crossover. If you can afford to use two or more amplifiers, then consider using the electronic (active) crossover. ● **SEE FIGURE 61–14** for an example of crossovers used in factory-installed systems.

AFTERMARKET SOUND SYSTEM UPGRADE

POWER AND GROUND UPGRADES If adding an amplifier and additional audio components, be sure to include the needed power and ground connections. These upgrades can include:

- A separate battery for the audio system
- An inline fuse near the battery to protect the wiring and the components
- Wiring that is properly sized to the amperage draw of the system and the length of wire (The higher the output wattage the greater the amperage required and the larger the wire gauge needed. The longer the distance between the battery and the components, the larger the wire gauge needed for best performance.)
- Ground wires at least the same gauge as the power side wiring (Some experts recommend using extra ground wires for best performance.)

Read, understand, and follow all instructions that come with audio system components.

POWERLINE CAPACITOR A **powerline capacitor,** also called a **stiffening capacitor,** refers to a large capacitor (often abbreviated CAP) of 0.25 farad or larger connected to an amplifier power wire. The purpose and function of this capacitor is to provide the electrical reserve energy needed by the amplifier to provide deep bass notes. ● **SEE FIGURE 61–15**.

Battery power is often slow to respond; and when the amplifier attempts to draw a large amount of current, the capacitor will try to stabilize the voltage level at the amplifier by discharging stored current as needed.

A rule of thumb is to connect a capacitor with a capacity of 1 farad for each 1,000 watts of amplifier power. ● **SEE CHART 61–1**.

POWERLINE CAPACITOR USAGE GUIDE

WATTS (AMPLIFIER)	RECOMMENDED CAPACITOR IN FARADS (MICROFARADS)
100 W	0.10 farad (100,000 µF)
200 W	0.20 farad (200,000 µF)
250 W	0.25 farad (250,000 µF)
500 W	0.50 farad (500,000 µF)
750 W	0.75 farad (750,000 µF)
1,000 W	1.00 farad (1,000,000 µF)

CHART 61–1

The rating of the capacitor needed to upgrade an audio system is directly related to the wattage of the system.

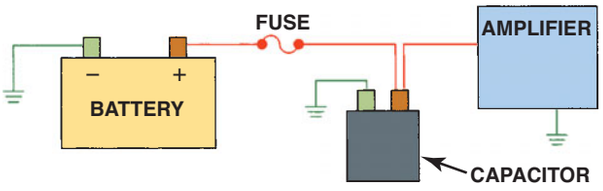


FIGURE 61–16 A powerline capacitor should be connected through the power wire to the amplifier as shown. When the amplifier requires more electrical power (watts) than the battery can supply, the capacitor will discharge into the amplifier and supply the necessary current for the fraction of a second it is needed by the amplifier. At other times when the capacitor is not needed, it draws current from the battery to keep it charged.

CAPACITOR INSTALLATION

A powerline capacitor connects to the power leads between the inline fuse and the amplifier. ● **SEE FIGURE 61–16**.

If the capacitor were connected to the circuit as shown without "precharging," the capacitor would draw so much current that it would blow the inline fuse. To safely connect a large capacitor, it must be *precharged.* To precharge the capacitor, follow these steps.

STEP 1 Connect the negative (−) terminal of the capacitor to a good chassis ground.

STEP 2 Insert an automotive 12 V light bulb, such as a headlight or parking light, between the positive (+) terminal of the capacitor and the positive terminal of the battery. The light will light as the capacitor is being charged and then go out when the capacitor is fully charged.

STEP 3 Disconnect the light from the capacitor, then connect the power lead to the capacitor. The capacitor is now fully charged and ready to provide the extra power necessary to supplement battery power to the amplifier.

VOICE RECOGNITION

PARTS AND OPERATION

Voice recognition is an expanding technology. It allows the driver of a vehicle to perform tasks, such as locate an address in a navigation system by using voice commands rather than buttons. In the past, users had to say the exact words to make it work such as the following examples listed from an owner manual for a vehicle equipped with a voice-actuated navigation system.

"Go home"

"Repeat guidance"

"Nearest ATM"

The problem with these simple voice commands was that the exact wording had to be spoken. The voice recognition software would compare the voice command to a specific list of words or phrases stored in the system in order for a match to occur. Newer systems recognize speech patterns and take action based on learned patterns. Voice recognition can be used for the following functions.

1. Navigation system operation (● **SEE FIGURE 61–17**.)
2. Sound system operation
3. Climate control system operation
4. Telephone dialing and other related functions (● **SEE FIGURE 61–18**.)



FIGURE 61–17 Voice commands can be used to control many functions, including navigation systems, climate control, telephone, and radio.

? FREQUENTLY ASKED QUESTION

What Do the Amplifier Specifications Mean?

RMS power	**RMS** means root-mean-square and is the rating that indicates how much power the amplifier is capable of producing continuously.
RMS power at 2 ohms	This specification in watts indicates how much power the amplifier delivers into a 2 ohm speaker load. This 2 ohm load is achieved by wiring two 4 ohm speakers in parallel or by using 2 ohm speakers.
Peak power	Peak power is the maximum wattage an amplifier can deliver in a short burst during a musical peak.
THD	**Total harmonic distortion (THD)** represents the amount of change of the signal as it is being amplified. The lower the number, the better the amplifier (e.g., a 0.01% rating is better than a 0.07% rating).
Signal-to-noise ratio	This specification is measured in decibels (dB) and compares the strength of the signal with the level of the background noise (hiss). A higher volume indicates less background noise (e.g., a 105 dB rating is better than a 100 dB rating).

A microphone is usually placed in the driver's side sun visor or in the overhead console in the center top portion of the windshield area.

DIAGNOSIS AND SERVICE

Voice recognition is usually incorporated into many functions of the vehicle. If a problem occurs with the system, perform the following steps.

1. Verify the customer complaint (concern). Check the owner manual or service information for the proper voice commands and verify that the system is not functioning correctly.



FIGURE 61–18 The voice command icon on the steering wheel of a Cadillac.



FIGURE 61–19 Bluetooth earpiece that contains a microphone and speaker unit that is paired to a cellular phone. The telephone has to be within 33 ft (10 m) of the earpiece.

2. Check for any aftermarket accessories that may interfere or were converted to components used by the voice recognition system, such as remote start units, MP3 players, or any other electrical component.
3. Check for stored diagnostic trouble codes (DTCs) using a scan tool.
4. Follow the recommended troubleshooting procedures as stated in service information.

BLUETOOTH

OPERATION

Bluetooth is a (radio frequency) standard for short-range communications. The range of a typical Bluetooth device is 33 ft (10 m) and it operates in the ISM (industrial, scientific, and medical) band between 2.4000 and 2.4835 MHz.

Bluetooth is a wireless standard that works on two levels.

- It provides physical communication using low power, requiring only about 1 milliwatt (1/1,000 of a watt) of electrical power, making it suitable for use with small handheld or portable devices, such as an ear-mounted speaker/microphone.
- It provides a standard protocol for how bits of data are sent and received.

The Bluetooth standard is an advantage because it is wireless, low cost, and automatic. The automotive use of Bluetooth technology is in the operation of a cellular telephone being tied into the vehicle. The vehicle allows the use of hands-free telephone usage. A vehicle that is Bluetooth telephone equipped has the following components.

- A Bluetooth receiver can be built into the navigation or existing sound system.
- A microphone allows the driver to use voice commands as well as telephone conversations from the vehicle to the cell via Bluetooth wireless connections.

Many cell phones are equipped with Bluetooth which may allow the caller to use an ear-mounted microphone and speaker. ● **SEE FIGURE 61–19**.

If the vehicle and the cell phone are equipped with Bluetooth, the speaker and microphone can be used as a hands-free telephone when the phone is in the vehicle. The cell phone can be activated in the vehicle by using voice commands.

? FREQUENTLY ASKED QUESTION

Where Did Bluetooth Get Its Name?

The early adopters of the standard used the term Bluetooth, and they named it for Harold Bluetooth, the king of Denmark in the late 900s. The king was able to unite Denmark and part of Norway into a single kingdom.

? FREQUENTLY ASKED QUESTION

Can Two Bluetooth Telephones Be Used in a Vehicle?

Usually. In order to use two telephones, the second phone needs to be given a name. When both telephones enter the vehicle, check which one is recognized. Say "phone status" and the system will tell you to which telephone the system is responding. If it is not the one you want, simply say, "next phone" and it will move to the other one.

SATELLITE RADIO

PARTS AND OPERATION

Satellite radio, also called **Satellite Digital Audio Radio Services** or **SDARS,** is a fee-based system that uses satellites to broadcast high-quality radio. SDARS broadcasts on the S-band of 2.1320 to 2.345 GHz.

SIRIUS/XM RADIO

Sirius/XM radio is standard equipment or optional in most vehicles. XM radio uses two satellites launched in 2001 called Rock (XM-2) and Roll (XM-1) in a geosynchronous orbit above North America. Two replacement satellites, Rhythm (XM-3) and Blues (XM-4) were launched in 2006. Sirius and XM radio combined in 2008 and now share some programming. The two types of satellite radios use different protocols and, therefore, require separate radios unless a combination unit is purchased.

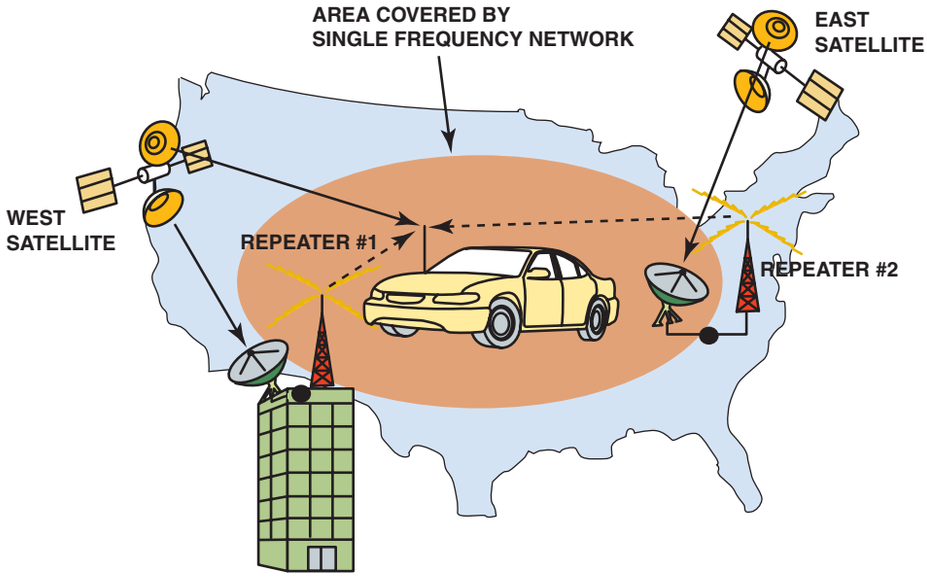


FIGURE 61–20 SDARS uses satellites and repeater stations to broadcast radio.



FIGURE 61–21 An aftermarket XM radio antenna mounted on the rear deck lid. The deck lid acts as the ground plane for the antenna.



FIGURE 61–22 A shark-fin-type factory antenna used for both XM and OnStar.

RECEPTION Reception from satellites can be affected by tall buildings and mountains. To help ensure consistent reception, both SDARS providers do the following:

- Include in the radio itself a buffer circuit that can store several seconds of broadcasts to provide service when traveling out of a service area
- Provide land-based repeater stations in most cities (● **SEE FIGURE 61–20**.)

ANTENNA To be able to receive satellite radio, the antenna needs to be able to receive signals from both the satellite and the repeater stations located in many large cities. There are various types and shapes of antennas, including those shown in ● **FIGURES 61–21 AND 61–22**.

DIAGNOSIS AND SERVICE The first step in any diagnosis is to verify the customer complaint (concern). If no satellite service is being received, first check with the customer to verify that the monthly service fee has been paid and the account is up to date. If poor reception is the cause, carefully check the antenna for damage or faults with the lead-in wire. The antennas must be installed on a metal surface to provide the proper ground plane.

For all other satellite radio fault problems, check service information for the exact tests and procedures. Always follow the factory recommended procedures. Check the following websites for additional information.

- **www.xmradio.com**
- **www.sirius.com**
- **www.siriusxm.com**

RADIO INTERFERENCE

DEFINITION Radio interference is caused by variations in voltage in the powerline or picked up by the antenna. A "whine" that increases in frequency with increasing engine speed is usually referred to as an **alternator whine** and is eliminated by installing a radio choke or a filter capacitor in the power feed wire to the radio. ● **SEE FIGURE 61–23**.

CAPACITOR USAGE Ignition noise is usually a raspy sound that varies with the speed of the engine. This noise is usually eliminated by the installation of a capacitor on the positive side of the ignition coil. The capacitor should be connected to the power feed wire to either the radio or the amplifier, or both. The capacitor *has* to be grounded. A capacitor allows AC interference to pass through to

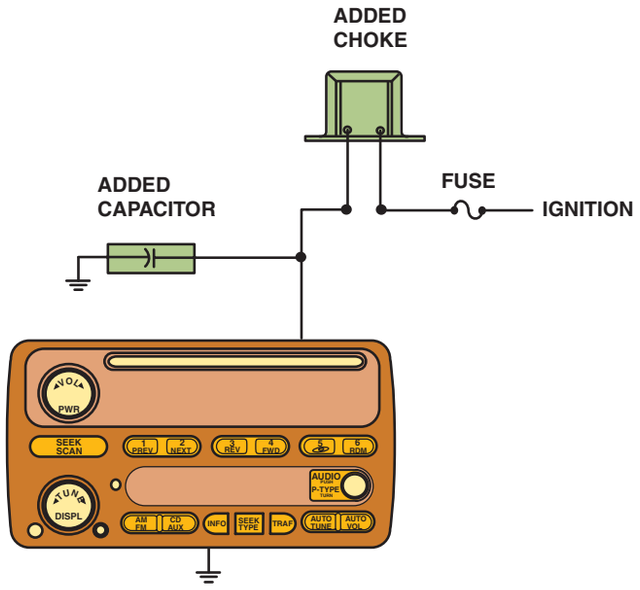


FIGURE 61–23 A radio choke and/or a capacitor can be installed in the power feed lead to any radio, amplifier, or equalizer.

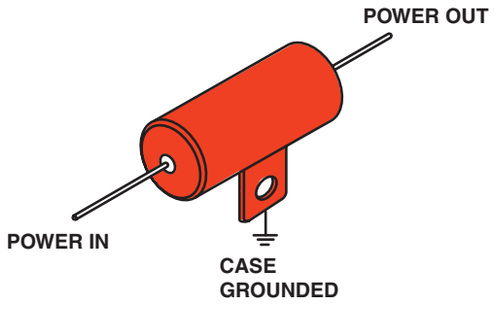


FIGURE 61–24 Many automobile manufacturers install a coaxial capacitor, like this one, in the power feed wire to the blower motor to eliminate interference caused by the blower motor.

ground while blocking the flow of DC current. Use a 470 µF, 50 volt electrolytic capacitor, which is readily available from most radio supply stores. A special coaxial capacitor can also be used in the powerline. ● **SEE FIGURE 61–24**.

RADIO CHOKE A **radio choke,** which is a coil of wire, can also be used to reduce or eliminate radio interference. Again, the radio choke is installed in the power feed wire to the radio equipment. Radio interference being picked up by the antenna can best be eliminated by stopping the source of the interference and making certain that all units containing a coil, such as electric motors, have a capacitor or diode attached to the power-side wire.

BRAIDED GROUND WIRE Using a braided ground wire is usually specified when electrical noise is a concern. The radio-frequency signals travel on the surface of a conductor rather than through the core of the wire. A braided ground strap is used because the overlapped wires short out any radio-frequency signals traveling on the surface.

AUDIO NOISE SUMMARY In summary:

- Radio noise can be broadcast or caused by noise (voltage variations) in the power circuit to the radio.
- Most radio interference complaints come when someone installs an amplifier, power booster, equalizer, or other radio accessory.
- *A major cause of this interference is the variation in voltage through the ground circuit wires. To prevent or reduce this interference, make sure all ground connections are clean and tight.*
- Placing a capacitor in the ground circuit also may be beneficial.

CAUTION: Amplifiers sold to boost the range or power of an antenna often increase the level of interference and radio noise to a level that disturbs the driver.

Capacitor and/or radio chokes are the most commonly used components. Two or more capacitors can be connected in parallel to increase the capacity of the original capacitor. A "sniffer" can be used to locate the source of the radio noise. A sniffer is a length of antenna wire with a few inches of insulation removed from the antenna end. The sniffer is attached to the antenna input terminal of the radio, and the radio is turned on and set to a weak station. The other end of the sniffer is then moved around areas of the dash to locate where the source of the interference originates. The radio noise will greatly increase if the end of the sniffer comes close to where electromagnetic leakage is occurring. ● **SEE FIGURE 61–25**.

● **SEE CHART 61–2**.



FIGURE 61–25 A "sniffer" can be made from an old antenna lead-in cable by removing about 3 in. of the outer shielding from the end. Plug the lead-in cable into the antenna input of the radio and tune the radio to a weak station. Move the end of the antenna wire around the vehicle dash area. The sniffer is used to locate components that may not be properly shielded or grounded and can cause radio interference through the case (housing) of the radio itself.

FREQUENTLY ASKED QUESTION

What Does ESN Mean?

ESN means electronic serial number. This is necessary information to know when reviewing satellite radio subscriptions. Each radio has its own unique ESN, often found on a label at the back or bottom of the unit. It is also often shown on scan tools or test equipment designed to help diagnose faults in the units.

TECH TIP

The Separate Battery Trick

Whenever diagnosing sound system interference, try running separate 14 gauge wire(s) from the sound system power lead and ground to a separate battery outside of the vehicle. If the noise is still heard, the interference is *not* due to an alternator diode or other source in the wiring of the vehicle.

AUDIO NOISE CONTROL SYMPTOM CHART		
NOISE SOURCE	**WHAT IT SOUNDS LIKE**	**WHAT TO TRY**
Alternator	A whine whose pitch changes with engine speed	Install a capacitor to a ground at the alternator output
Ignition	Ticking that changes with engine speed	Use a sniffer to further localize the source of the problem
Turn signals	Popping in time with the turn signals	Install a capacitor across the turn signal flasher
Brake lights	Popping whenever the brake pedal is depressed	Install a capacitor across the brake light switch contacts
Blower motor	Ticking in time with the blower motor	Install a capacitor to ground at the motor hot lead
Dash lamp dimmer	A buzzy whine whose pitch changes with the dimmer setting	Install a capacitor to ground at the dimmer hot lead
Horn switch	Popping when the horn is sounded	Install a capacitor between the hot lead and horn lead at the horn relay
Horn	Buzzing synchronized with the horn	Install a capacitor to ground at each horn hot lead
Amplifier power supply	A buzz, not affected by engine speed	Ground the amplifier chassis using a braided ground strap

CHART 61–2

Radio noise can have various causes, and knowing where or when the noise occurs helps pin down the location.



REAL WORLD FIX

Lightning Damage

A radio failed to work in a vehicle that was outside during a thunderstorm. The technician checked the fuses and verified that power was reaching the radio. Then the technician noticed the antenna. It had been struck by lightning. Obviously, the high voltage from the lightning strike traveled to the radio receiver and damaged the circuits. Both the radio and the antenna were replaced to correct the problem.

● **SEE FIGURE 61–26.**



FIGURE 61–26 The tip of this antenna was struck by lightning.



REAL WORLD FIX

The General Motors Security Radio Problem

A customer replaced the battery in a General Motors vehicle and now the radio display shows "LOC." This means that the radio is locked and there is a customer code stored in the radio.

Other displays and their meaning include:

"InOP" This display indicates that too many incorrect codes have been entered and the radio must be kept powered for one hour and the ignition turned on before any more attempts can be made.

"SEC" This display means there is a customer's code stored and the radio is unlocked, secured, and operable.

"---" This means there is no customer code stored and the radio is unlocked.

"REP" This means the customer's code has been entered once and the radio now is asking that the code be repeated to verify it was entered correctly the first time.

To unlock the radio, the technician used the following steps (the code number being used is 4321).

STEP 1 Press the "HR" (hour) button: "000" is displayed.
STEP 2 Set the first two digits using the hour button: "4300" is displayed.
STEP 3 Set the last two digits of the code using the "MIN" (minutes) button: "4321" is displayed.
STEP 4 Press the AM-FM button to enter the code. The radio is unlocked and the clock displays "1:00."

Thankfully, the owner had the security code. If the owner had lost the code, the technician would have to secure a scrambled factory backup code from the radio and then call a toll-free number to obtain another code for the customer. The code will only be given to authorized dealers or repair facilities.

REVIEW QUESTIONS

1. Why do AM signals travel farther than FM signals?
2. What are the purpose and function of the ground plane?
3. How do you match the impedance of speakers?
4. What two items may need to be added to the wiring of a vehicle to control or reduce radio noise?

CHAPTER QUIZ

1. Technician A says that a radio can receive AM signals, but not FM signals, if the antenna is defective. Technician B says that a good antenna should give a reading of about 500 ohms when tested with an ohmmeter between the center antenna wire and ground. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. An antenna lead-in wire should have how many ohms of resistance between the center terminal and the grounded outer covering?
   a. Less than 5 ohms
   b. 5 to 50 ohms
   c. 300 to 500 ohms
   d. Infinity (OL)
3. Technician A says that a braided ground wire is best to use for audio equipment to help reduce interference. Technician B says to use insulated 14 gauge or larger ground wire to reduce interference. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. What maintenance should be performed to a power antenna to help keep it working correctly?
   a. Remove it from the vehicle and lubricate the gears and cable.
   b. Clean the mast with a soft cloth and lubricate with a light oil.
   c. Disassemble the mast and pack the mast with silicone grease (or equal).
   d. Loosen and then retighten the retaining nut.
5. If two 4 ohm speakers are connected in parallel, meaning positive (+) to positive (+) and negative (−) to negative (−), the total impedance will be _____.
   a. 8 ohms
   b. 4 ohms
   c. 2 ohms
   d. 1 ohm
6. If two 4 ohm speakers are connected in series, meaning the positive (+) of one speaker connected to the negative (−) of the other speaker, the total impedance will be _____.
   a. 8 ohms
   b. 4 ohms
   c. 5 ohms
   d. 1 ohm
7. An aftermarket satellite radio has poor reception. Technician A says that a lack of a proper ground plane on the antenna could be the cause. Technician B says that mountains or tall buildings can interfere with reception. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. 100,000 µF means _____.
   a. 0.10 farad
   b. 0.01 farad
   c. 0.001 farad
   d. 0.0001 farad
9. A radio choke is actually a _____.
   a. Resistor
   b. Capacitor
   c. Coil (inductor)
   d. Transistor
10. What device passes AC interference to ground and blocks DC voltage, and is used to control radio interference?
    a. Resistor
    b. Capacitor
    c. Coil (inductor)
    d. Transistor

SECTION VIII

Heating and Air Conditioning

62 Heating and Air-Conditioning Components and Operation
63 Automatic Air-Conditioning System Operation
64 Heating and Air-Conditioning System Diagnosis
65 Heating and Air-Conditioning System Service

chapter 62

HEATING AND AIR-CONDITIONING COMPONENTS AND OPERATION

OBJECTIVES: **After studying Chapter 62, the reader will be able to:** • Prepare for ASE Heating and Air-conditioning (A7) certification test content area "A" (Air Conditioning System Diagnosis and Repair) and content area "C" (Heating and Engine Cooling Systems Diagnosis and Repair). • Describe how the heater functions. • Describe how the refrigeration cycle functions. • List the parts of a typical air-conditioning system. • Explain how the air-conditioning system removes heat from the passenger compartment.

KEY TERMS: Absolute humidity 714 • Axial compressor 728 • Barrier hose 723 • Blower motor 714 • Boiling point 713 • Calorie (c) 713 • Capillary tube 723 • CFC-12 (R-12) 718 • Compressor 715 • Condenser 715 • Condensate line 721 • Condensation point 713 • Cycling clutch orifice tube (CCOT) 716 • Desiccant 721 • Electromagnetic clutch 717 • Ester oil 720 • Evaporator 715 • Evaporator pressure regulator (EPR) valve 718 • Freon 718 • Heat 713 • Heater core 714 • Heater hoses 714 • Heating, ventilation, and air-conditioning system (HVAC) 712 • HFC-134a (R-134a) 718 • Humidity 714 • H-valve 725 • Hygrometer 714 • Kinetic energy 713 • Latent heat of vaporization 713 • Liquid 713 • Miscible 720 • Pilot operated absolute (POA) valve 718 • Pintle valve 723 • Positive-displacement compressor 726 • Psychrometer 714 • Reed valve 727 • Relative humidity 714 • Section 609 (clean air act) 719 • Solid 713 • Superheat 724 • Swash plate 728 • Thermostatic expansion valve (TEV or TXV) system 716 • Thermo switch (icing switch or defrost switch) 718 • Vapor 713

PURPOSE AND FUNCTION

Driver and passenger comfort is the primary purpose of the heating, ventilation, and air-conditioning system, often abbreviated **HVAC.** The heater is also needed in cold climates to prevent freezing or death.

PRINCIPLES INVOLVED On earth, matter is found in one of three different phases or states: solid, liquid, or vapor (gas). The state depends upon the nature of the substance, the temperature, and the pressure or force exerted on it. Water occurs naturally in all three states: solid ice, liquid water, and water vapor, depending upon the temperature and pressure of the location. ● **SEE FIGURE 62–1.**

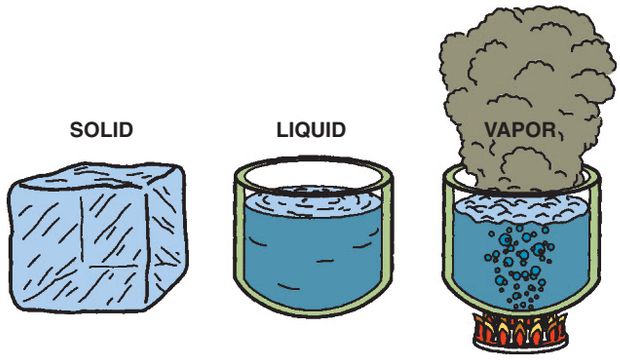
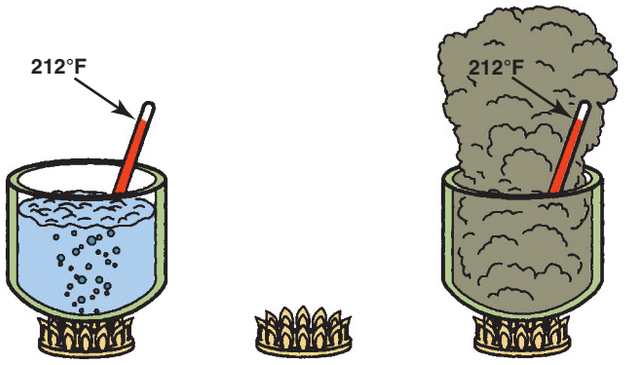


FIGURE 62–1 Water is a substance that can be found naturally in solid, liquid, and vapor states.

FREQUENTLY ASKED QUESTION

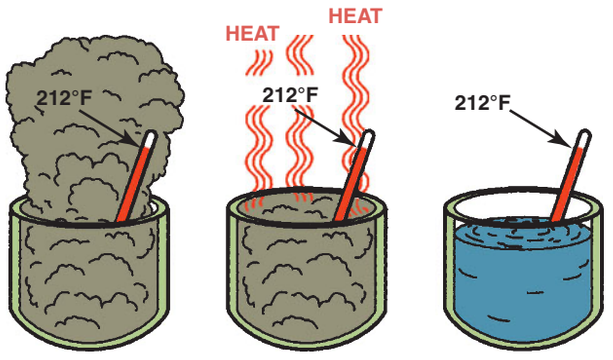
Why Is Liquid Sprayed from a Can Cold?

If you spray a can of liquid continuously, the can becomes cold, and the liquid being sprayed becomes cold. The can becomes cold because the pressure in the can is reduced while spraying, allowing the liquid propellant inside the can to boil and absorb heat. The liquid being sprayed has also been cooled by the liquid propellant. The propellant vapor is further cooled as it decompresses when it hits the open air. Rapid decompression results in a rapid temperature drop.



1 GRAM WATER + 540 CALORIES = 1 GRAM VAPOR
1 POUND WATER + 970 BTUs = 1 POUND VAPOR

FIGURE 62–2 The extra heat required to change a standard amount of water at its boiling point to a vapor is called **latent heat of vaporization.**



1 GRAM VAPOR + 540 CALORIES = 1 GRAM WATER
1 POUND VAPOR + 970 BTUs = 1 POUND WATER

FIGURE 62–3 The latent heat of vaporization that water vapor stores is given off when the vapor condenses to a liquid. The temperature stays the same.

CHANGES OF STATE

A **solid** is a substance that cannot be compressed and has strong resistance to flow. The molecules of a solid attract each other strongly, and resist changes in volume and shape.

A substance is solid at any temperature below its melting point. A melting point is a characteristic of a substance, and is related to the temperature at which a solid turns to a liquid. For water, the melting point is 32°F (0°C), which means that we can observe changes between liquid water and ice under normal weather conditions.

A **liquid** is a substance that cannot be compressed. A substance in a liquid state has a fixed volume, but no definite shape.

The **boiling point** is the temperature at which a liquid substance turns to a vapor. For water at normal sea level conditions, the boiling point is 212°F (100°C).

A **vapor** is a substance that can be easily compressed, has no resistance to flow, and no fixed volume. Since a vapor flows, it is considered a fluid just like liquids are.

A substance changes to a vapor if the temperature rises above its boiling point. A vapor condenses to liquid if the temperature falls below it. Just like melting and freezing, the boiling point and **condensation point** are the same temperature. Again, the difference is simply whether heat is being added or taken away. Boiling point and condensation point temperatures are not fixed; they vary with pressure.

HEAT AND TEMPERATURE

Molecules in a substance tend to vibrate rapidly in all directions, and this disorganized energy is called **heat.** The intensity of vibration depends on how much **kinetic energy,** or energy of motion, the atom or molecule contains. We measure the level of this energy as temperature.

Heat and temperature are not the same. Temperature is measured in degrees. Heat is measured in **calories (c).** The calorie is a metric unit that expresses the amount of heat needed to raise the temperature of one gram of water one degree Celsius.

Heat is also measured in British Thermal Units (BTU). One BTU is the heat required to raise the temperature of one pound of water 1°F at sea level. One BTU equals 252 calories.

LATENT HEAT

Latent heat is the "extra" heat that is needed to transform a substance from one state to another. Imagine that a solid or a liquid is being heated on a stove. When the solid reaches its melting point, or the liquid reaches its boiling point, their temperatures stop rising. The solid begins to melt, and the liquid begins to boil. This occurs without any change in temperature, even though heat is still being poured in from the burner.

The water in the container on the stove boils at a temperature of 212°F (100°C) at sea level, for as long as any liquid water remains. As you continue to add heat with the burner, it will all be absorbed in changing the state of the liquid to a vapor. This extra, hidden amount of energy necessary to change the state of a substance is called latent heat. ● **SEE FIGURES 62–2 AND 62–3.**

Latent heat is important in air-conditioning system operation because the cooling effect is derived from changing the state of liquid refrigerant to a vapor. The refrigerant absorbs latent heat of vaporization, cooling the air blown into the passenger compartment. Heat is taken away to cool the air.

TEMPERATURE, VOLUME, AND PRESSURE OF A VAPOR

Unlike a solid, a vapor has no fixed volume. Increasing the temperature of a vapor, while keeping the volume confined in the same space, increases the pressure. This happens as the vibrating vapor molecules collide more and more energetically with the walls of the container. Conversely, decreasing the temperature decreases the pressure. This relationship between temperature and pressure in vapor is why a can of nonflammable refrigerant can explode when heated by a flame—the pressure buildup inside the can will eventually exceed the can's ability to contain the pressure.

Increasing the pressure by compressing a vapor increases the temperature. Decreasing the pressure by permitting the vapor to expand decreases the temperature.

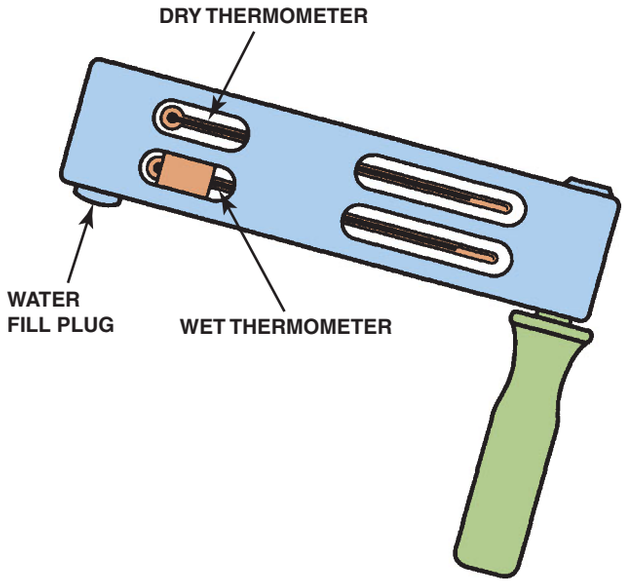


FIGURE 62–4 A sling psychrometer is used to measure relative humidity.

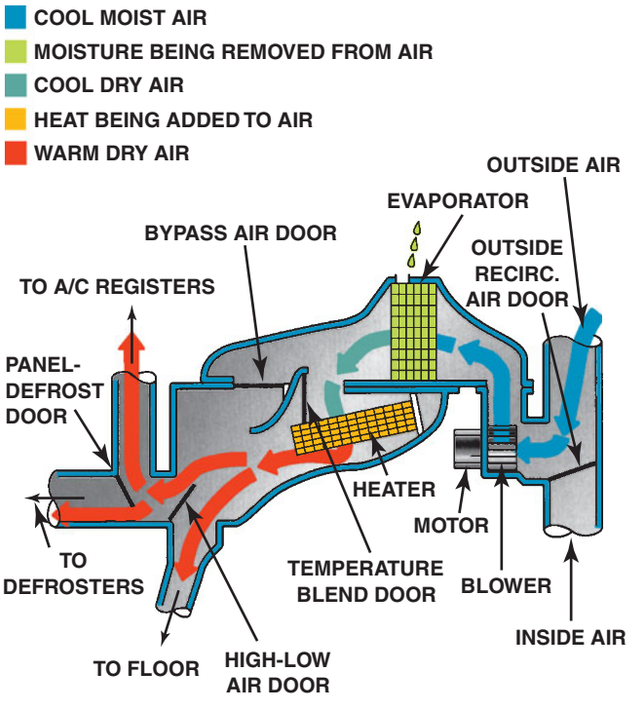


FIGURE 62–5 Typical flow of air through an automotive heat, ventilation, and air-conditioning system when placed in the heat position.

PRESSURE-TEMPERATURE RELATIONSHIPS

There are two aspects of the relationship between pressure and temperature that are important to understanding the operating of an HVAC system:

- The temperature at which a liquid boils (and vapor condenses) rises and falls with the pressure.
- Pressure in a sealed system that contains both liquid and vapor rises and falls with the temperature.

HUMIDITY

Water vapor is in the air in varying concentrations. **Humidity** refers to water vapor present in the air. The level of humidity depends upon the amount of water vapor present and the temperature of the air.

The amount of water vapor in the air tends to be higher near lakes or the ocean, because more water is available to evaporate from their surfaces. In desert areas with little open water, the amount of water vapor in the air tends to be low.

Absolute humidity is the measurement of the weight of the water vapor in a given volume of air. **Relative humidity** is the percentage of how much moisture is present in the air compared to how much moisture the air is capable of holding at that temperature.

Relative humidity is commonly measured with a **hygrometer** or a **psychrometer.** A hygrometer depends on a sensitive element that expands and contracts, based on the humidity. Hygrometers typically resemble a clock, with the scale reading from 0% to 100% relative humidity. Permanent-recording hygrometers may be constructed so that an ink pen or electric stylus makes a continuous record on a rotating paper disc or paper-covered drum.

A psychrometer uses two thermometers, one of which has the bulb covered in a cotton wick soaked in distilled water from a built-in reservoir. ● **SEE FIGURE 62–4**. The wick keeps the bulb of the "wet thermometer" wet so that it can be cooled by evaporation. To take a relative humidity reading, the psychrometer is placed in the airflow for a certain time. As the evaporator blows air, the wet bulb's temperature drops, and the dry bulb reads the temperature of the airflow. Sling psychrometers are spun around in the air a certain number of times. Water evaporates from the cotton wick at a rate inversely proportional to the relative humidity of the air; faster if the humidity is low, and slower if the humidity is high.

The "dry thermometer" registers ordinary air temperature. The higher the relative humidity, the closer the readings of the two thermometers, and the lower the humidity, the greater the difference. The different temperatures indicated by the wet and dry thermometers are compared to a chart, which gives the relative humidity.

HEATING SYSTEM

PURPOSE AND FUNCTION

All automotive and light-truck heater systems use the hot coolant from the engine to produce heat. The heater system is designed to provide passenger comfort and the heat needed to defrost windshield and front side windows in many vehicles. Therefore the heating system is a major safety system in the vehicle.

PARTS AND OPERATION

The engine coolant (antifreeze and water) flows through **heater hoses** and a **heater core.** The engine water pump supplies the force necessary to circulate the engine coolant through the heater core. The heater core is a small radiator with tubes and fins that help transfer the heat from the coolant to the air flowing through the heater core. ● **SEE FIGURE 62–5**. A **blower motor** with a squirrel cage-type fan is usually used to force air through the heater core and into the passenger compartment. ● **SEE FIGURE 62–6**. Before the heater can function correctly, the cooling system has to be functioning correctly. The following parts are also used to control the flow of coolant and therefore control the temperature of the passenger compartment.

1. Heater control valve.

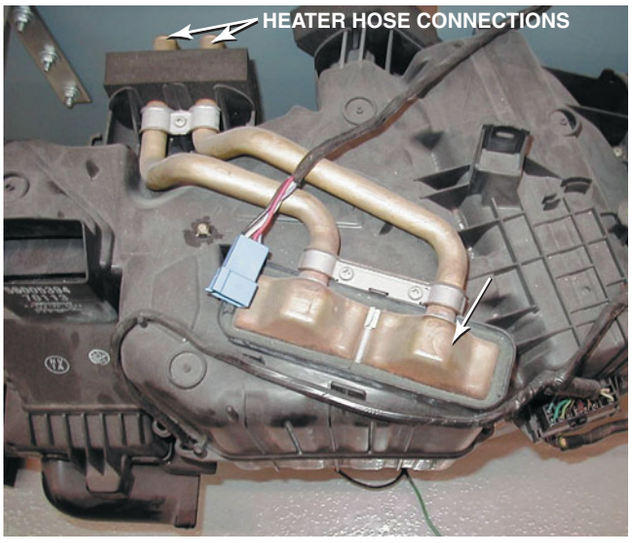


FIGURE 62–6 A typical heater core as installed in an HVAC housing.

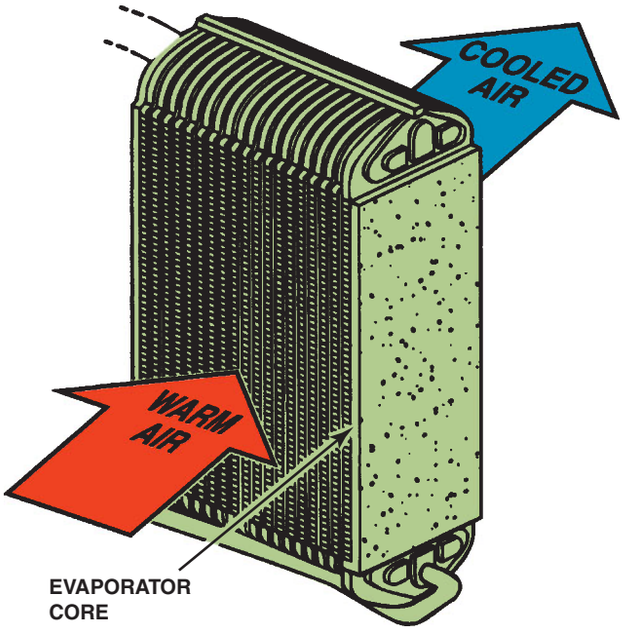


FIGURE 62–7 The evaporator removes heat from the air that enters a vehicle by transferring it to the vaporizing refrigerant.

? FREQUENTLY ASKED QUESTION

What Is an Auxiliary Electric Water Pump?

Some vehicles are equipped with an auxiliary electric water pump. The purpose and function of this pump is to help warm the interior of the vehicle by circulating coolant from the engine through the heater core when the engine is at idle speed. At idle speed, the water pump does not circulate a sufficient quantity of coolant through the heater core to warm the interior in freezing weather.

? FREQUENTLY ASKED QUESTION

How Does the Inside of the Vehicle Get Cooled?

The underlying principle involved in air-conditioning or refrigeration is that "cold attracts heat." Therefore, a cool evaporator attracts the hot air inside the vehicle. Heat always travels toward cold and when the hot air passes through the cold evaporator, the heat is absorbed by the cold evaporator, which lowers the temperature of the air. The cooled air is then forced into the passenger compartment by the blower through the air-conditioning vents.

AIR-CONDITIONING REFRIGERATION CYCLE

All automotive air-conditioning systems are closed and sealed. A refrigerant is circulated through the system by a **compressor** that is powered by the engine through an accessory drive belt. Older systems used a refrigerant, CFC-12, commonly referred to by its Dupont trade name of Freon or R-12. Starting in the early 1990s, vehicle manufacturers now all use HFC-134a, a refrigerant that is less harmful to the atmosphere. The basic principle of the refrigeration cycle is that as a liquid changes into a gas, heat is absorbed. The heat that is absorbed by an automotive air-conditioning system is the heat from inside the vehicle. This is how the system works:

1. The liquid refrigerant evaporates in a small radiator-type unit called the **evaporator.** As the refrigerant evaporates, it absorbs heat as it changes from a liquid to a gas. As the heat is absorbed by the refrigerant, the evaporator becomes cold. ● **SEE FIGURE 62–7**.
2. After the refrigerant has evaporated into a *low-pressure gas* in the evaporator, the refrigerant flows into the engine-driven compressor. The compressor compresses the low-pressure refrigerant gas into a high-pressure gas and forces the refrigerant through the system. ● **SEE FIGURE 62–8**.
3. This high-pressure gas flows into the condenser located in front of the cooling system radiator. The **condenser** looks like another radiator, and its purpose and function is the same as the cooling system radiator, to remove heat from the high-pressure gas. In the condenser, the high-pressure gas changes (condenses) to form a high-pressure liquid as the heat from the refrigerant is released to the air. ● **SEE FIGURE 62–9**.
4. The high-pressure liquid then flows through a device that meters the flow into the evaporator. When the high pressure of the liquid drops, it causes the refrigerant to vaporize.
5. Air is blown through the evaporator by the blower motor. The air is cooled as heat is removed from the air and transferred to the refrigerant in the evaporator. This cooled air is then directed inside the passenger compartment through vents.

EXPANSION VALVE SYSTEMS

An expansion valve is attached to the inlet to the evaporator and controls the amount of refrigerant flow into the evaporator. The expansion valve controls the flow of the refrigerant based on the

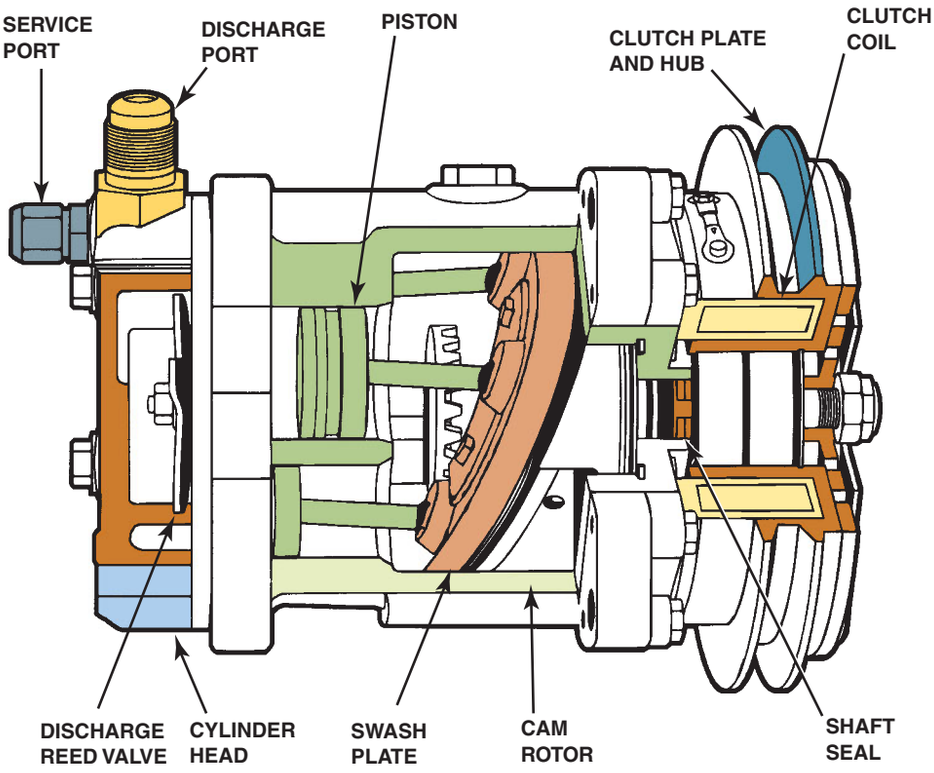


FIGURE 62–8 The compressor provides the mechanical force needed to pressurize the refrigerant.

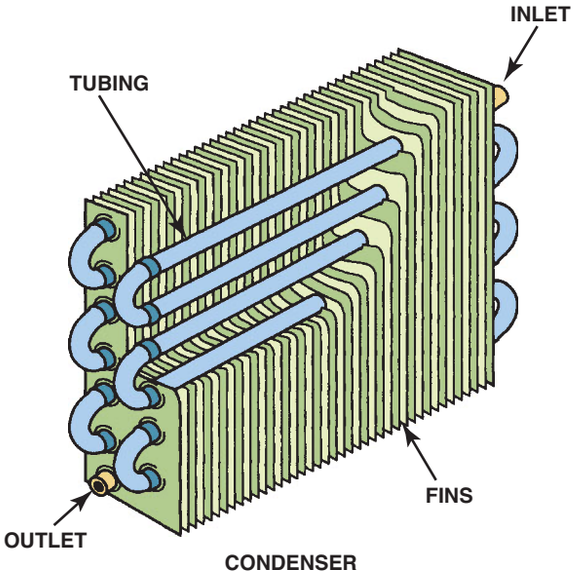


FIGURE 62–9 The condenser changes the refrigerant vapor into a liquid by transferring heat from the refrigerant to the air stream that flows between the condenser fins.

temperature at the outlet of the evaporator, which is measured by a temperature-sensing bulb and tube. When the outlet of the evaporator is warm, the opening of the expansion valve is increased. This opening allows refrigerant to flow into the evaporator. As the temperature at the outlet of the evaporator decreases, the sensing bulb and tube cause the expansion valve to restrict the flow of refrigerant into the evaporator. This type of system is called the **thermostatic expansion valve** system—usually abbreviated **TEV** or **TXV**. ● **SEE FIGURE 62–10**.

ORIFICE TUBE SYSTEMS

Many air-conditioning systems today use a fixed-orifice tube at the inlet to the evaporator. As refrigerant flows through this orifice (small hole), it expands inside the evaporator, where it absorbs heat and expands into a low-pressure gas. A pressure switch located in the low-pressure line at the outlet of the evaporator senses when the pressure is too low. Too low a pressure in the evaporator can cause the temperature of the evaporator to drop to below freezing. A cold evaporator can therefore cause the moisture in the air to freeze into ice, creating a blockage to air flow through the evaporator. Therefore, whenever the pressure drops below a certain pressure (typically about 3 to 33 PSI [214 to 228 kPa]), a pressure switch breaks the circuit to the air-conditioning compressor clutch, which stops the flow of refrigerant through the evaporator. Then, when the temperature (and pressure) increases in the evaporator, the pressure switch closes, restoring the electrical current flow to the compressor clutch and causing the compressor to start forcing refrigerant through the evaporator again. This type of system is commonly called a **cycling clutch orifice tube** (or **CCOT**) system. ● **SEE FIGURES 62–11 AND 62–12**.

THERMOSTATIC CONTROL

The lower the pressure of the refrigerant, the lower the temperature. If the pressure in the evaporator is above 30 PSI (220 kPa) for R-12 or 28 PSI (193 kPa) for an R-134a system, the temperature of the evaporator will remain about freezing, 32°F (0°C). Temperature control must be used to prevent the temperature of the evaporator from

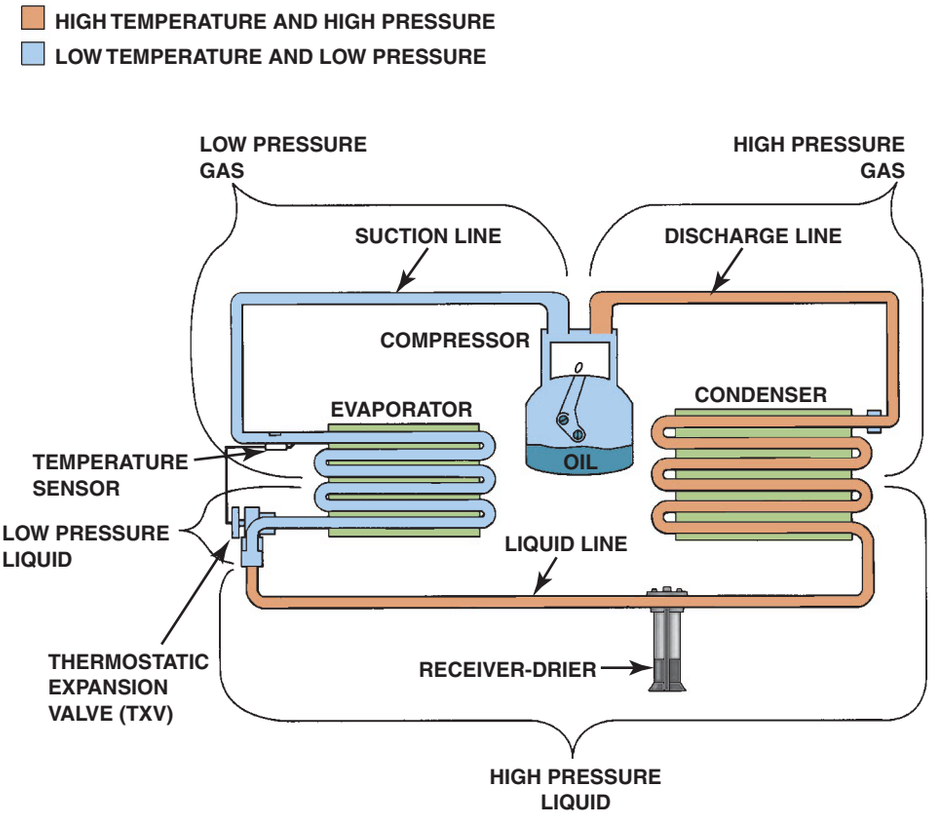


FIGURE 62–10 A typical air-conditioning system that uses an expansion valve. A temperature sensor bulb is attached to the outlet of the evaporator to control the amount of refrigerant allowed to flow into the evaporator.

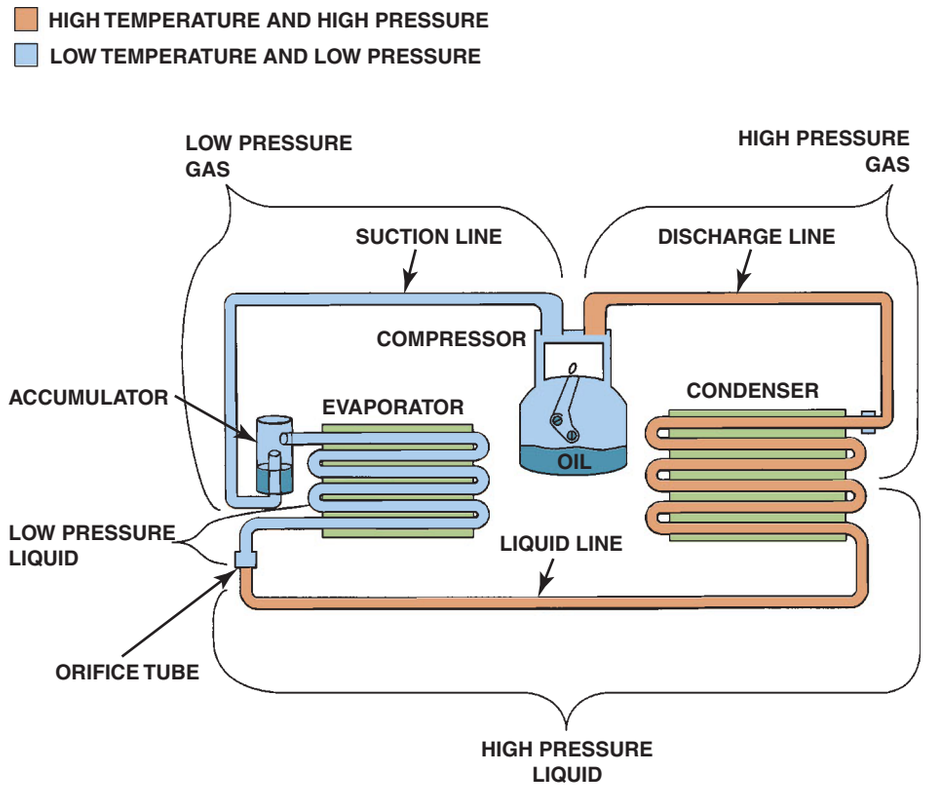


FIGURE 62–11 A typical automotive air-conditioning system that uses a cycling clutch and an orifice tube.

dropping below 32° F (0°C). At this temperature, the moisture in the air freezes. The resulting ice would clog the airflow through the evaporator. If air cannot flow through the evaporator, the air-conditioning system stops functioning and would be immediately noticed by the driver and any passengers. If the A/C is turned off, heat from the surrounding air will melt the ice and the air-conditioning system will again function until it ices up again.

A commonly used method to control evaporator temperature is to use a thermostat to control the compressor. Air-conditioning compressors use an **electromagnetic clutch.** ● **SEE FIGURE 62–13.**

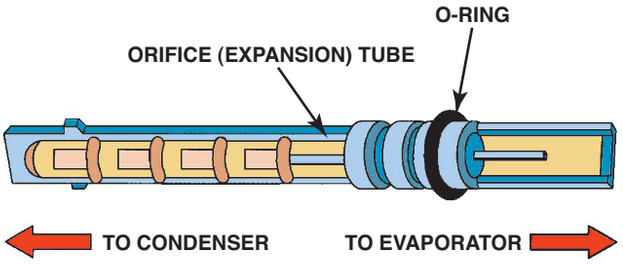


FIGURE 62–12 Typical orifice tube.

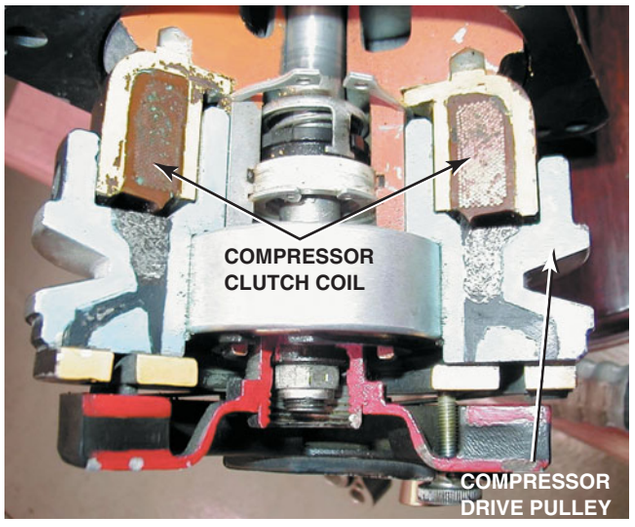


FIGURE 62–13 A cutaway of an air-conditioning compressor electromagnetic clutch.

When the thermostat senses that the temperature is near freezing, 32°F (0°C), the switch opens the electrical circuit to the compressor and the compressor stops circulating refrigerant. This thermostat switch is also called a **thermo switch, icing switch,** or **defrost switch**.

NOTE: Older vehicles used a system to control evaporator pressure when used with a continuously-operating compressor, including:

POA valve—A POA valve (meaning pilot operated absolute)
EPR valve—An evaporator pressure regulator valve maintains at least 30 psi in the evaporator to prevent evaporator freeze-up.

REFRIGERANTS

Air-conditioning refrigerant is used to transfer heat from the inside of the vehicle to the condenser located in the front of the vehicle. A refrigerant absorbs heat when it changes state from a liquid to a gas. One of the first refrigerants was **CFC-12,** commonly referred to as **R-12** or by its brand name **Freon,** a registered trade name of the DuPont Corporation. CFC-12 consists of one carbon atom surrounded by two chlorine (CL) and two fluorine (F) atoms and is therefore called a chlorofluorocarbon (CFC) compound. Its chemical name is dichlorodifluoromethane. It is the chlorine atoms that are believed to contribute to the destroying of the ozone layer in our upper atmosphere.



FIGURE 62–14 R-134a is available in 12 oz cans as well as larger 30-lb containers.

Another refrigerant, **HFC-134a,** also called **R-134a**, has been selected by vehicle manufacturers to replace the ozone-harming CFC. HFC-134a compound contains two carbon atoms and four fluorine atoms plus two hydrogen atoms and is therefore called a hydrofluorocarbon. Its chemical name is tetrafluorolthene, and Dupont calls it Suva®. ● **SEE FIGURE 62–14**. The boiling points and therefore the operation characteristics of CFC-12 and HFC-134a are similar.

CFC-12 and HFC-134a Boiling Temperatures at Various Pressures

Temperature °F (°C)	Pressure (PSI) (kPa) CFC-12	Pressure (PSI) (kPa) HFC-134a
0 (−22)	9 (62)	6 (41)
5 (−15)	12 (83)	9 (62)
10 (−12)	15 (103)	12 (83)
15 (−9)	18 (124)	15 (103)
20 (−7)	21 (145)	18 (124)
25 (−4)	25 (172)	22 (152)
30 (−1)	29 (200)	26 (179)
35 (2)	33 (228)	31 (214)
40 (4)	37 (255)	35 (241)
45 (7)	42 (290)	40 (276)
50 (10)	47 (324)	45 (310)
55 (13)	52 (359)	51 (352)
60 (16)	47 (324)	57 (393)
65 (18)	64 (441)	64 (441)
70 (21)	70 (483)	71 (490)
75 (24)	77 (531)	79 (544)
80 (27)	84 (579)	87 (600)
85 (29)	92 (634)	95 (655)
90 (32)	100 (690)	104 (717)
95 (35)	108 (745)	114 (786)
100 (38)	117 (807)	124 (855)
105 (41)	127 (876)	147 (1013)
110 (43)	136 (938)	158 (1089)

HFC-134a is a smaller molecule than CFC-12. However, HFC-134a can more easily leak out through small holes or openings in the system. HFC-134a systems require that the inside layer of

the rubber refrigerant hoses contain a barrier to prevent penetration through the microscopic holes/standard rubber refrigerant holes.

NOTE: Look at the size of a blue HFC-134a 30-pound container compared to a white CFC-12 30-pound container. The blue R-134a container is larger because it requires more HFC-134a to achieve 30 pounds.

NOTE: Many vehicle manufacturers started using barrier-type refrigerant hoses on their vehicles in the late 1980s in anticipation of the conversion from CFC-12 to HFC-134a in future models.

REFRIGERANTS AND THE ENVIRONMENT

Air-conditioning refrigerants have been discovered to be harmful to the ozone layer. The ozone (O_3) layer is in the upper atmosphere and blocks out ultraviolet rays from the sun. ● **SEE FIGURE 62–15**. It has been discovered that certain chemicals, such as chlorofluorocarbon (CFC), are rapidly destroying this layer of ozone, which is 10 to 30 miles above Earth's surface. ● **SEE FIGURE 62–16** for how ozone is destroyed.

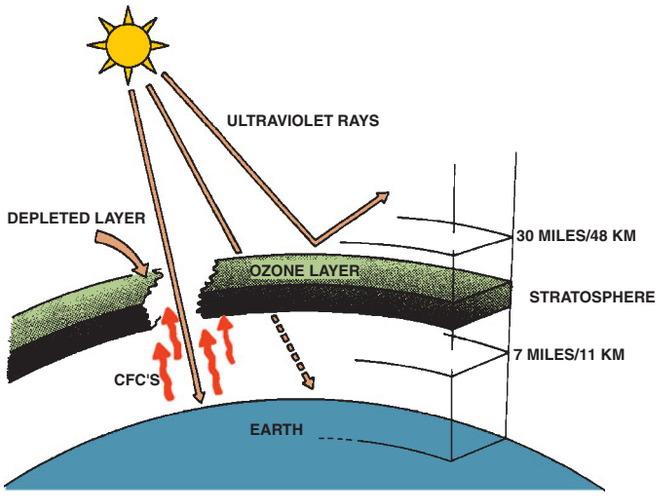


FIGURE 62–15 A depletion of the ozone layer allows more ultraviolet radiation from the sun to reach Earth's surface.

MONTREAL PROTOCOL A conference was held in Montreal, Canada, in 1987, where the United States and 22 other countries agreed to limit the production of ozone-depleting refrigerants. The Clean Air Act of 1990 specified that the production of R-12 refrigerant would cease at the end of 1995. **Section 609** of the Clean Air Act required the following:

- All technicians who service or repair automotive air-conditioning systems shall be properly trained and certified.
- Recovery and recycling equipment must be properly approved.
- Each shop that performs automotive air-conditioning service should comply to the Environmental Protection Agency (EPA) that it is using approved recycling equipment and that only properly trained and certified technicians are using the equipment.

? FREQUENTLY ASKED QUESTION

Is Carbon Dioxide the Next Refrigerant?

Not likely. While carbon dioxide (CO_2) (R744) is being used on prototype vehicles, such as the Toyota Fuel Cell Hybrid Vehicle (FCHV), it requires extremely high pressures, up to 2000 psi and is not as efficient as a refrigerant as R-134a. ● **SEE FIGURE 62–17**.



FIGURE 62–17 The label on a Toyota Fuel Cell Hybrid Vehicle (FCHV) showing that CO_2 is being used as the refrigerant.

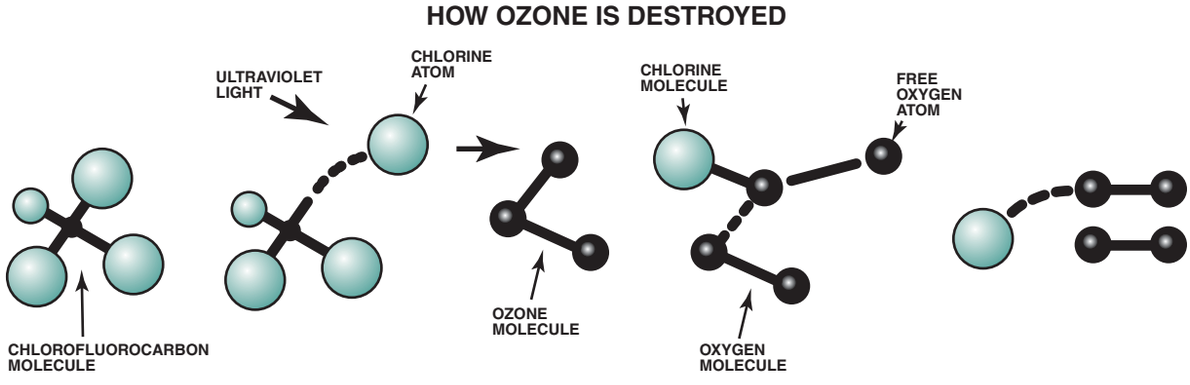


FIGURE 62–16 Chlorofluorocarbon molecules break apart in the atmosphere.



FIGURE 62–18 PAG oil used in Chrysler vehicles equipped with HFC-134a refrigerant. Notice that different oils are used for different systems depending primarily on the manufacturer of the compressor. Also notice that both PAG oils are in metal cans. PAG oil absorbs moisture so readily that it can even absorb moisture that is in the air through plastic—that is why metal containers are used.



FIGURE 62–19 Ester refrigerant oils are often specified for use when retrofitting an R-12 system to R-134a by companies who supply refit kits. Ester refrigerant oil is not recommended by many vehicle or air-conditioning compressor manufacturers. Always use the recommended refrigerant oil for the vehicle and system being serviced.

REFRIGERANT OILS

The oil carried by the refrigerant through the various components is often the only source of lubrication for the compressor. The oil used must be able to be mixed without separating in the refrigerant. This characteristic of being able to be mixed is called **miscible.** CFC-12 systems must use mineral oil. Mineral oil is not miscible in HFC-134a, and so such systems must use synthetic polyalkyline glycol, usually referred to as PAG oil. There are numerous different PAG oils, and each vehicle manufacturer (or air-conditioning compressor manufacturer) recommends which PAG to use. ● **SEE FIGURE 62–18**.

Another type of refrigerant oil is called **ester oil.** Ester is a classification of hydrocarbons and is specified for use in air-conditioning systems that have been charged (retrofitted) from CFC-12 to HFC-134a. Ester oil will mix with any remaining mineral oil and will work to lubricate the system even if some CFC-12 is still in the system. ● **SEE FIGURE 62–19**.

All refrigerant oils have a viscosity rating. Viscosity is the measure of the oil's thickness or resistance to flow. Always use the type and viscosity of oil specified by the manufacturer.

CAUTION: Failure to use the correct refrigerant oil in an air-conditioning system can cause serious (and expensive) damage to the air-conditioning compressor. Always use the refrigerant oil specified by the manufacturer.

CONDENSER

The condenser looks like a cooling system radiator. In fact, a condenser is a radiator because it is designed to radiate heat from the refrigerant to the outside air.

When the refrigerant leaves the compressor it is over 300°F (150°C) as it enters the condenser. Even on a hot 100°F (38°C) day, there is a difference in temperature between the outside air around the condenser and the temperature of the refrigerant inside the condenser. Heat always travels hot to cold. Therefore, the heat in the hot refrigerant has a natural tendency to radiate into the outside air. As the heat travels into the air, the high-pressure gas refrigerant changes state and becomes a high-pressure liquid. This is the reason the condenser is called by that name: as the heat leaves the refrigerant, it **condenses** from a gas (vapor) to a liquid. ● **SEE FIGURE 62–20**.

To help in the heat transfer, most vehicles are equipped with cooling fans driven either electrically or by the engine through an accessory drive belt. The fan draws air through the condenser and increases the heat transfer rate.

EVAPORATOR

The evaporator looks like a small radiator that is located in the evaporator housing on the passenger side of the bulkhead (firewall). The purpose of the evaporator is to transfer heat from the air to the refrigerant flowing through it. Heat from the air causes the low-pressure liquid inside the evaporator to evaporate into a low-pressure gas. As the refrigerant changes state from a liquid to a gas, it absorbs heat. A blower motor equipped with a squirrel cage–type fan circulates air through the evaporator and forces the cooler air into the passenger compartment.

Another benefit of the cooling of the air is a result of what happens to any moisture that may be in the air. Moisture in the air is called relative humidity and represents the percentage of water vapor that could be in the air to the actual amount in the air. High humidity feels uncomfortable. Because the evaporator is cold (usually just above the freezing point of 32°F (0°C)), any moisture in the air condenses on its cool surface. This removes the moisture from the air and lowers the relative humidity. The moisture that condenses

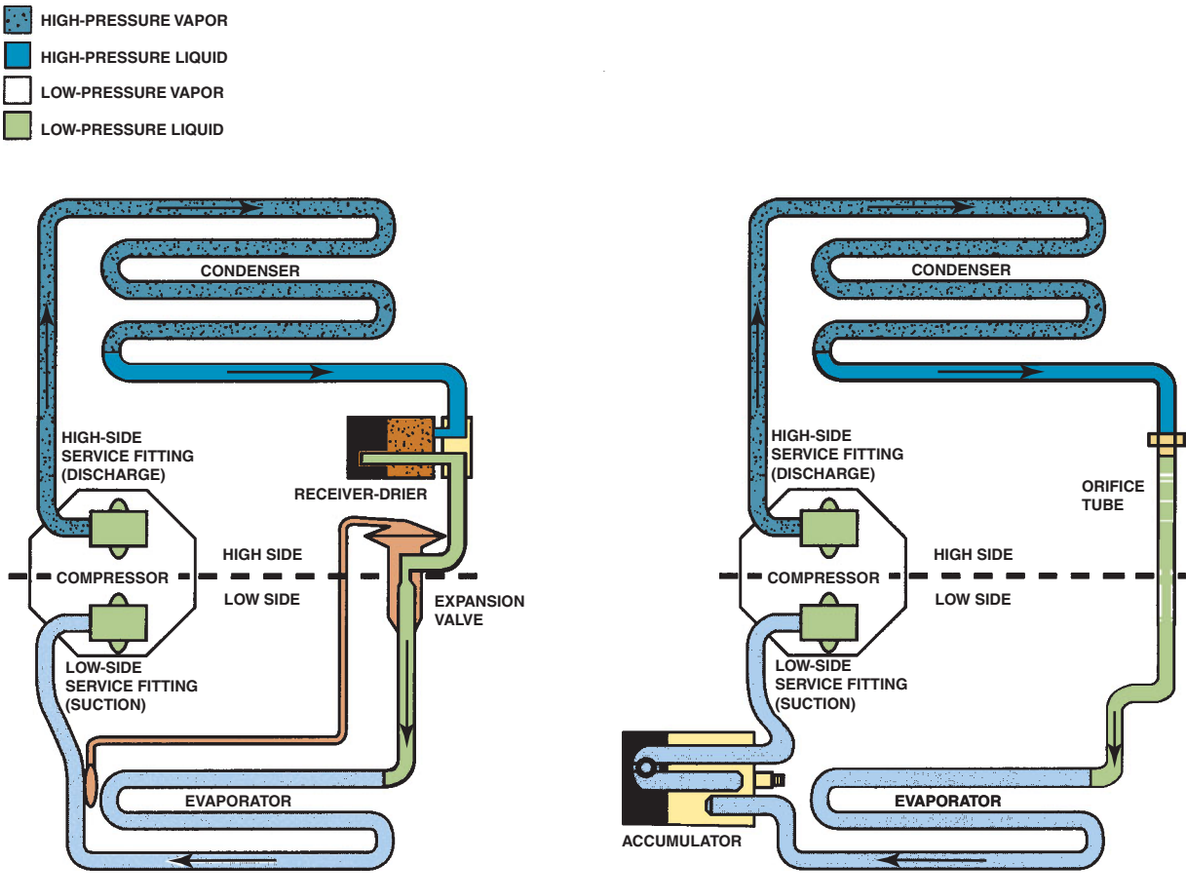


FIGURE 62–20 The condenser serves the same function for both the orifice-tube and the expansion valve–type air-conditioning system, and that is to remove the heat from the refrigerant and cause the hot refrigerant vapors to condense into a hot liquid.

TECH TIP

Broken Condenser Line? Check the Engine Mounts!

Most air-conditioning systems use aluminum and flexible rubber lines between the compressor and the condenser. Because the compressor is mounted on and driven by the engine and the condenser is mounted to the body, these lines can break if the engine mounts are defective. The rubber hoses attached between the aluminum fittings of the compressor and condenser are designed to absorb normal engine movement. Worn engine mounts would allow the engine to move too much. Aluminum lines cannot stand to be flexed without crushing and breaking.

Therefore, the wise technician will carefully inspect and replace any and all worn engine mounts if a broken aluminum condenser line is discovered to prevent a premature failure of a replacement condenser. ● **SEE FIGURE 62–21**.

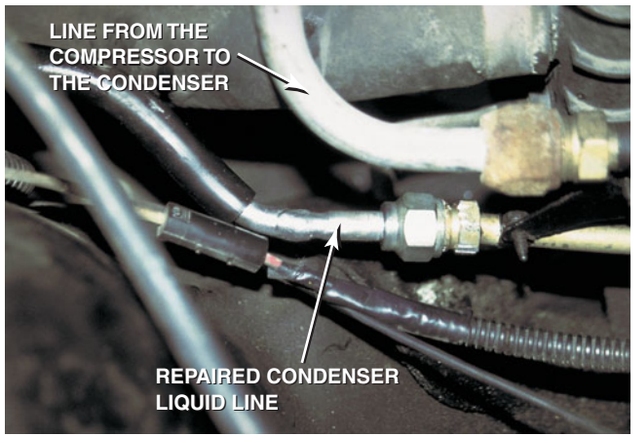


FIGURE 62–21 A repaired condenser refrigerant line.

out of the air then becomes water that is allowed to flow out of the evaporator housing and onto the ground. ● **SEE FIGURE 62–22**.

NOTE: If the carpet (or floor) of the vehicle is wet on the passenger side, the cause is often a clogged evaporator drain hose. The opening, called the condensate line, is frequently clogged with mud, road debris, or leaves. To check the drain opening, hoist the vehicle and insert a wire or screwdriver into the end of the hose opening at the bottom of the evaporator housing.

RECEIVER-DRIER

A receiver-drier is used on an air-conditioning system that uses an expansion valve. The receiver-drier is located between the condenser and the evaporator. This section of the air-conditioning system contains *high-pressure liquid refrigerant*. The purpose of the receiver is to provide temporary storage for the liquid refrigerant and it also usually includes a filter to trap debris and a desiccant to remove moisture. Many receiver-driers contain a sight glass that provides a view of the liquid refrigerant in the system.

A drier is needed to remove moisture from the system. The drier contains a **desiccant** (usually silica alumina or silica gel). A

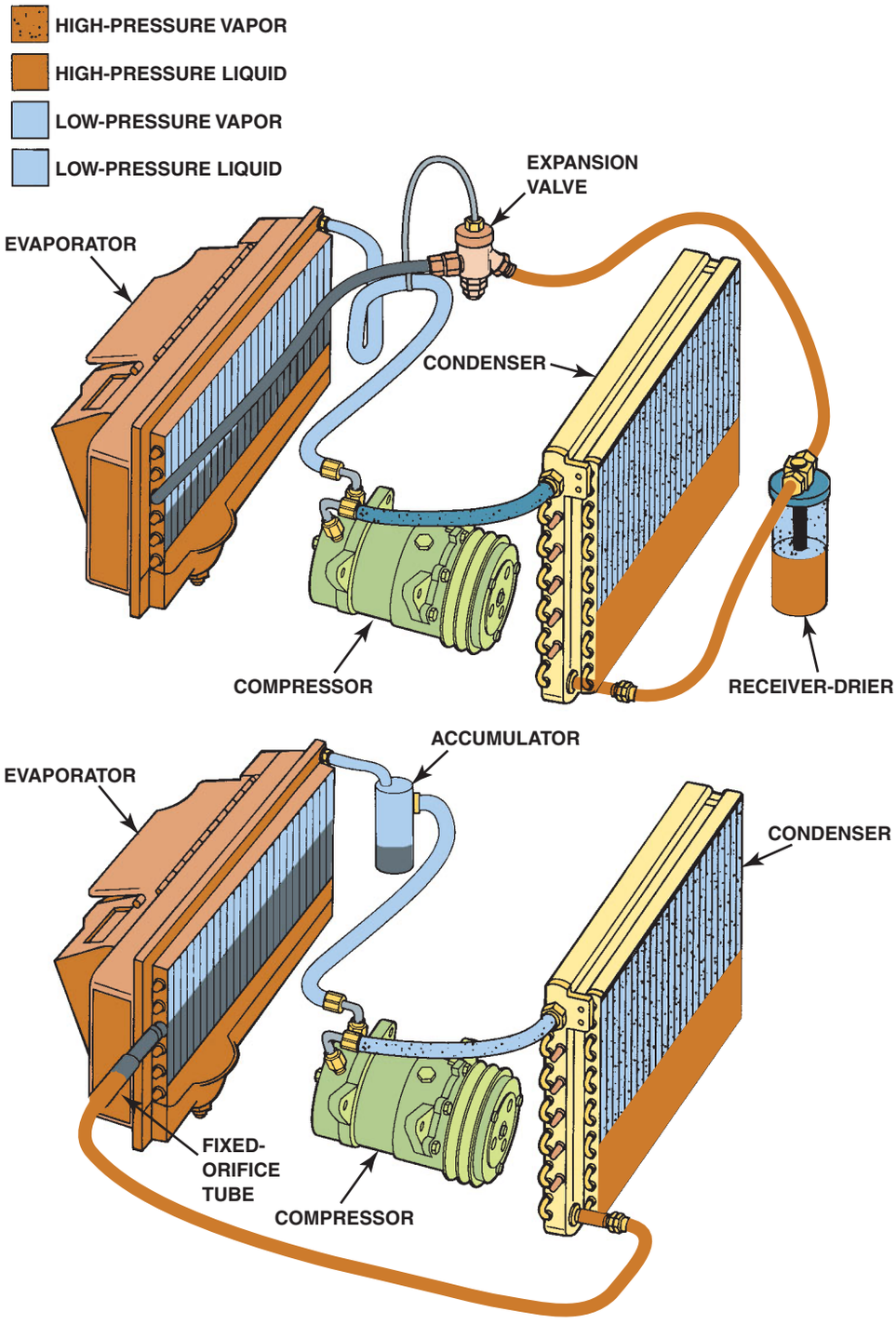


FIGURE 62–22 The evaporator serves the same function for both the orifice-tube and the expansion valve–type air-conditioning system, and that is to allow the liquid refrigerant to evaporate and absorb heat from the passenger compartment.

desiccant is a drying agent that absorbs any moisture (water) that gets into the air-conditioning refrigerant system. Moisture can combine with refrigerant to form an acid. Water can also freeze and form ice in the system.

The desiccant is classified as XH-5 for CFC-12 systems and XH-7 or XH-9 for HFC-134a systems. The desiccant used on a CFC-12 system is not compatible with HFC-134a systems. Therefore, whenever a system is changed (retrofitted) from CFC-12 to HFC-134a, the desiccant *must* be replaced.

The desiccant (accumulator or receiver-drier) should also be replaced on any air-conditioning system that has been left open to the atmosphere for any length of time (over 24 hours) or whenever the system has been left in a discharged condition. ● **SEE FIGURE 62–23**.

ACCUMULATOR

An accumulator is used on systems that use an orifice tube. It is located between the evaporator and the compressor. The refrigerant in this section of the refrigerant cycle is a *low-pressure gas*. The purposes of the accumulator include:

- Preventing liquid refrigerant from reaching the compressor

NOTE: A liquid cannot be compressed. If liquid refrigerant were to enter the compressor, the compressor would lock up and be damaged.

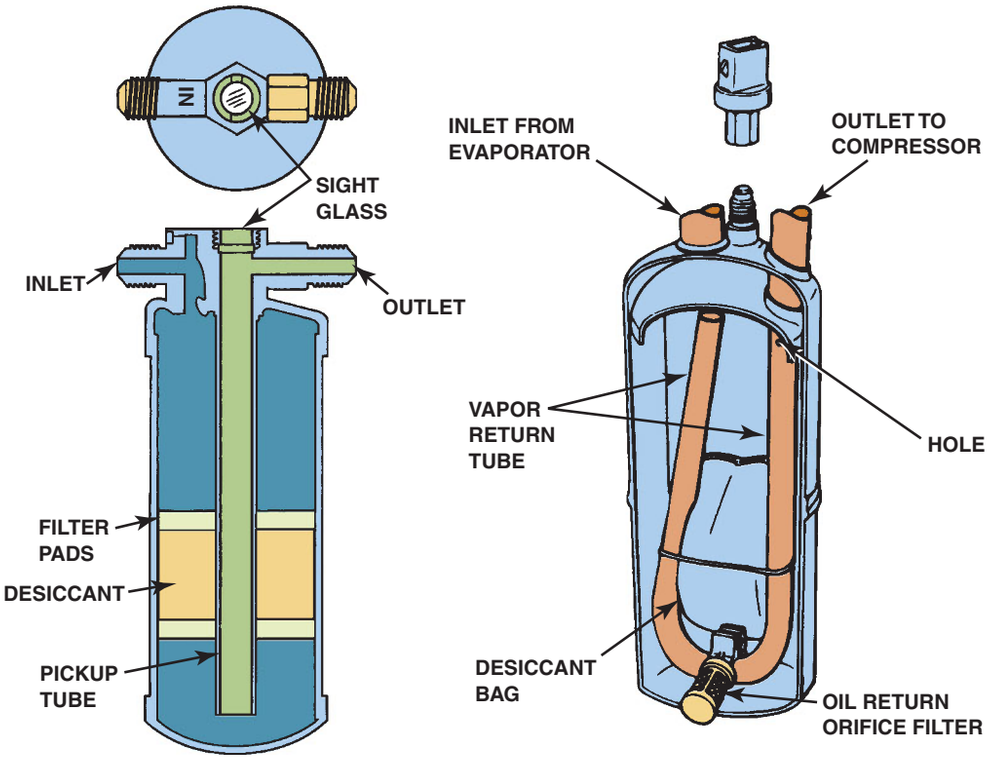


FIGURE 62–23 Expansion-valve systems store excess refrigerant in a receiver-drier, which is located in the high-side liquid section of the system, whereas orifice-tube systems store excess refrigerant in an accumulator located in the low-side vapor section of the system.

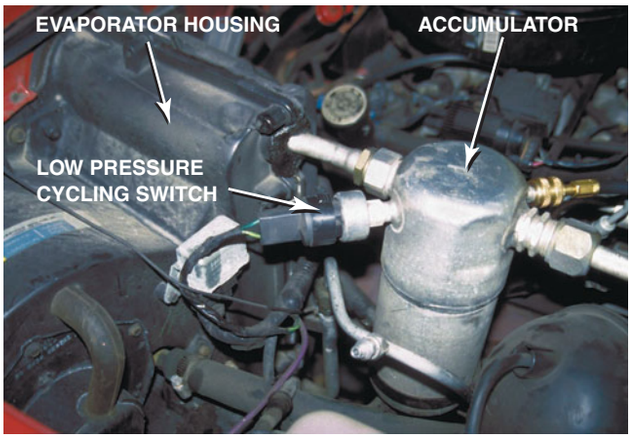


FIGURE 62–24 A typical accumulator used on a cycling clutch orifice-tube (CCOT) system.

- Holding a reserve of refrigerant
- Holding the desiccant (helping to remove moisture from the system)

● **SEE FIGURE 62–24.**

REFRIGERANT LINES AND HOSES

Aluminum tubing is used to connect many stationary items together like the condenser to the receiver-drier and the receiver-drier to the evaporator. Rubber lines are usually used to and from the compressor. Because the compressor is attached to the engine and the engine is mounted on flexible rubber mounts, there is movement between the compressor and the other air-conditioning components that are attached to the body of the vehicle. These flexible refrigerant hoses are constructed from many layers of rubber and fabric. ● **SEE FIGURE 62–25**. Most hoses used on vehicles since the early 1990s use a nonpermeable inside layer of material that prevents the loss of refrigerant through the hose itself. These hoses, called **barrier hoses,** are required for use with HFC-134a refrigerant.

THERMOSTATIC EXPANSION VALVES

Thermostatic expansion valve (TXV) systems, as shown in **FIGURE 62–26**, use a temperature-sensitive bulb located on the evaporator outlet tube. The sensing bulb is insulated with a special tape, so it reacts only to temperature changes it senses from the outlet tube. The sensing bulb works in combination with a pressure-sensitive diaphragm inside the TXV body to control the size of the variable orifice. This regulates the rate at which liquid refrigerant flows into the evaporator.

The key to the operation of the expansion valve is the variable orifice. In these systems, the outlet from the high-pressure side to the low-pressure side is a variable-diameter hole. A **pintle valve** is a ball-and-seat valve used to increase or decrease the size of the opening. ● **SEE FIGURE 62–27**. The expansion valve uses the pintle valve to control how rapidly refrigerant enters the evaporator. The expansion valve controls the refrigerant flow in response to the temperature of the evaporator outlet, measured by the remotely mounted sensing bulb and **capillary tube.** ● **SEE FIGURE 62–28**. The sensing bulb may be clamped to the outlet pipe or mounted inside a passage near the outlet of the evaporator. The bulb and tube contain refrigerant. The rise or fall of the evaporator outlet

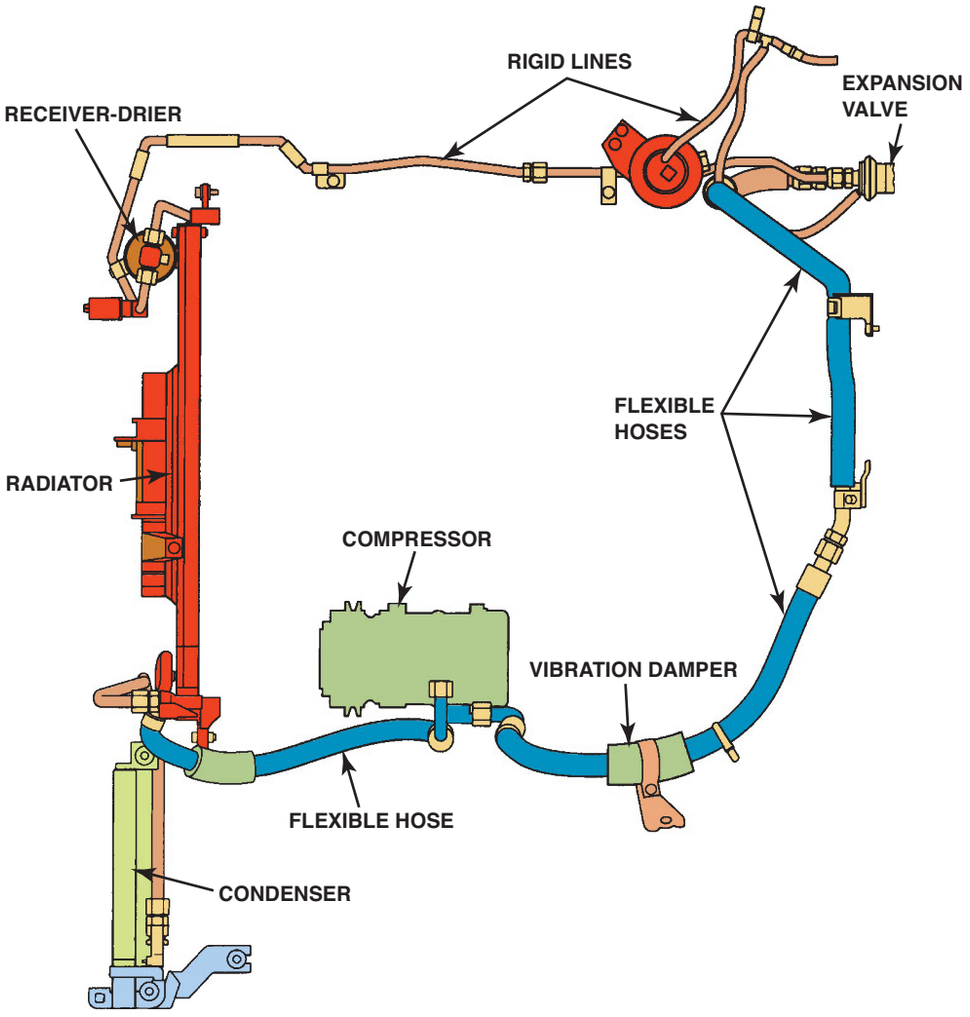


FIGURE 62–25 Rigid lines and flexible hoses are used throughout the air-conditioning system. The line to and from the compressor must be flexible because it is attached to the engine, which moves on its mounts during normal vehicle operation.

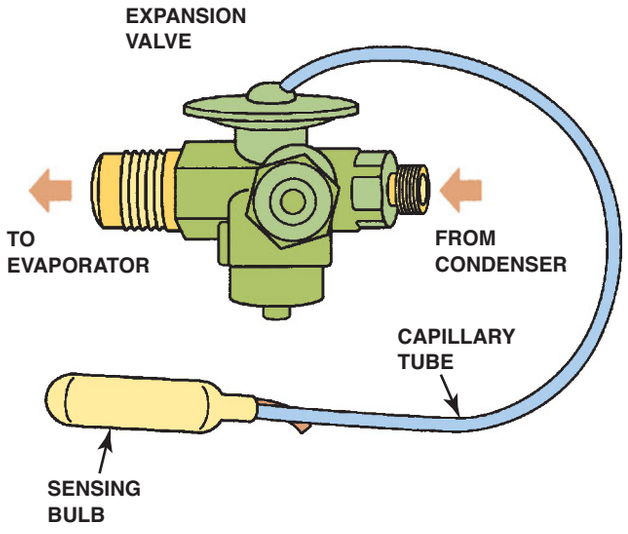


FIGURE 62–26 A typical expansion valve which uses an inlet and outlet attachment for the evaporator, and a temperature-sensing bulb that is attached to the evaporator outlet tube.

temperature causes the refrigerant in the bulb to expand or contract, resulting in a rise or fall of pressure inside the capillary.

This outlet-temperature-sensitive pressure is applied to one side of the spring-loaded diaphragm inside the expansion valve. ● **SEE FIGURE 62–29**. As the capillary tube warms, the refrigerant inside expands, forcing the diaphragm downward. The diaphragm magnifies this pressure and uses it to open the valve by pushing the pintle and ball away from its seat. This increases the size of the orifice and allows more refrigerant into the evaporator, increasing the cooling capacity.

When the evaporator cools in response to the boiling of the added refrigerant, the refrigerant in the capillary tube contracts. This relieves the pressure on the expansion valve diaphragm, which closes the pintle and ball, and reduces refrigerant flow.

Pressure on the top of the diaphragm is applied through the capillary tube. The equalizing pressure on the underside of the diaphragm can be internal (from the evaporator inlet) or external (from the evaporator outlet):

- An internally equalized expansion valve has a passage that permits evaporator inlet pressure to reach the underside of the diaphragm.
- An externally equalized expansion valve has an extra line mounted to the underside of the diaphragm housing. This line monitors the outlet pressure of the evaporator. The connection can be either at the outlet of the evaporator or at the outlet of the evaporator pressure control device.

In an expansion-valve system, the refrigerant vapor that leaves the evaporator is warmer than the liquid refrigerant that entered it. The heat that warms the refrigerant is referred to as **superheat.**

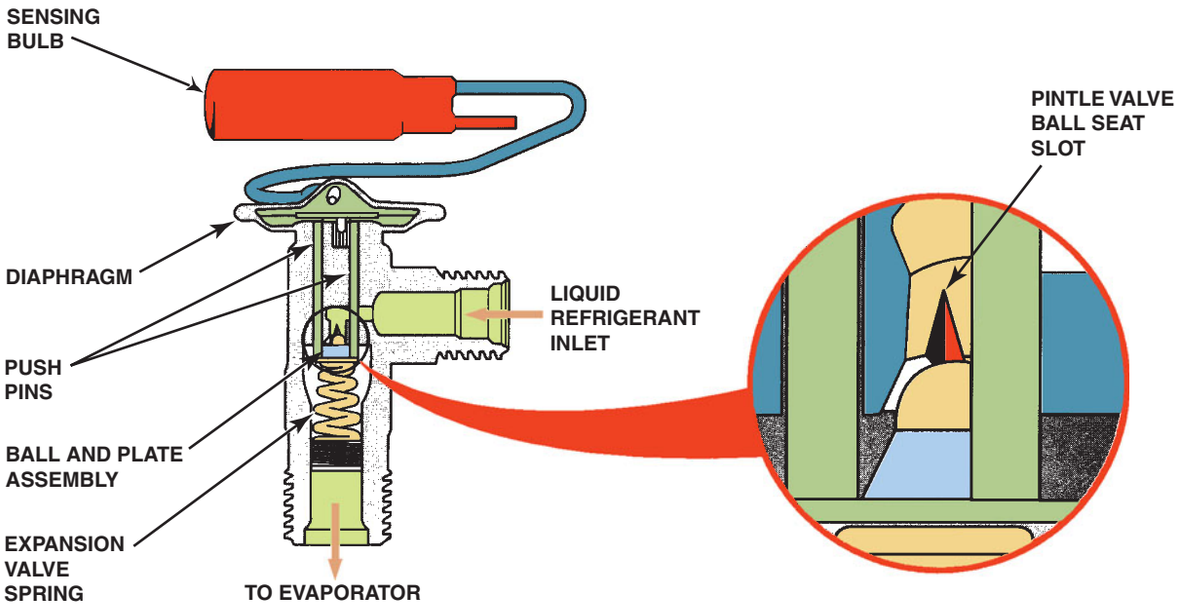


FIGURE 62–27 A slot cut in the ball seat inside the expansion valve permits a small amount of refrigerant and oil to pass through at all times, even when the valve is closed. This flow of oil through the system is necessary to make sure that the compressor receives the oil it needs for lubrication.

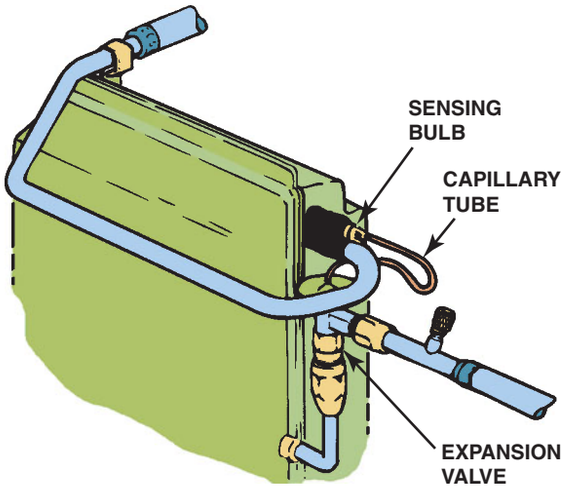


FIGURE 62–28 The sensing bulb is attached to the evaporator outlet tube. Refrigerant inside the bulb expands or contracts in response to the evaporator temperature.

Superheat is usually measured as the actual temperature difference between the boiling point of the refrigerant at the inlet and at the outlet of the evaporator. Typical values for superheat in an evaporator are between 4° and 16°F (3° and 10°C).

Superheat is important because it ensures that all (or almost all) of the refrigerant vaporizes before leaving the evaporator.

Chrysler uses a valve called an **H-valve.** It includes both the temperature-sensing and pressure-sensing functions of the expansion valve, but does not have any external tubes.

The H-valve has two refrigerant passages that form the legs of the "H" as shown in **FIGURES 62–30 AND 62–31**. The lower passage is the refrigerant line from the condenser to the evaporator, and contains the ball and spring valve. The upper passage is the refrigerant line from the evaporator to the compressor, and contains the temperature-sensing element. A pushrod connects the diaphragm of the temperature sensor located at the top of the block to the valve ball at the bottom.

The cycling-clutch switch, which senses the suction line, detects the evaporator outlet temperature and cycles the compressor clutch to control system cooling. This capillary device does not directly control the metering orifice. ● **SEE FIGURE 62–32**.

FIXED-ORIFICE TUBES

Liquid refrigerant flows from the condenser to the orifice tube. As with expansion valves, fixed-orifice tubes provide a restriction that separates the high-pressure from the low-pressure side of the system. ● **SEE FIGURE 62–33**. When it reaches the fixed-orifice tube, the refrigerant undergoes rapid expansion and changes from a warm, high-pressure liquid to a cold, low-pressure liquid and vapor mixture.

As it passes through the restriction to the low side, the refrigerant changes state from a liquid to a vapor because the pressure in the evaporator is so much lower than in the refrigerant line upstream from the orifice tube. The refrigerant begins to vaporize quickly as it absorbs the heat from the evaporator.

The orifice tube, located between the condenser and the evaporator inlet, may be inserted in the refrigerant line or may be part of the inlet refrigerant line assembly.

COMPRESSORS

The air-conditioning compressor is driven by the engine with an accessory drive belt. A magnetic clutch is usually used to connect and disconnect the drive pulley to the compressor as needed for cooling or defrosting. The compressor performs the following functions:

- Compresses the low-pressure gas refrigerant from the evaporator into a high-pressure gas that is then sent to the condenser

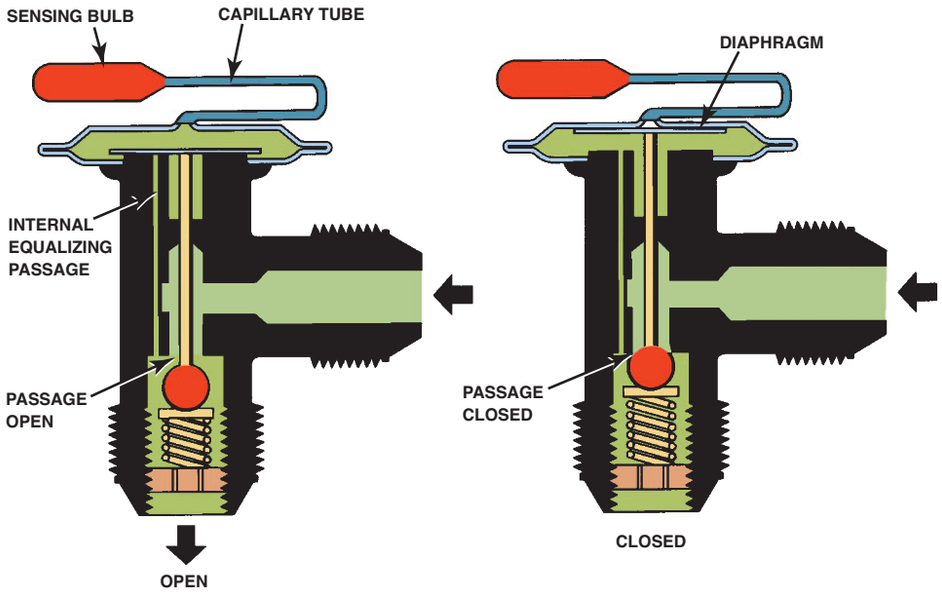


FIGURE 62–29 Pressure from the capillary tube pushes on the spring-loaded diaphragm to open the expansion valve. As the pressure in the capillary tube contracts, the reduced pressure on the diaphragm allows the valve to close.

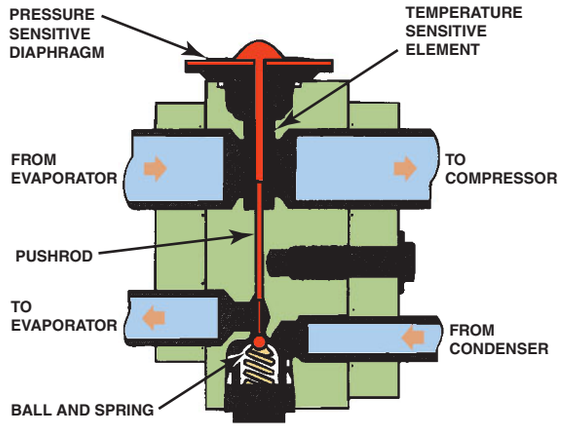


FIGURE 62–30 An H-valve (H-block) combines the temperature-sensing and pressure-regulating functions into a single assembly.

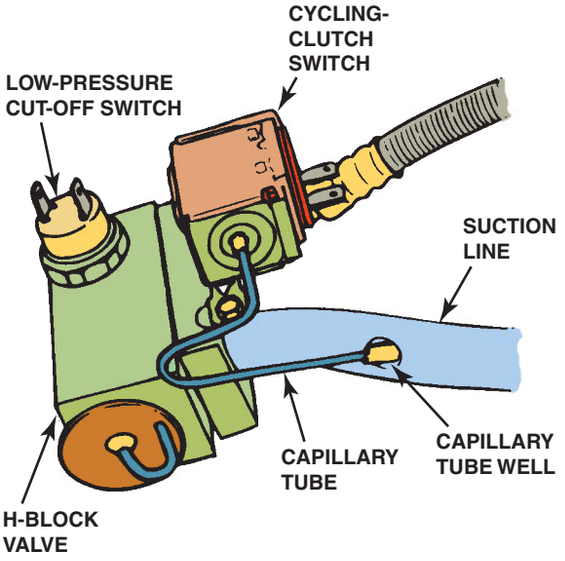


FIGURE 62–32 In this Chrysler system, a low-pressure cutoff switch and a cycling-clutch switch are mounted on the H-valve.

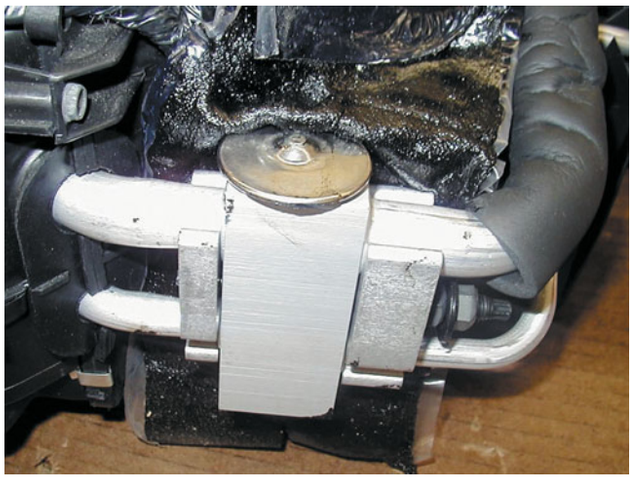


FIGURE 62–31 An H-valve as used on a Chrysler minivan.

- Raises the temperature of the gas so that there is a difference in temperature between the outside (ambient) air and the refrigerant in the condenser
- Acts as the pump used to circulate the refrigerant throughout the system
- Often switches on and off (cycles) to control evaporator temperatures
- Is the major reason why there is refrigerant oil in the system. The oil in the refrigerant lubricates the moving parts of the compressor.

POSITIVE-DISPLACEMENT PISTON COMPRESSORS

A **positive-displacement compressor** displaces a constant, uniform volume of refrigerant for each revolution or operating cycle. Most

automotive air-conditioner compressors are positive-displacement piston designs. These compressors have from one to 10 cylinders depending on manufacturer and application. Most of these compressors use a piston-in-cylinder arrangement with intake and discharge strokes to draw in, compress, and discharge refrigerant. ● **SEE FIGURE 62–34**.

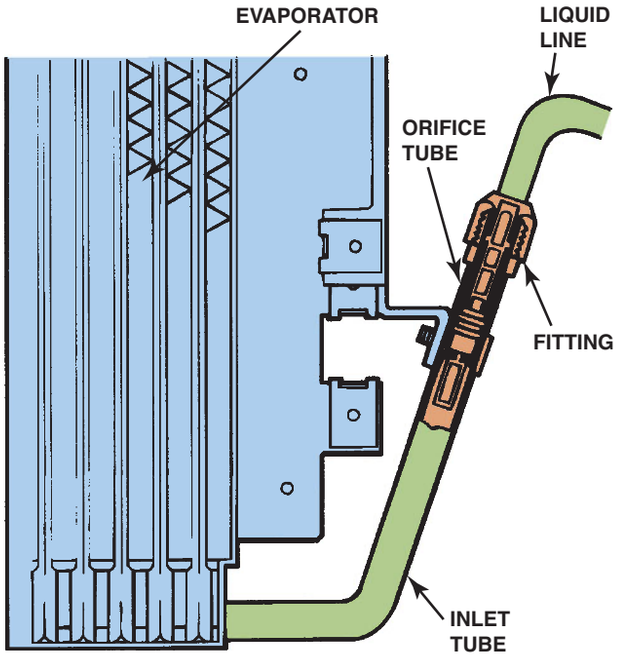


FIGURE 62–33 The orifice tube is usually located at the inlet tube to the evaporator.

The compressor intake stroke is also known as the suction stroke. The suction stroke of a positive-displacement compressor is like that of a two-stroke gasoline engine. Just as the intake stroke of an engine's piston creates a low-pressure area that draws the air–fuel mixture in through the cylinder head, the suction stroke of the compressor piston creates a low-pressure area to draw refrigerant vapor into the cylinder. However, the similarity ends here. In a two-stroke engine, the compression stroke compresses the air–fuel mixture inside a sealed cylinder, with both the intake and exhaust valves closed. In the two-stroke piston AC compressor, the discharge valve does not resist the refrigerant flow during the upward piston stroke. As the compressor operates, the maximum possible charge of refrigerant vapor has been drawn in at bottom dead center of the compressor piston's suction stroke. When the piston begins its discharge stroke, the pressure increases, shutting the suction valve and opening the discharge valve at the same time. The charge of refrigerant vapor is pushed out of the compressor into the high-side refrigerant line and travels toward the condenser. Therefore, the refrigerant vapor is compressed simultaneously throughout the entire high side of the air-conditioning system.

All piston compressors use one suction valve and one discharge valve for each piston. The typical valve used in compressors is the **reed valve:** a one-way, flap-type check valve that is built into the valve plate which seals one or more cylinders. ● **SEE FIGURE 62–35** on page 728. A reed valve flaps away from the valve plate to open, and toward the valve plate to close. Pressure pushes the valve in one direction or the other. The suction reed valve is located on the underside of the valve plate. When the suction created by the piston's downward stroke becomes strong enough, the suction reed valve bends, or flaps, off its seat. Low-pressure refrigerant vapor then flows into the compressor. The refrigerant vapor fills the partial vacuum created by the moving piston.

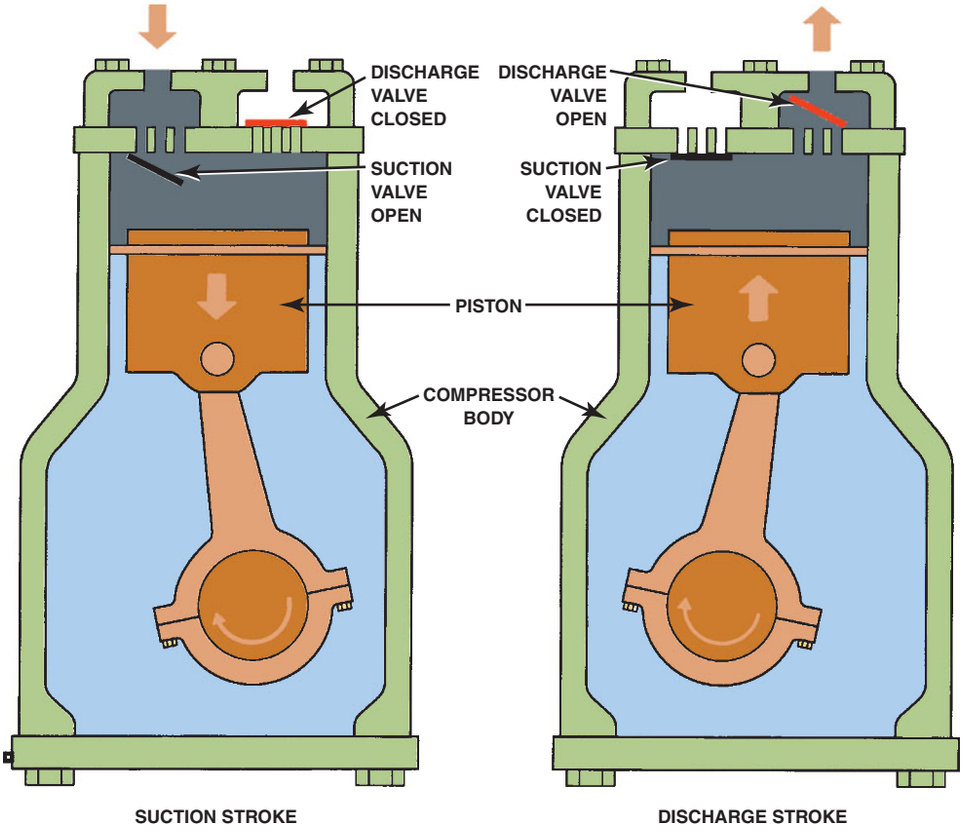


FIGURE 62–34 In a positive-displacement compressor, the descending piston creates a drop in pressure inside the cylinder. The resulting pressure differential allows low-side pressure to force the suction valve open. Refrigerant then flows into the cylinder. On the piston's discharge stroke, the pressure caused by the ascending piston closes the intake valve and forces the refrigerant out the discharge valve.

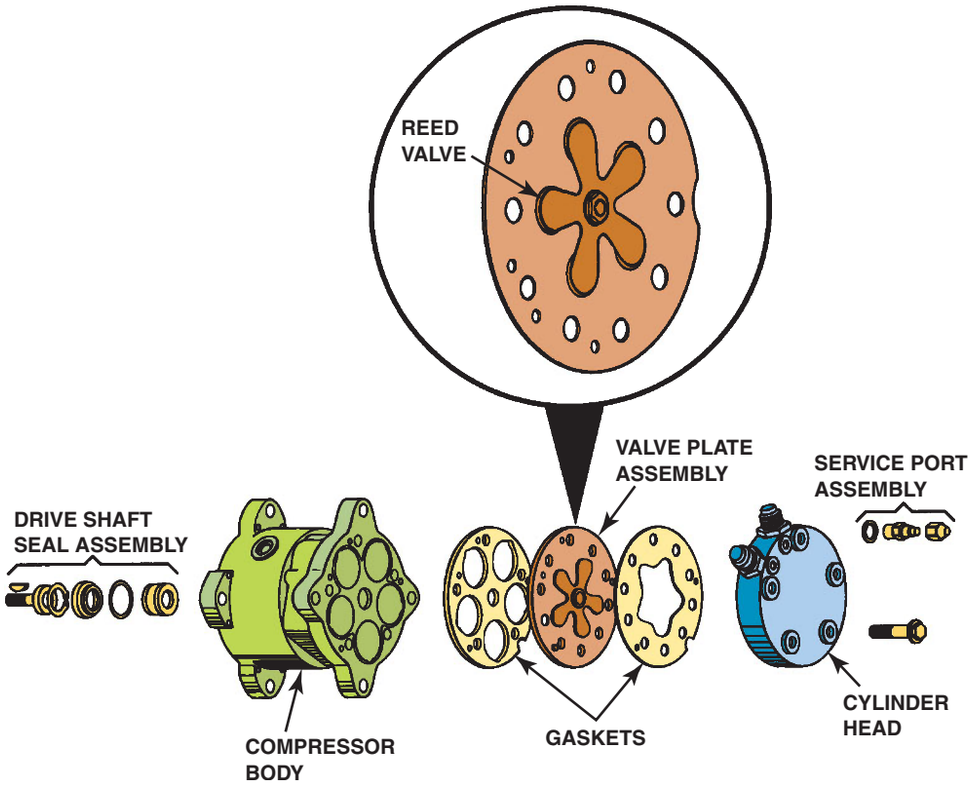


FIGURE 62–35 A reed valve is a one-way check valve that flaps away from the valve plate to open, and toward the valve plate to close.

The discharge reed valve is on the top side of the valve plate. The partial vacuum in the cylinder also pulls the discharge valve tightly against its seat, sealing off the system's high side from the cylinder during the suction stroke.

The reeds behave in exactly the opposite way during the piston's discharge stroke. The increasing cylinder pressure pushes the suction valve tightly against its seat, sealing off the system's low side. The discharge valve on the opposite side of the valve plate is unseated as the pressure in the cylinder increases as a result of the upward moving piston. The piston pushes the refrigerant through the discharge valve, out of the compressor, and into the air-conditioning system high side.

PISTONS AND RINGS

The basic two-stroke cycle depends upon the pistons and their sealing rings to provide an adequate seal against the high-side refrigerant pressure. Most piston compressors have from two to six cylinders.

Some compressors use a **swash plate,** or axial plate. This plate is rigidly mounted to the belt-driven shaft at an angle. ● **SEE FIGURE 62–36** on page 729. The pistons may be on one or both sides of the plate. The pistons are connected to the swash plate by means of a large ball bearing. As the pulley turns, the shaft and angled swash plate assembly rotate. This forces the pistons back and forth in their bores. In this way, the swash plate changes the rotating action of the shaft to a reciprocating action that provides driving force for each piston. Compressors that use a swash plate are often called **axial compressors.**

VARIABLE DISPLACEMENT COMPRESSOR

Some air-conditioning systems use variable displacement to control the amount of refrigerant flowing through the evaporator. The pressure difference between the high side and the low side causes the swash plate to move inside the compressor. As the swash plate changes its angle, the stroke of the piston is increased for more cooling or decreased to reduce the amount of cooling. ● **SEE FIGURE 62–37** on page 729.

TECH TIP

The Radio "POP" Trick

Most air-conditioning compressor clutch circuits contain a diode that is used to suppress the high-voltage spike that is generated whenever the compressor clutch coil is disengaged (turned off). If this diode were to fail, a high voltage (up to 400 volts!) could damage sensitive electronic components in the vehicle including the electronic air-conditioning compressor clutch control unit (if so equipped).

Another thing that can occur is that the radio will often turn off and then back on whenever the electronics inside the radio detect a high-voltage spike. This can create a "pop" in the radio that is very intermittent because it only occurs when the air-conditioning compressor clutch cycles off. To check this diode, simply tune the radio to a weak AM station near 1400 Hz and cycle the air-conditioning compressor on and off. If a "pop" is heard from the radio speaker(s), then the diode is defective and must be replaced.

NOTE: While some A/C compressor diodes can be replaced separately, some of these air-conditioning compressor clutch diodes are part of an entire wiring harness assembly.

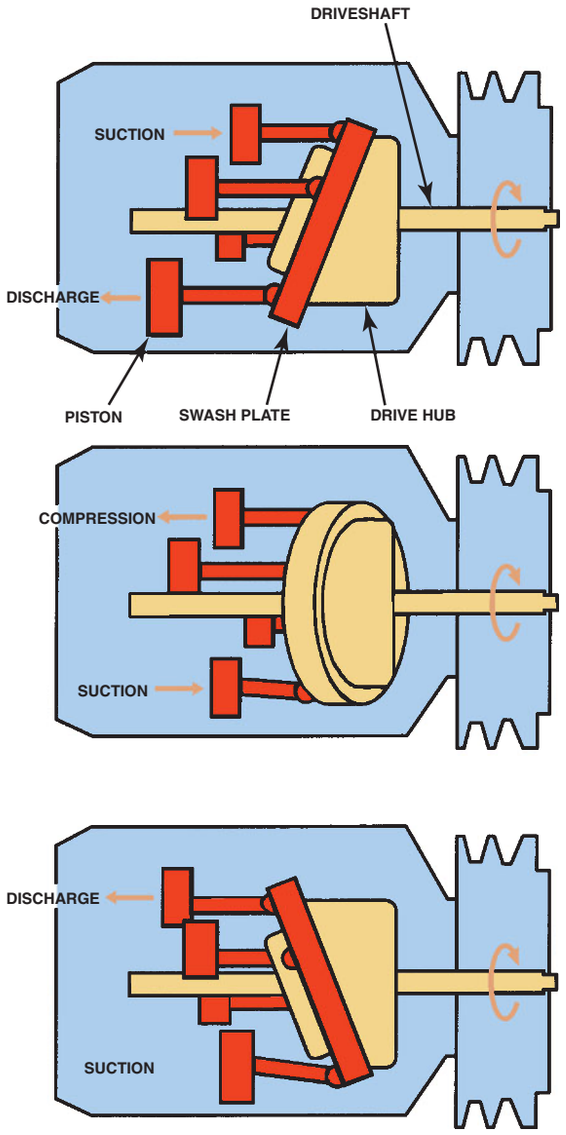


FIGURE 62–36 The swash plate, attached to the crankshaft at an angle, converts the pulley's rotary motion to axial motion, which drives the pistons in a reciprocating motion.

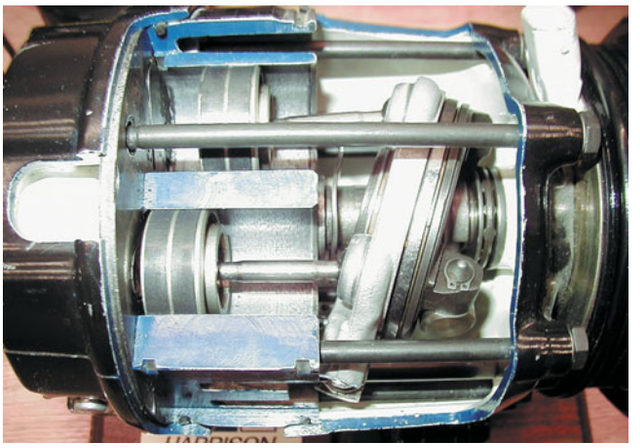


FIGURE 62–37 A V-5 variable displacement compressor. Internal pressures act on the swash plate, which changes the stroke of the piston and then displacement based on the pressures in the system.

COMPRESSOR CONTROLS

Most air-conditioning compressors use an electromagnetic clutch. A coil of wire inside the clutch creates a strong magnetic field that when activated connects the input shaft of the compressor to the drive pulley. Most electromagnetic coil assemblies have between 3 and 4 ohms of resistance. According to Ohm's law, about 3 to 4 amperes of current are required to energize the air-conditioning compressor clutch. All electrical circuits require three things to operate:

1. A voltage source
2. An electrical load (the air-conditioning compressor clutch)
3. A ground connection

All three of these must be in sync before current (amperes) can flow causing the compressor clutch to engage. Most vehicle manufacturers connect several components in series with the compressor clutch so that all have to be functioning before the compressor clutch can be engaged. The most commonly used switches include:

- **Low-pressure switch:** This pressure switch is electrically closed only if there is at least 25 psi of refrigerant pressure. This amount of pressure means that the system is sufficiently charged to provide lubrication for the compressor. This switch also prevents the air-conditioning compressor from being engaged when the temperature is low (low temperature means low refrigerant pressures). ● **SEE FIGURE 62–38.**
- **High-pressure switch:** This pressure switch is located in the high-pressure side of the air-conditioning system. If the pressure exceeds a certain level (typically 375 psi [2,600 kPa]), the pressure switch opens, thereby preventing possible damage to the air-conditioning system due to excessively high pressure.

REAL WORLD FIX

What Throttle Switch?

A service technician was tracing the cause of an inoperative air compressor on a Saab. The service manual showed a schematic of the air-conditioning compressor that indicated a number of switches that had to be closed for the compressor clutch to be supplied with battery voltage. Besides the low pressure switch (to assure that the system is charged so as not to damage the compressor), a throttle switch was shown on the schematic. Obviously, someone else had worked on the vehicle because the throttle switch was missing entirely—just two wires remained to indicate that anything had been installed. Connecting the two wires together provided voltage to the air-conditioning compressor clutch. The customer decided not to replace the throttle switch after learning that its purpose was to disconnect (open circuit) the air-conditioning compressor when the throttle was at wide open positive to allow the maximum power for passing.

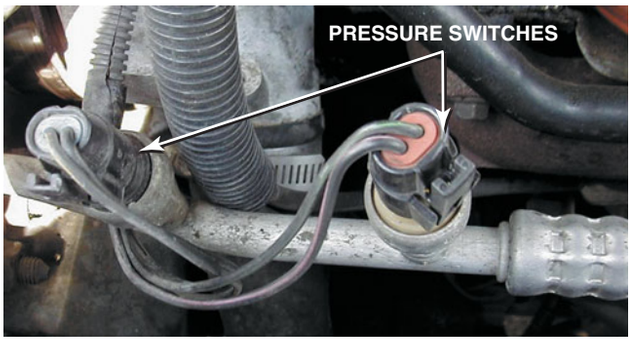


FIGURE 62–38 Typical air-conditioning pressure switches. A service manual would be needed to determine the function of each switch. One switch could be the low-pressure switch and the other a high-pressure switch.

- **Power steering pressure switch:** This switch is used on many vehicles, especially those with four-cylinder engines. It opens the circuit to the air-conditioning compressor clutch when the driver turns the steering wheel. This reduces the load on the engine at the same time power is needed by the power steering pump. Because the wheel is seldom held in a turning maneuver for a long period of time, this stoppage of the air-conditioning compressor has little, if any, effect on passenger cooling.

REVIEW QUESTIONS

1. Discuss how the air-conditioning system removes moisture from the air.
2. Describe the operation of the typical automotive air-conditioning system.
3. Explain why a desiccant is needed in automotive air-conditioning systems.
4. List three methods used to prevent the evaporator from becoming too cold and freezing.

CHAPTER QUIZ

1. Technician A says that heat is measured in degrees. Technician B says that temperature is measured in degrees. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
2. When the defrost setting is selected, the air-conditioning compressor operates.
   a. True
   b. False
3. Where in the air-conditioning system is the refrigerant a low-pressure gas?
   a. Condenser outlet **c.** Evaporator inlet
   b. Evaporator outlet **d.** Condenser inlet
4. Where in the air-conditioning system is the refrigerant a high-pressure liquid?
   a. Condenser outlet **c.** Evaporator inlet
   b. Evaporator outlet **d.** Condenser inlet
5. The compressor operates continuously with which type of system controls?
   a. Orifice tube
   b. POA/EPR
6. Technician A says that all HFC-134a uses the same refrigerant oil. Technician B says that refrigerant oil, regardless of type, must be kept in a sealed container to keep it from absorbing moisture from the air. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. A front-wheel-drive vehicle has a broken condenser line. What other vehicle component may also be defective that could have caused the condenser line to break?
   a. Shock absorbers
   b. Engine mounts
   c. Cooling fan
   d. Air-conditioning compressor drive belt
8. Clear water is observed dripping out from beneath the evaporator. Technician A says that is normal. Technician B says that the evaporator housing is defective and should be replaced. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. The material used to absorb moisture from inside the air-conditioning system is called:
   a. Drier
   b. Desiccant
   c. Ester
   d. PAG
10. Which position on the climate control panel should the driver select to avoid having the air-conditioning compressor turn on?
    a. Heat
    b. Defrost
    c. A/C
    d. Both a and b

chapter 63

AUTOMATIC AIR-CONDITIONING SYSTEM OPERATION

OBJECTIVES: **After studying Chapter 63, the reader will be able to:** • Prepare for ASE Certification test content area Heating and Air Conditioning (A7), test content area "D," Operating Systems and Related Controls Diagnosis and Repair. • Identify the type of HVAC system being used on a vehicle. • Describe how dual-climate and rear air-conditioning systems work. • Discuss vacuum and electric motor controls.

KEY TERMS: Afterblow 731 • Ambient air temperature sensor 732 • Aspirator tube 732 • Automatic temperature control (ATC) system 732 • Cabin filter 732 • Discharge air temperature (DAT) sensor 732 • Dual-position actuator 732 • Hybrid electric vehicle (HEV) 736 • Photo diode 732 • Three-position actuator 732 • Variable-position actuator 732

AIRFLOW MANAGEMENT

All automatic heating, ventilation, and air-conditioning (HVAC) systems use a combination of the following components to control airflow into the passenger compartment:

- Vents
- Ducts
- Air doors (also called flap doors or valves)

The use of these components allows the system to provide airflow under the following conditions:

1. Fresh outside air or recirculated air
2. Air conditioning
3. Defrost
4. Heat

● **SEE FIGURE 63–1**.

The following are the typical settings for a manual or automatic air-conditioning system.

Heat

- Temperature set to the desired setting
- Air intake—select outside air (for faster heating, select recirculation for the first few minutes)
- Air conditioning set to off
- Set airflow to flow
- Fan speed to desired speed

Air Conditioning

- Temperature set to the desired setting
- Air intake—set to outside air (for faster cooling, select recirculation for the first few minutes)
- Airflow—select dash vents (also called panel vents)
- Air conditioning set to on
- Fan speed set to desired speed

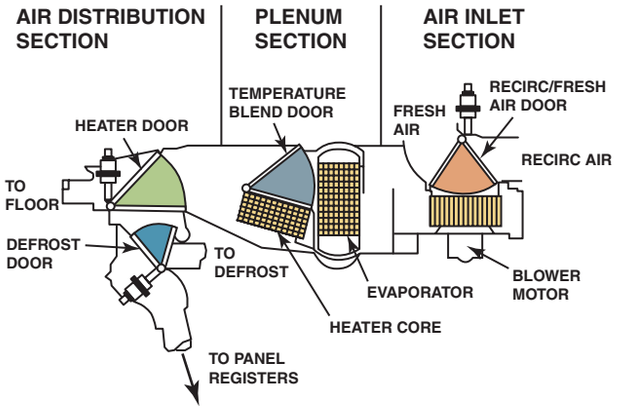


FIGURE 63–1 The three major portions of the A/C and heat system are air inlet, plenum, and air distribution. The shaded portions show the paths of the four control doors.

? FREQUENTLY ASKED QUESTION

What Is "Afterblow"?

Afterblow is a term used to describe the operation of the blower motor after the ignition has been turned off. The purpose of afterblow is to dry the evaporator to help prevent the formation of mold and mildew in the evaporator case. The operation of the blower motor after the ignition is turned off has created some customer complaints. Check service information to be sure that the condition is normal or not on the vehicle being investigated. For example, in a typical General Motors system, the following conditions must be met for afterblow to occur:

1. The engine has been off for 30 minutes.
2. The outside air temperature is 70°F (21°C) or higher.
3. The battery voltage is 12 volts or higher.

If the above conditions exist, the afterblow is commanded to be on for 20 seconds, off for 10 seconds, and then back on for another 20 seconds.

Ventilation

- Temperature set to lowest temperature
- Air intake—select outside air
- Airflow—set to dash (panel) vents
- Air conditioning set to off
- Fan speed set to desired speed

Defogging or Defrosting the Inside of the Windshield

- Temperature set to high temperature
- Air intake set to outside air
- Airflow set to windshield
- Fan speed set to desired speed

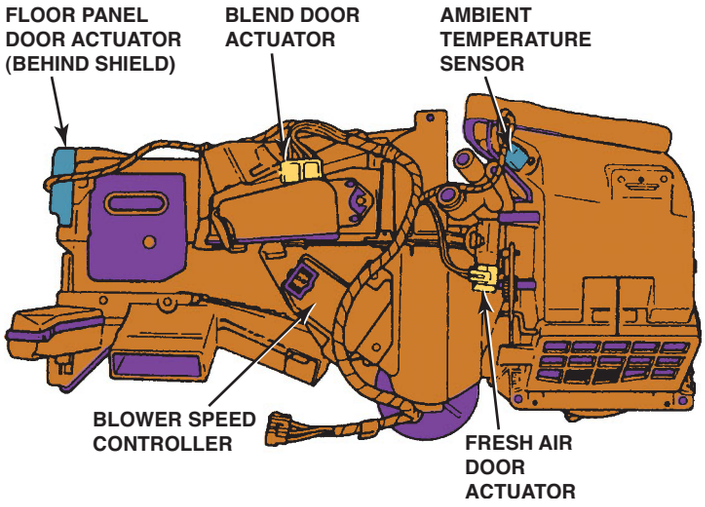


FIGURE 63–2 The ambient temperature sensor in this system is located in the fresh air intake duct for the HVAC system.

AUTOMATIC AIR CONDITIONING

Automatic air-conditioning systems are usually called **automatic temperature control (ATC) systems.** Automatic systems use many of the same components as a normally adjusted system but with additional sensors. These sensors and their purpose and function include:

OUTSIDE AIR TEMPERATURE (OAT) SENSOR This sensor is usually located at the front of the vehicle behind the grille but in front of the radiator. The purpose of this sensor is to detect the temperature of the outside air. This sensor is commonly called the **ambient air temperature sensor** and is also used to supply temperature information for the driver on a display. ● **SEE FIGURE 63–2**.

INSIDE VEHICLE TEMPERATURE SENSOR Many older ATC systems used a temperature sensor located behind the instrument panel. Air to the sensor was forced to flow past the sensor by using an **aspirator tube,** which was connected to the blower motor case.

DISCHARGE AIR TEMPERATURE SENSOR The **discharge air temperature (DAT) sensor** is located at the outlet of the vents. The purpose of this sensor is to inform the controller of the actual temperature at the discharge ducts.

EVAPORATOR OUTLET TEMPERATURE SENSOR This sensor is used to control the AC compressor to keep the evaporative temperature within the specified temperature range for most efficient operation.

SUNLOAD SENSOR Sunload sensors are mounted on the top of the dash so that they can adjust the temperature and the fan speed to match the increased heating through the windows from the sun. The most common type of sunload sensor is a **photo diode.** This type of sensor produces a voltage which is directly related to the amount of light received. The voltage varies from 0.3 volt (dash) to 3.0 volts (light).

NOTE: Some vehicles are equipped with a dual-zone sunload sensor that has two sensors included. This sensor allows the system to automatically adjust the airflow and air temperature based on the actual sun intensity experienced by both the driver and the passenger.

ACTUATORS

An actuator is a part that moves the vanes or valves. Actuators used in air-conditioning systems are either electric or vacuum operated and include three different types.

DUAL-POSITION ACTUATOR A **dual-position actuator** is able to move either open or closed. An example of this type of actuator is the recirculation door, which can be either open or closed.

THREE-POSITION ACTUATOR A **three-position actuator** is able to provide three air door positions, such as the bi-level door, which could allow defrost only, floor only, or a mixture of the two.

VARIABLE-POSITION ACTUATOR A **variable-position actuator** is capable of positioning a valve in any position. All variable-position actuators use a feedback potentiometer, which is used by the controller to detect the actual position of the door or valve. ● **SEE FIGURE 63–3**.

CABIN FILTERS

Most late-model air-conditioning systems include a **cabin filter,** which is an air filter in the outside air inlet. The purpose of the cabin filter is to filter dirt and dust from the air before it enters the interior of the vehicle. Cabin air filters can be accessed either in the dash, usually behind the glove box, or from under the hood. Cabin air filters should be replaced regularly, usually every two years during normal service and more often if the vehicle is driven in dusty areas. ● **SEE FIGURE 63–4**.

NOTE: Some cabin filters contain activated charcoal which absorbs hydrocarbons and helps to deodorize the air as it enters the interior. For best results, use the designated replacement filter.

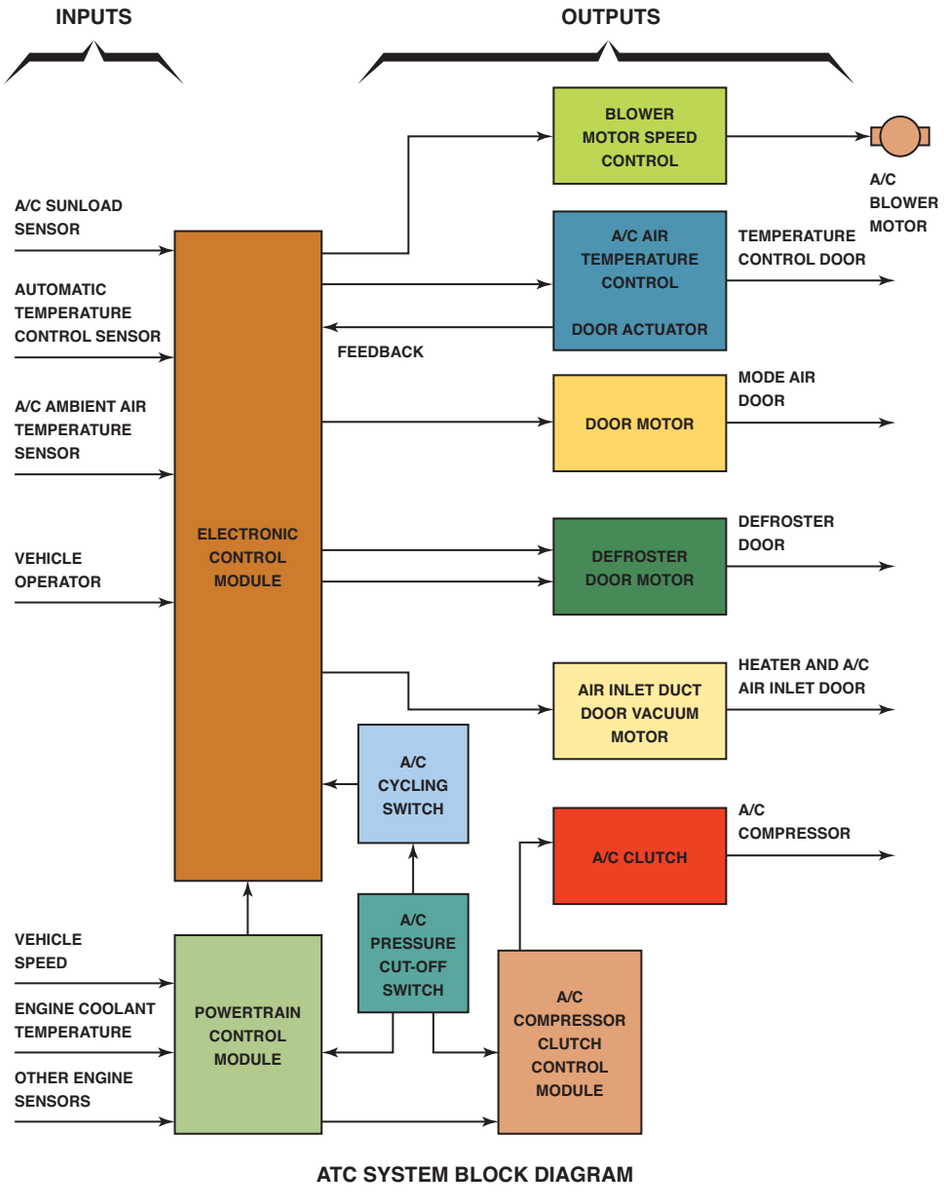


FIGURE 63–3 A block diagram showing the inputs to the electronic control assembly and the outputs; note that some of the outputs have feedback to the ECM.



FIGURE 63–4 A typical cabin filter being removed from behind the glove compartment.

VACUUM CONTROL CIRCUITS

Vacuum control circuits use vacuum created in the intake manifold of the engine. Because vacuum decreases to close to zero during heavy acceleration, a vacuum accumulator is used to store vacuum during the short periods of acceleration. ● **SEE FIGURE 63–5**.

ELECTRIC SERVOMOTOR CIRCUITS

Most HVAC systems use electric motors to move valves and doors. ● **SEE FIGURE 63–6** on page 734. Each servomotor contains a feedback potentiometer, which is used by the air conditioning control unit to indicate the actual position of the valve or door. If the commanded position and the actual position are not the same, then most systems are designed to store a diagnostic trouble code indicating which door is out of calibration. ● **SEE FIGURE 63–7** on page 734.

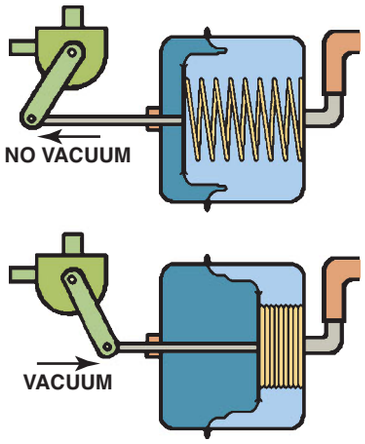


FIGURE 63–5 With no vacuum signal, the spring extends the actuator shaft to place the door in a certain position (top). A vacuum signal pulls the shaft inward and moves the door to the other position (bottom).

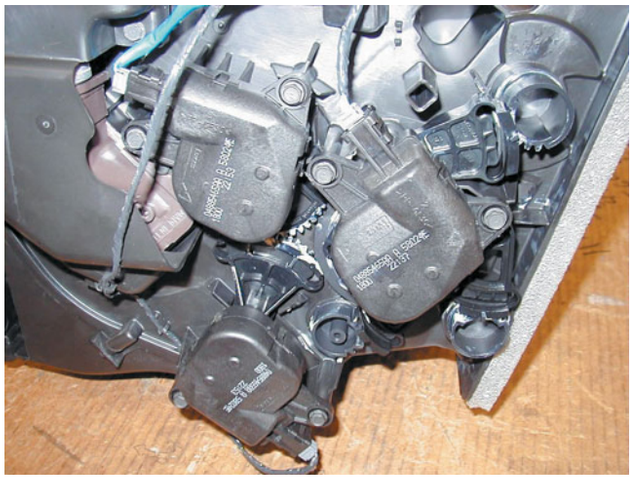


FIGURE 63–6 Three electric actuators can be easily seen on this demonstration unit. However, accessing these actuators in a vehicle can be difficult.

BLOWER MOTOR CONTROL

Blower motors are used to move air. The air is directed by the doors of the HVAC system. Most blower motors use resistors to control the speed of the motors by dropping the amount of current flow through the motor at the lower speed. The resistor lowers the voltage and the current to the motor. The control then allows full system voltage to be applied to the motor during high-speed operation. The blower motor resistor is always located in the plenum near the blower motor so that airflow past the resistor can help keep it cool. ● **SEE FIGURES 63–8 AND 63–9**.

DUAL-ZONE CLIMATE CONTROLS

Dual-zone climate controls allow the driver and the passenger to select different temperatures, as much as a 30°F (17°C) difference. In a dual-zone climate control system, the ducts and airflow are split and two air mix doors are used, with each door being controlled by its own actuator. ● **SEE FIGURE 63–10** on page 735.

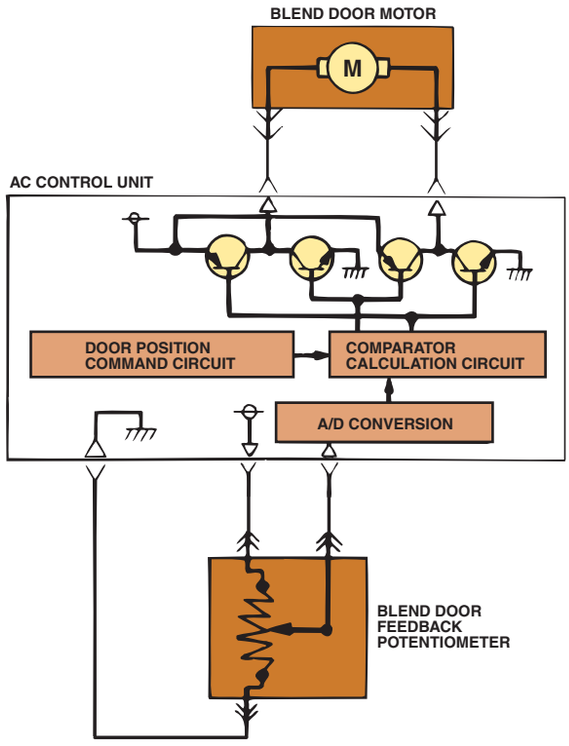


FIGURE 63–7 The feedback circuit signals the AC control unit with the blend door position.

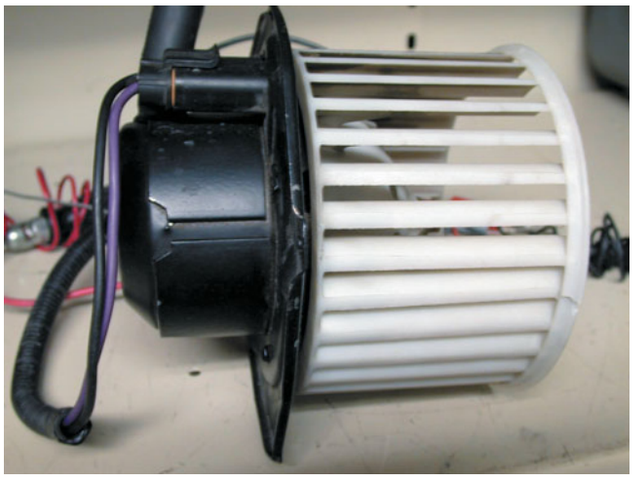


FIGURE 63–8 A typical blower motor assembly with attached squirrel cage blower. A replacement motor does not include the squirrel cage blower so it needs to be switched to the replacement motor.



FIGURE 63–9 A "credit card" resistor used in the rear blower assembly in a Dodge minivan.

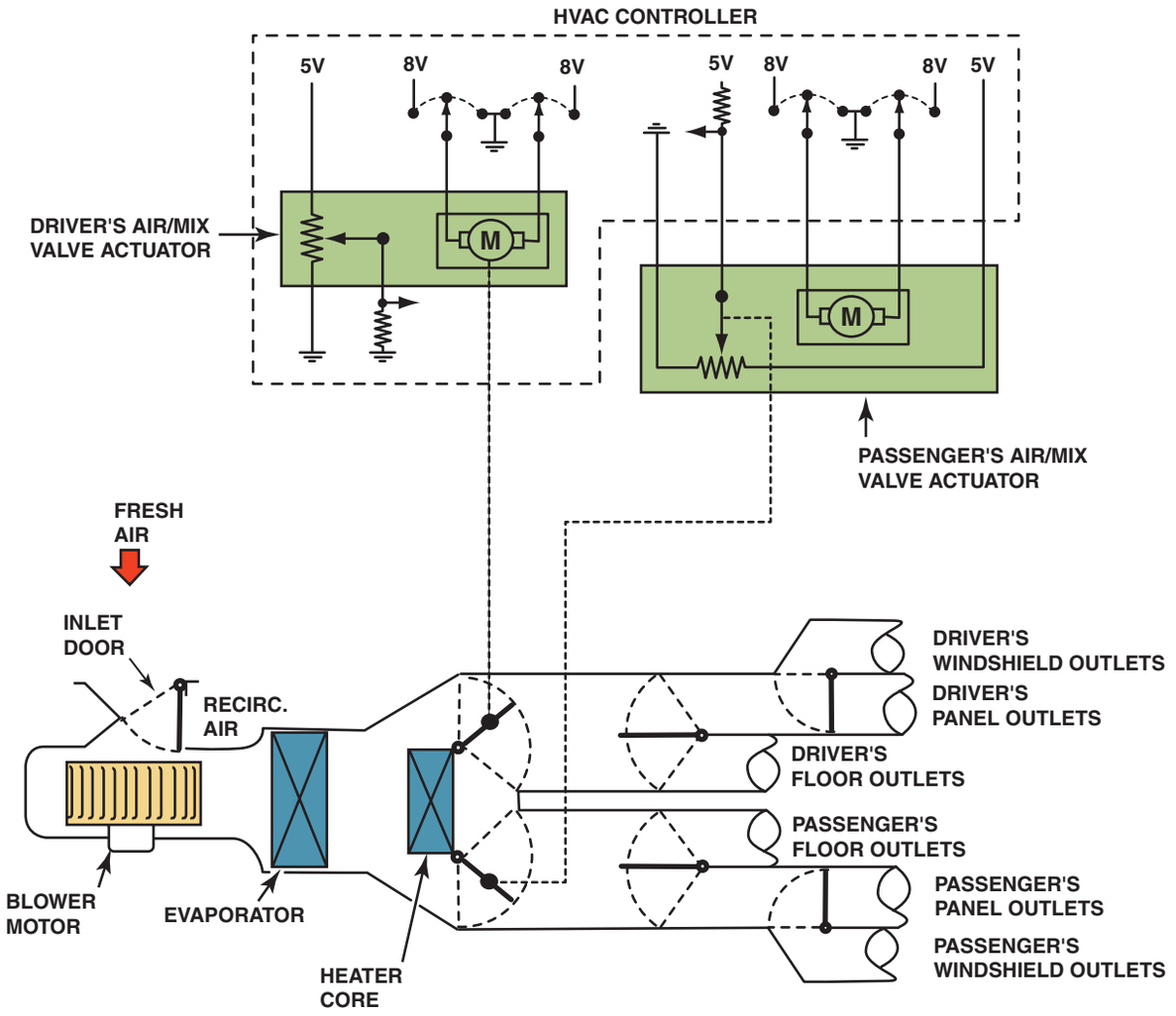


FIGURE 63–10 A dual climate control system showing the airflow and how it splits.



FIGURE 63–11 A typical dual-zone climate control panel showing left and right side temperature control levers.

REAR AIR-CONDITIONING SYSTEM

Many larger trucks, vans, and sport utility vehicles (SUVs) are equipped with rear heat and air-conditioning units. Many vehicles are equipped with ducts that route heated or cooled air to rear-seat passengers. ● **SEE FIGURE 63–11**. However, many larger vehicles require a separate heater core and air-conditioner evaporator in the rear to provide adequate heating and cooling. Most rear HVAC systems include the following components:

- A larger capacity air-conditioning compressor
- A second evaporator located at the rear of the vehicle
- A second heater core located at the rear of the vehicle
- A second blower motor and blower motor control at the rear of the vehicle
- Lines and fittings connecting the front heater and air-conditioning components to the rear system
- Rear controls for speed and temperature on some models

● **SEE FIGURE 63–12 AND FIGURE 63–13.**

RECIRCULATION OPERATION

When recirculation is selected, about 90% of the air is drawn from the passenger compartment and the other 10% is drawn from outside air. The purpose is to speed up the cooling of the inside of the vehicle.

However, the body control module may also select recirculation operation if the high-side air-conditioning system pressures exceed 320 PSI (2,200 kPa) to help lower the high-side pressure using cooler inside air through the evaporator. This condition should not normally occur, but if it does, this could cause a customer concern because the blower noise is greatly increased in the recirculation position.



FIGURE 63–12 Heated or cooled air is supplied to the rear seat passengers of most vehicles through ducts that run under the front seats.



FIGURE 63–13 A rear heat and air conditioning system on a Honda Odyssey minivan.

HYBRID ELECTRIC VEHICLE HEATING AND COOLING SYSTEMS

Hybrid electric vehicle (HEV) systems need to be different than conventional systems because the engine stops when at idle if the engine is warm. As a result, the engine-driven air-conditioning compressor will also stop. To allow idle-stop mode and still provide air conditioning, several methods are used depending on the exact vehicle. These methods include:

1. Idle-stop mode is disabled if max cooling is selected.
2. Honda uses a hybrid compressor which has a smaller capacity part of the compressor being operated by an electric motor, which is powered by the high-voltage (HV) batteries.
3. Toyota uses an air-conditioning compressor that is entirely driven by the high-voltage batteries and is therefore capable of providing cooling under all conditions, including when the engine is not operating.

Toyota uses electric heating devices called positive temperature coefficient (PTC) thermistor installed in the heater core to provide heat to the passenger compartment. These heaters are powered by the high-voltage electric system.

REVIEW QUESTIONS

1. What are the four airflow locations?
2. Automatic air-conditioning systems include which sensors?
3. Why is a feedback potentiometer used on an electric actuator?
4. What components are needed for rear air conditioning and heat?

CHAPTER QUIZ

1. In heating mode, where is the airflow directed?
   a. Dash vents
   b. Floor
   c. Windshield
   d. Both b and c
2. Which sensor is also called the ambient air temperature sensor?
   a. Outside air temperature (OAT)
   b. Inside vehicle temperature
   c. Discharge air temperature
   d. Evaporator outlet temperature
3. What is the most common type of sunload sensor?
   a. Potentiometer
   b. Negative temperature coefficient (NTC) thermistor
   c. Photo diode
   d. Positive temperature coefficient (PTC) thermistor
4. An actuator can be capable of how many position(s)?
   a. Two
   b. Three
   c. Variable
   d. All of the above
5. Some cabin filters contain _____ to absorb odors.
   a. Perfume
   b. Activated charcoal
   c. Paper filter material
   d. Synthetic fibers
6. Which sensor might use an aspirator tube?
   a. Inside vehicle temperature
   b. Outside air-temperature (OAT)
   c. Discharge air temperature
   d. Evaporator outlet temperature

7. Technician A says that some cabin filters are accessible behind the glove compartment. Technician B says that some cabin filters are accessible from under the hood. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. The blower motor resistors are used to limit _____ to the motor.
   a. Voltage
   b. Current
   c. Airflow
   d. Both a and b
9. Which is *not* part of a rear air-conditioning system?
   a. Rear evaporator
   b. Rear heater core
   c. Rear AC compressor
   d. Rear blower motor
10. What components in the air-conditioning system may be different on a hybrid electric vehicle?
   a. Evaporator
   b. Compressor
   c. Condenser
   d. Blower motor

chapter 64 HEATING AND AIR-CONDITIONING SYSTEM DIAGNOSIS

OBJECTIVES: **After studying Chapter 64, the reader will be able to:** • Prepare for ASE Heating and Air Conditioning (A7) certification test content area "A" (Air Conditioning System Diagnosis and Repair), content area "B" (Refrigeration System Component Diagnosis and Repair), content area "C" (Heating and Engine Cooling Systems Diagnosis and Repair), content area "D" (Operating Systems and Related Controls Diagnosis and Repair), and content area "E" (Refrigeration, Recovery, Recycling, and Handling). • Diagnose lack of heat problems. • List the air-conditioning system performance check procedures. • Discuss methods used to locate the source of an air-conditioning system leak. • Describe how to recover, evacuate, and recharge an air-conditioning system. • Discuss what is necessary to retrofit a CFC-12 system to be able to use HFC-134a refrigerant.

KEY TERMS: Bleeder valves 739 • High-side pressure 741 • Low coolant level 740 • Low-side pressure 741

HVAC DIAGNOSTIC PROCEDURE

When diagnosing a heating and air-conditioning system problem, most vehicle manufacturers recommend that the following steps be performed.

STEP 1 **Verify the customer complaint (concern).** Sometimes the customer does not understand how the system is supposed to work or does not explain the fault clearly. Verifying the fault also means that the technician can verify that the problem has been corrected after the service procedure has been performed.

STEP 2 **Do a thorough visual inspection.** Heating and air-conditioning problems are often found by looking carefully at all of the components, checking for obvious faults or damage due to an accident or road debris.

STEP 3 **Check for diagnostic trouble codes.** Many heating and air-conditioning systems use sensors and actuators, which are computer controlled and will set diagnostic trouble codes in the event of component failure.

STEP 4 **Check for related technical service bulletins (TSBs).** If there has been a bulletin released to solve a known problem, it saves a lot of time to know what to do rather than spend a lot of time trying to find and correct a problem.

STEP 5 **Determine the root cause.** Be sure to find and correct the root cause of the problem. A low refrigerant level means that there was a leak in the system. Finding and correcting the leak that caused the low refrigerant level is correcting the root cause.

STEP 6 **Verify the repair.** Drive the vehicle under similar conditions which caused the customer to complain and verify that the concern has been corrected.

HEATER DIAGNOSIS

Most of the heat absorbed from the engine by the cooling system is wasted. Some of this heat, however, is recovered by the vehicle heater. Heated coolant is passed through tubes in the small core of the heater. Air is passed across the heater fins and is then sent to the passenger compartment. In some vehicles, the heater and air

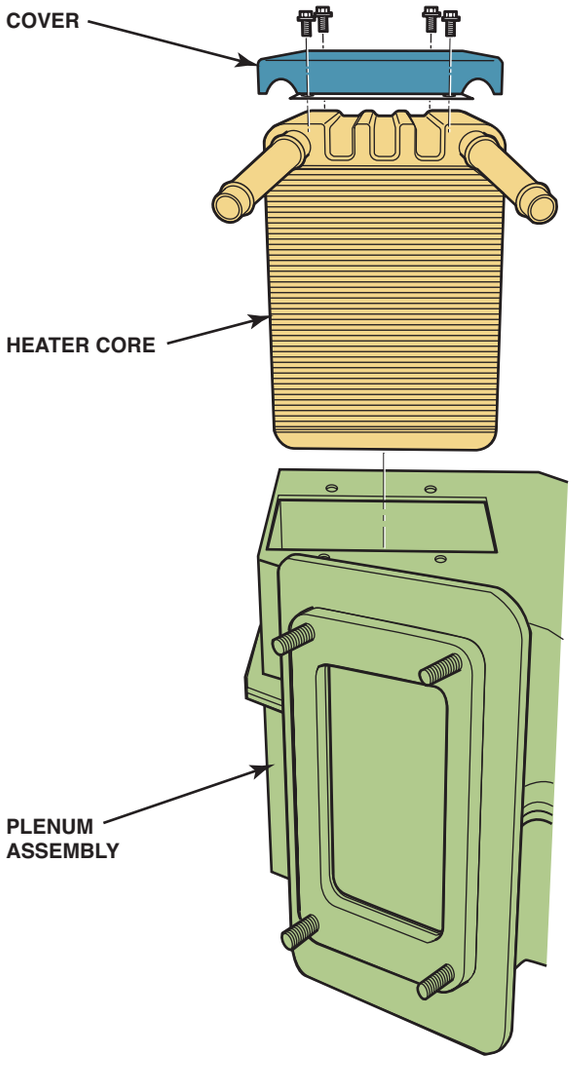


FIGURE 64–1 The heater core is mounted inside a heater plenum chamber where air passes over it to absorb heat from the warmed engine coolant.

conditioning work in series to maintain vehicle compartment temperature. ● **SEE FIGURE 64–1**.

THERMOSTAT DIAGNOSIS

When the vehicle's heater does not produce the desired amount of heat, many owners and technicians replace the thermostat before doing any other troubleshooting. While it is true that a defective thermostat can be the reason for the engine not to reach normal operating temperatures, there are many other causes that can result in lack of heat from the heater. To determine the exact cause, follow this procedure:

STEP 1 After the engine has been operating for 15 minutes, feel the upper radiator hose. If the engine is up to proper operating temperature, the upper radiator hose should be too hot for you to keep your hand on it. The hose should also be pressurized.

a. If the hose is not hot enough, replace the thermostat.

b. If the hose is not pressurized, pressure test the cooling system with a pressure tester to locate leaks. Replace the radiator pressure cap if it will not hold the specified pressure.

c. If okay, see step 2.

TECH TIP

Water on the Carpet? Check the Evaporator Water Drain

If the evaporator water drip tube becomes clogged with mud, leaves, or debris, water will build up inside the evaporator housing and spill out onto the carpet on the passenger side. Customers often think that the windshield or door seals are leaking. Most evaporator water drains are not visible unless the vehicle is hoisted.

STEP 2 With the engine running, feel both heater hoses. (The heater should be set to the maximum heat position.) Both hoses should be too hot to hold. If both hoses are warm (not hot) or cool, check the heater control valve, if equipped, for proper operation. If one hose is hot and the other (return) is just warm or cool, remove both hoses from the heater core or engine and flush the heater core with water from a garden hose.

HEATER TROUBLE DIAGNOSIS

A lack of heat from the heater or having heat coming out of the wrong vents can be a dangerous and uncomfortable problem. The first step in the diagnostic process is to perform a thorough visual inspection and perform simple tests. This includes the following:

- **Check the coolant level.** Low coolant level can cause a lack of heat from the heater. Low coolant level can also cause occasional loss of heat.

  CAUTION: Do not remove the radiator cap when the engine is hot. Allow the vehicle to sit several hours before removing the pressure cap to check the radiator coolant level.

- **Carefully touch the upper radiator hose with the engine running.** On most vehicles, the temperature of the hose should be so hot that you cannot keep your hand on it (between 190° to 220°F [88° to 104°C]).

  NOTE: An infrared thermometer (pyrometer) can be used to measure the temperature of the upper radiator hose and the area around the thermostat housing.

- **Results:** If the upper radiator hose is not too hot to hold, then the engine thermostat is defective. If the radiator hose is too hot to handle, then the lack of heat from the heater is not due to a lack of hot water in the engine.

● **SEE FIGURE 64–2**.

- **Results:** (a) If neither heater hose is hot to the touch, it is likely there is an air pocket in the heater that is preventing the flow of coolant into the heater core. (b) If only one heater hose is hot to the touch, then the heater core is likely to be clogged or partially clogged. A clogged heater core would prevent enough hot coolant from circulating through the heater core to provide adequate heat to the passenger compartment.

VISUAL INSPECTION

The diagnosis of a heater problem or concern should start with a visual inspection. The following items should be checked or tested:

TECH TIP

Defrost All the Time? Check the Vacuum

A common problem involves airflow from the defroster ducts even though the selector lever is in other positions. The defrost setting is the default position in the event of a failure with the vacuum supply. The defrost position is used because it is the *safest* position. For safety, the windshield must remain free from frost. Heat is also supplied to the passenger compartments not only through defrost ducts but also through the heater vents at floor level.

If the airflow is mostly directed to the windshield, check under the hood for a broken, disconnected, or missing vacuum hose. Check the vacuum reserve container for cracks or rust (if metal) that could prevent the container from holding vacuum. Check all vacuum hose connections at the intake manifold and trace each carefully, inspecting for cracks, splits, or softened areas that may indicate a problem.

HINT: This problem of incorrect airflow inside the vehicle often occurs after another service procedure has been performed, such as spark plug replacement. The movement of the technician's body and arms can cause a hose to be pulled loose or a vacuum fitting to break without the service technician being aware that anything wrong has occurred.

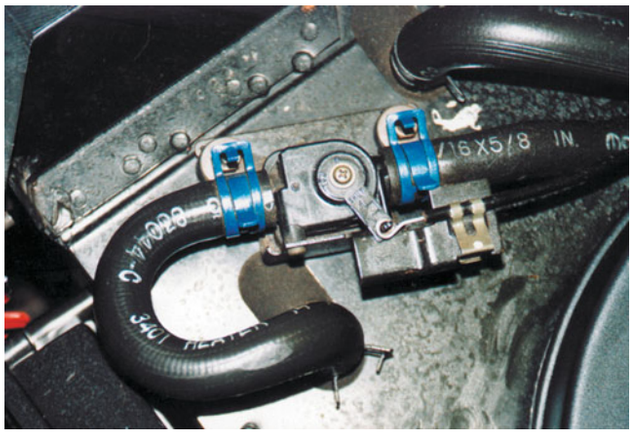


FIGURE 64–2 A cable controlled heater control valve. This valve is normally open, allowing engine coolant to flow through the heater core. When the air conditioning is switched to maximum cooling, the valve shuts off the flow of coolant to the heater.

TECH TIP

The Hand Test

To check a radiator or condenser for possible clogged or restricted areas, simply touch the outside of the unit with your hand. Any cool spots indicate that the radiator or condenser is clogged in that cool area.

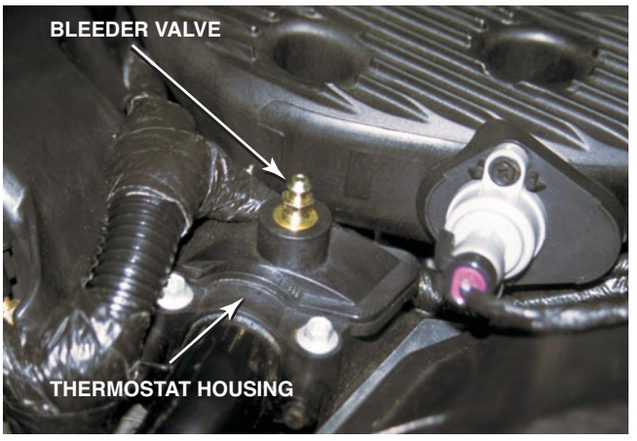


FIGURE 64–3 Many engines are equipped with a bleeder valve to permit a technician to bleed any trapped air from the cooling system. The valve is loosened as coolant is poured into the system. Because air is lighter than coolant, the air tends to float toward the highest part of the cooling system.

FREQUENTLY ASKED QUESTION

How Can You Easily Burp Air from the Cooling System?

The first step in being certain there is no air in the cooling system is to try to avoid getting air into the system in the first place during cooling system service. If the engine is equipped with **bleeder valves** near the high spots of the cooling system, these valves should be open when refilling the radiator. ● **SEE FIGURE 64–3**. Any trapped air will always travel to the highest portion of the cooling system and escape out of these bleeder openings. Close the valves as soon as coolant is observed coming out of the valve opening.

If the cooling system is not equipped with bleeder valves, fill the cooling system as full as possible and then start the engine. With the radiator cap removed, the coolant level will often rise as the trapped air is expanding, then drop down as the trapped air escapes out of the radiator neck opening. Air can still remain trapped. To help speed up the process, try installing the radiator cap just to the first notch. (In this position the radiator cap is closed, but will not seal enough to allow pressure to build in the cooling system.) To help force any trapped air from the cooling system, simply drive the vehicle normally for several miles. By driving the vehicle under load, the engine will warm up faster and the thermostat will open allowing the coolant to flow from the engine and through the radiator. Any trapped air is then released into the radiator where it can easily escape through the unsealed radiator cap. After filling the radiator, securely tighten the radiator cap and test-drive the vehicle to verify proper operation. Always check service information for the exact procedure to follow when replacing coolant.

NOTE: An air bubble could be lodged in the heater core. This is a common occurrence especially if the coolant (antifreeze) has been recently replaced. Failure to properly "burp" the air from the cooling system can cause a pocket of air to remain trapped in the heater core, preventing coolant from flowing through. See Frequently Asked Question "How Can You Easily Burp Air from the Cooling System?"

TECH TIP

Hot/Cold/Hot/Cold Heater Diagnosis

A common customer complaint is a lack of heat from the heater but only while driving, even though there seems to be plenty of heat when the engine is at idle speed and the vehicle is stopped. This is a classic symptom of **low coolant level.** The lower than normal coolant level in the radiator prevents enough flow to supply the heater core. When the engine speed is reduced, the water pump turns slower and coolant can more easily flow through the heater core resulting in heat from the heater. As the engine speed increases, the water pump speed also increases. Because there is less than the proper amount of coolant in the system, the water pump will only be able to supply coolant through the engine (a path of lower resistance).

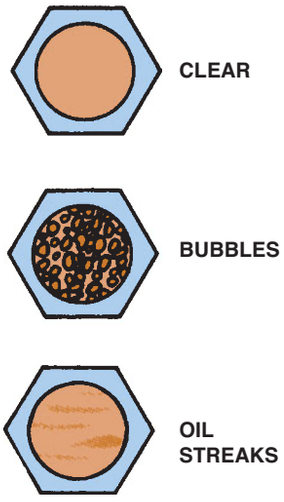


FIGURE 64–4 Many older CFC-12 systems are equipped with a sight glass either on or near the receiver-drier. A fully-charged (or completely empty) system is indicated by a clear sight glass. Bubbles or foam indicate that the system is not fully charged. An empty system may have oil streaks on the sight glass being moved by the vapor remaining in the system.

CHECKING A/C SYSTEM PERFORMANCE

The first step in the diagnosis of any cooling system problem is to verify the complaint (concern).

STEP 1 Start the engine and turn the A/C system to maximum with the engine operating between 1500 and 2000 RPM with the doors open. Operate the system for 5 to 10 minutes.

STEP 2 Verify by visual inspection that the A/C compressor clutch is engaged. Check the sight glass if the vehicle is so equipped, as shown in ● **FIGURE 64–4**.

HINT: If the A/C compressor clutch cannot be observed, have an assistant turn the air conditioning on and then off and listen for the "click" of the A/C compressor clutch.

STEP 3 Place an air-conditioning thermometer in the A/C vent near the center of the vehicle. Wait several minutes to allow the system to reach maximum output and observe the thermometer.

- *If 35° to 45°F (2° to 7°C)*, the system is functioning okay. Continue a thorough visual inspection looking for any faults that may cause an intermittent problem.
- *If over 45°F (7°C)*, continue with pressure gauge testing (Step 4).

STEP 4 *Identify the refrigerant*. Before connecting the pressure gauges or performing any other service to an automotive air-conditioning system, verify the refrigerant that is presently in the system. Connect a refrigerant identification machine to the system. ● **SEE FIGURE 64–5**.

STEP 5 *Connect both high-pressure and low-pressure gauges to the service ports*. Start the engine and turn the air conditioning system on and set to maximum cooling. The low-side pressure should be about 25 to 35 PSI. The high-side pressure should be about 150 to 200 PSI. Compare your readings to the normal and abnormal readings in the following chart. ● **SEE FIGURES 64–6 AND 64–7**.



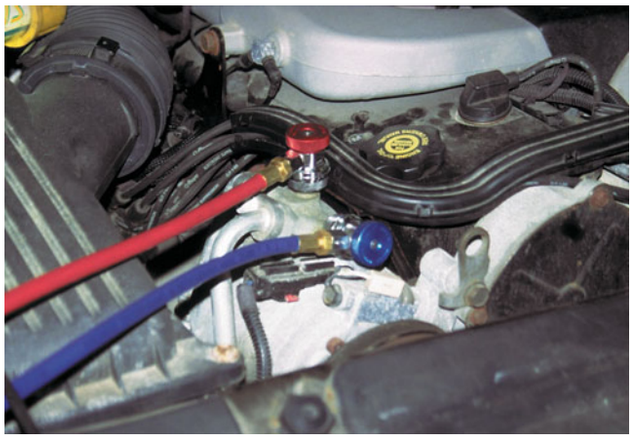
FIGURE 64–5 A typical refrigerant identification machine. The readout indicates what kind of refrigerant is in the system. If a blend or some other contaminated refrigerant is discovered, it should be recovered and stored in a separate container to keep it from contaminating fresh refrigerant.

A/C Pressure Gauge Chart

Low Side	High Side	Condition (Possible Cause)
25–35 PSI	170–200	Normal
Low	Low	Low refrigerant charge level
Low	High	Restriction in high-side line
High	High	System is overcharged. Expansion valve stuck open
High	Low	Restriction in the low-side line

TEMPERATURE AND PRESSURE MEASUREMENTS

Temperature and pressure are directly related in AC systems. As the ambient temperature increases, the high-side pressure must also increase to have a heat transfer at the condenser. The temperature



(a)



(b)

FIGURE 64–6 (a) Both high-pressure (red) and low-pressure (blue) hoses have been attached to the vehicle. (b) High-side pressure can be compared to the temperature of the outlet from the compressor. Here a service technician is using an infrared pyrometer to measure the temperature.

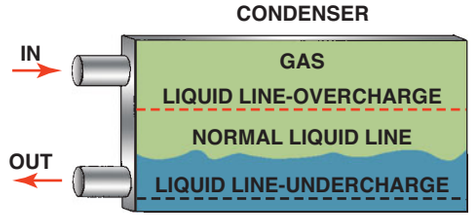


FIGURE 64–7 Hot refrigerant condenses in the condenser when it loses its heat to the outside air. Note how the level of the liquid line changes when undercharged or overcharged.

of the vapor must be higher than the ambient temperature to allow enough heat to be removed for condensation. Also, higher ambient temperatures, and high humidity, usually mean a higher heat load on the evaporator. This means a larger quantity of heat has to be removed at the condenser.

The **high-side pressure** is directly related to the amount of heat that needs to be removed, and the heat transfer at the condenser. **Low-side pressure** indicates the boiling point of the temperature of the evaporator. If the pressure is too high, the boiling point of the refrigerant and temperature of the evaporator are too high. Low-side pressure that is too low indicates the evaporator is too cold and may ice, or that there is not enough boiling refrigerant in the evaporator to remove an adequate amount of heat. ● **SEE FIGURE 64–8**.

The heat transfer at the condenser is usually the cause of high-side pressure that is too high. The number one cause of poor heat transfer is lack of airflow across the condenser. The vehicle is dependent upon fans to move enough air when you are testing in a stall. It may be necessary to drive the vehicle at 30 mph to get the ram air necessary to determine if lack of airflow is the reason for the poor heat transfer.

Another cause of excessive high-side pressure is contamination with a different refrigerant. Mixing R-12 and R-134a raises the condensing pressure of the mixture. If the system is contaminated with R22, the pressures can become extremely high. At 150°F, the pressure of R-12 is 235 PSI (1,620 kPa), R-134a is 263 PSI (1,813 kPa), and R-22 is 381 PSI (2,627 kPa). This is an important reason to use a refrigerant identifier.

As compressor efficiency is reduced, the high side decreases, and the low side increases. The function of the compressor is to pull down the low side and push up the high side. When the compressor is failing, it does not do either job well. Always look at both the high- and low-side pressures when diagnosing a problem. ● **SEE FIGURES 64–9 THROUGH 64–11**.

? **FREQUENTLY ASKED QUESTION**

What's Wrong When the A/C Compressor Clutch Cycles On and Off Rapidly?

This is a common occurrence on a vehicle equipped with a cycling clutch orifice tube (CCOT) system that is low on refrigerant charge. With a normal charge, the low-side pressure should be 15 to 35 PSI and the clutch should be on for 45 to 90 seconds and be off for only about 15 to 30 seconds.

R134a PRESSURE-TEMPERATURE CHART

AMBIENT AIR TEMPERATURE (°F)	HUMIDITY	LOW-SIDE PRESSURE (PSI)	HIGH-SIDE PRESSURE (PSI)
70	Low	25 to 30	140 to 190
	High	28 to 35	165 to 220
80	Low	26 to 33	150 to 200
	High	30 to 36	190 to 260
90	Low	31 to 37	170 to 220
	High	37 to 45	210 to 290
100	Low	35 to 44	195 to 245
	High	38 to 48	230 to 320
100	Low	40 to 50	235 to 285
	High	42 to 52	260 to 350

FIGURE 64–8 The average R-134a pressure–temperature readings during a performance test. The high-side pressure of R-12 systems will be lower at higher temperatures.

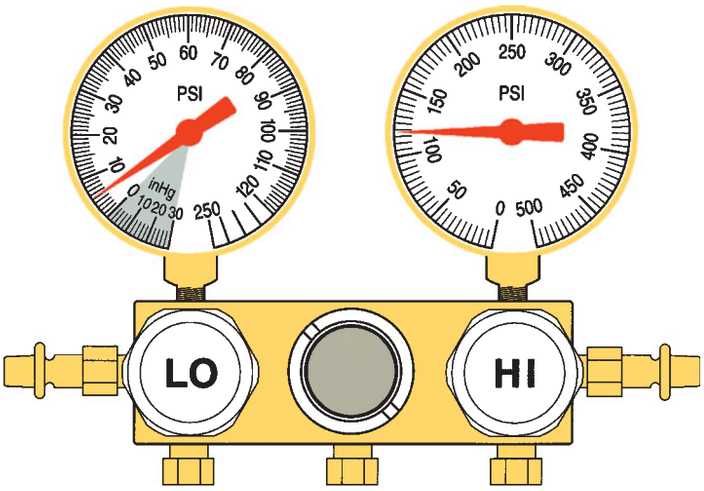


FIGURE 64–9 When both low- and high-side pressures are low, the system is undercharged with refrigerant.

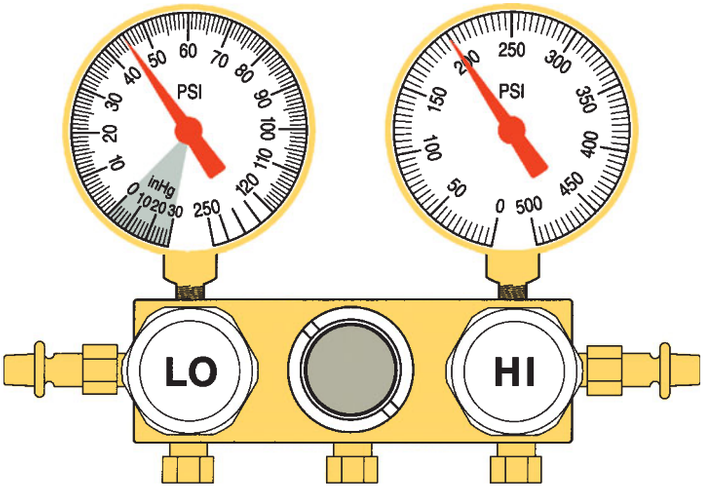


FIGURE 64–10 Both low- and high-side pressures higher than normal indicate that the system is overcharged with refrigerant.

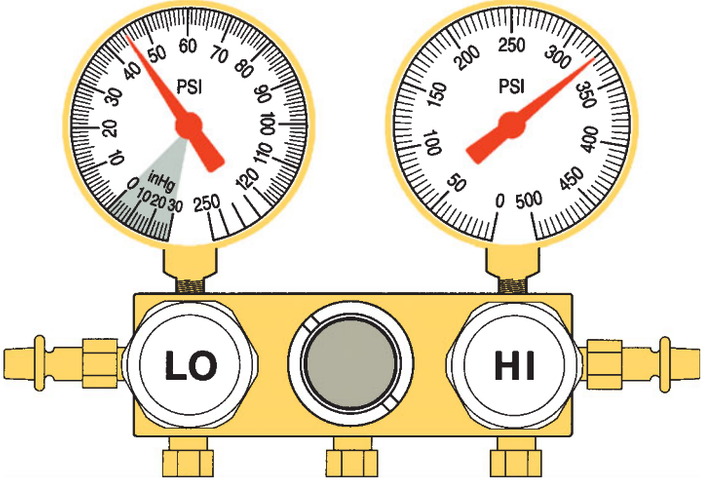


FIGURE 64–11 Lack of proper airflow across the condenser is usually the cause of this condition.



FIGURE 64–12 A clogged orifice tube.

TECH TIP

High-Side Pressure Tip

A quick and easy way to determine the correct high-side pressure is to add 100 to the ambient air temperature in Fahrenheit.

For example: 85°F outside air temperature

$$\begin{array}{r} +100 \\ \hline 185 \text{ PSI} = \text{typical normal high-side pressure} \end{array}$$

TECH TIP

Clogged Orifice Tube Test

A clogged orifice tube is a common air-conditioning system failure. When the orifice tube becomes clogged, it blocks the flow of refrigerant through the evaporator, which causes a reduced cooling of the passenger compartment. To check for a possible restriction in the system, follow these easy steps:

STEP 1 Connect the A/C pressure gauge to both low- and high-side pressure fittings.

STEP 2 Operate the A/C system for 5 to 10 minutes.

STEP 3 Shut off the A/C system and watch the pressure gauges. If the pressures do not equalize quickly, then there is a restriction in the system. ● **SEE FIGURES 64–12 AND 64–13.**

NOTE: To locate a restriction anywhere in the system, feel along the system lines. The restriction exists at the point of greatest temperature difference. "Frosting" is a good indication of a restriction.

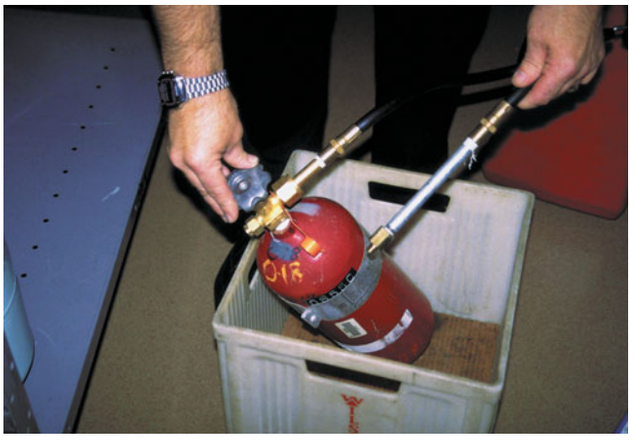
TECH TIP

The Fire Extinguisher Test

To test the expansion valve, start the engine and allow the A/C system to function with the control set to "recirculate." Using a CO_2 fire extinguisher, blast the expansion valve with CO_2. The valve should close and the low-side pressure should go into a vacuum. If the low-side pressure does not go into a vacuum, the expansion valve is faulty and should be replaced. ● **SEE FIGURE 64–14.**



FIGURE 64–13 Assortment of orifice tubes. Note that each is color coded and identified on the lid of the assortment. Even though some technicians have purposely installed an orifice tube with a larger opening in an attempt to increase cooling, it is always safe to use the exact orifice tube specified for the vehicle being serviced.



(a)



(b)

FIGURE 64–14 (a) A CO_2 fire extinguisher equipped with the fittings necessary to test the operation of an expansion valve. (b) The size of the opening at the end of the hose determines how much CO_2 is released to cool the expansion valve temperature sensor bulb.



FIGURE 64–15 A partially clogged evaporator.



REAL WORLD FIX

The Clogged Evaporator Problem

The owner of an older Buick complained that the blower motor must be defective because the air no longer flowed from the air-conditioning vents as it should. A check of the blower motor circuit revealed that the blower motor was working. To confirm the operation of the blower, the resistor pack was removed and air flowed out of the opening. Then the technician discovered the cause of the lack of airflow—the evaporator was covered with oily dirt. The technician recovered the refrigerant and removed the evaporator. Apparently, the evaporator had a small refrigerant leak that allowed the refrigerant oil to coat the fins of the evaporator. Any dirt in the air stuck to the evaporator until the dirt almost completely blocked the airflow. Replacing the evaporator and recharging the system fixed the blower motor problem. ● **SEE FIGURE 64–15**.



TECH TIP

The Touch, Feel Test

A quick-and-easy test to check the state of charge of an orifice tube system is to use one hand and touch the evaporator side of the orifice tube. Touch your other hand to the inlet to the accumulator. The following conditions can be determined by noticing the temperature of these two locations. ● **SEE FIGURE 64–16**.

Normal operation—both temperatures about the same

Undercharged condition—accumulator temperature higher (warmer) than the orifice tube temperature

Just remember: High pressure means that the temperature of the component or line will also be high (hot). Low pressure means that the temperature of the component or line will also be low (cold). For example, the inlet to the compressor (low pressure) should always be cool whereas the outlet of the compressor (high pressure) should always be hot.

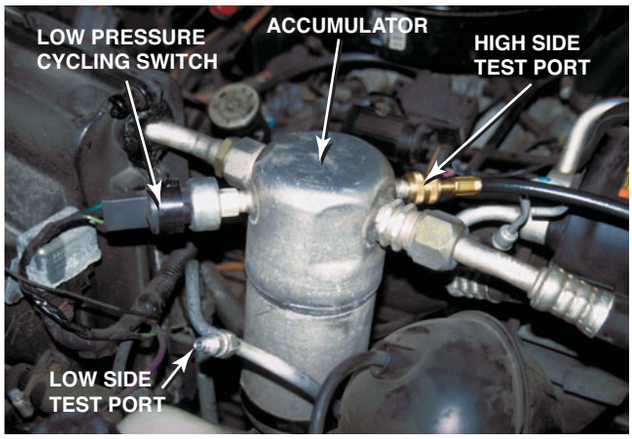


FIGURE 64–16 If the system is fully charged, the outlet temperature of the line leaving the evaporator should be about the same as the temperature of the line entering the evaporator after the expansion valve. The low-pressure cycling switch usually has to be disconnected and a jumper wire used to connect the two electrical terminals allowing the compressor to run if the system is low on charge.

TECH TIP

The Smell Test

Many air-conditioning systems form mildew inside the evaporator housing due to the moist condition that exists in this area. If a "wet" smell is noticed, the mold and mildew may be the cause and a biocide will need to be used to correct the problem.

TECH TIP

Leak-Testing the Evaporator

A quick-and-easy test to check whether the evaporator is leaking refrigerant is to remove the blower motor resistor pack. The blower motor resistor pack is almost always located directly "downstream" and near the blower motor. Removing the blower motor resistor pack gives access to the area near the evaporator. Inserting the probe of a leak detector into this open area allows the detector to test the air close to the evaporator. If the vehicle does not use a blower motor resistor or if it is difficult to access, hoist the vehicle and insert the sniffer probe in the condensate tube.



FIGURE 64–17 Typical electronic refrigerant leak detector. Many are capable of detecting either CFC-12 or HFC-134a.

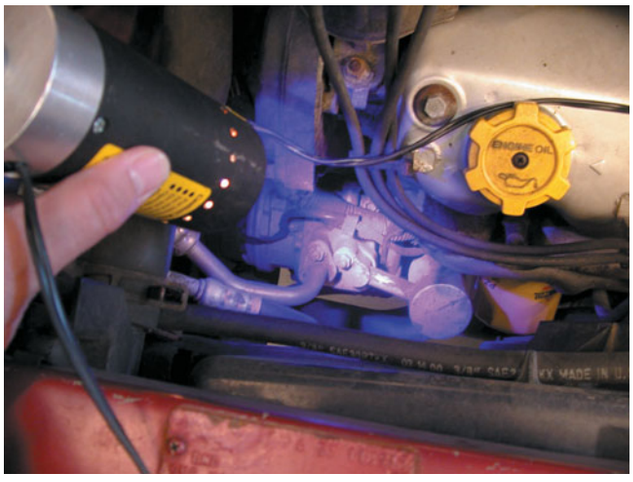


FIGURE 64–18 A black light being used to look for refrigerant leaks after a fluorescent dye was installed in the system.

LEAK DETECTION

If the A/C system is low on a charge of refrigerant, the sources of the leak should be found and corrected. Several different methods of leak detection are available including:

- **Visual inspection.** Look for oily areas that are formed when refrigerant leaks and some refrigerant oil is lost. It is this oil that indicates a refrigerant leak.
- **Electronic leak detector.** Many of these units can detect both CFC-12 and HFC-134a. The detector will sound a tone if a leak is detected. ● **SEE FIGURE 64–17**.
- **Dye in the refrigerant.** A dye is added to some refrigerant to help the technician visually spot a leak in the refrigerant system. This method works well except for leaks in the evaporator, which are usually not visible. ● **SEE FIGURE 64–18**.
- **Soap solution.** Mix a few drops of liquid soap or detergent into a small glass of water. Using a small brush or a small spray bottle, apply the soapy solution to all fittings and other areas such as the condenser and compressor, which often are sources of leaks. If the system is empty, pressurize the system with dry nitrogen.

REVIEW QUESTIONS

1. Discuss how to diagnose the lack of heat from the heater.
2. Explain how the sight glass can be used to determine the state of charge.
3. List the various methods that can be used to detect refrigerant leaks.

CHAPTER QUIZ

1. A customer complains that the heater works sometimes, but sometimes only cold air comes out while driving. Technician A says that the water pump is defective. Technician B says that the cooling system could be low on coolant. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
2. Airflow through a typical HVAC system is being discussed. Technician A says that outside air is always used in all heating and cooling positions. Technician B says that the temperature is controlled by blending airflow through the evaporator and heater core. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
3. The first step in the diagnostic procedure when attempting to solve an HVAC customer problem is _____.
   a. Visual inspection
   b. Check for diagnostic trouble codes
   c. Check for technical service bulletins
   d. Verify customer concern
4. The last step in the diagnostic procedure is _____.
   a. Determine the root cause
   b. Verify the repair
   c. Recharge the system
   d. Perform a visual inspection
5. Technician A says that one heater hose should be hot and the other hose cool if the heater is functioning okay. Technician B says that both hoses should be hot to the touch. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
6. Nothing is seen in the sight glass. Technician A says that the system may be completely empty of refrigerant. Technician B says that the system may be completely charged. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
7. Technician A says that evaporator leaks can be detected by installing dye into the system and looking for yellowish-green dye stains. Technician B says that a leak at the evaporator can be detected by removing the blower motor resistor pack and inserting an electronic leak detector probe into the air stream. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
8. Technician A says that with a properly operating air-conditioning system, the inlet to the compressor should be cold and the outlet from the compressor hot. Technician B says that the condenser should be hot and the evaporator cold. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
9. A clogged orifice tube can cause a lack of cooling.
   a. True
   b. False
10. What must the technician do before checking an air-conditioning system for refrigerant leaks using a black light?
    a. Evacuate the system
    b. Install dye in the system
    c. Overcharge the system by 10 oz
    d. Turn the system off and allow the pressure to equalize

chapter 65

HEATING AND AIR-CONDITIONING SYSTEM SERVICE

OBJECTIVES: **After studying Chapter 65, the reader will be able to:** • Prepare for the ASE A/C system service, diagnosis, and repair (A7) certification test content area "A". • Perform heating, ventilation, and air-conditioning (HVAC) system service procedures. • Identify precautions that should be adhered to during HVAC system service. • Discuss proper evacuation and refrigerant recovery procedures. • List the steps needed to be performed to retrofit an older R-12 system to R-134a. • Describe air-conditioning parts replacement and service procedures.

KEY TERMS: Air dam 746 • Fin comb 752 • Noncondensable gas 748 • O-ring seal 747 • Quick-disconnect valve 748 • Schrader valve 748 • Service cap 748

BLOWER MOTOR SERVICE

Blower motor related services include the following components and operation:

- **Blower motor and construction.** If the blower motor is not functioning, the switch, resistors, or blower motor itself may need to be replaced. If the resistors are found to be defective, then double-check that the current draw of the blower motor is within factory specifications. One of the most common reasons for a defective blower motor resistor is a defective blower motor that has worn bushings and draws more than normal current (amperes).
- **Relays and switches.** Switches and relays can be tested by proper operation and replaced if needed. Always follow the vehicle manufacturer's recommended replacement procedures.
- **Mechanical, electrical, and vacuum components.** Electrical wiring or terminals can often be repaired. Check service information for the recommended procedures to follow. If a component has been found to be defective, follow the vehicle manufacturer's recommended component replacement procedures.

See Chapter 59 for details on blower motor diagnosis.

COOLING SYSTEM SERVICE

COOLING SYSTEM THERMOSTAT REPLACEMENT

A defective (stuck open) thermostat can cause a lack of heat from the heater. If heat "comes and goes," check for proper coolant level in the radiator before replacing the thermostat. When replacing the thermostat, always follow the vehicle manufacturer's recommended procedures and use the designated coolant.

HEATER HOSE REPLACEMENT

Check heater hoses for signs of deterioration and replace as needed. ● **SEE FIGURE 65–1.** Follow the vehicle manufacturer's recommended procedures.

COOLING FAN

Inspect the cooling fan for dents, nicks, or other faults that can cause a vibration or reduce airflow through the radiator. Check the viscous fan clutch for leakage of silicone fluid and replace if needed.

See chapter 21 for details on cooling fan-relayed diagnosis and service procedures.

REFRIGERANT RECOVERY PROCEDURES

LEAK REPAIR PROCEDURES

After a leak has been found, the refrigerant should be recovered and the faulty part repaired or replaced. Leaks at joints may need a replacement O-ring. Often, the leak is at a component such as the evaporator, condenser, or refrigerant line. Leaking components are usually replaced rather than repaired.



FIGURE 65–1 Some heater hoses are best inspected by hoisting the vehicle and inspecting them from underneath the vehicle as shown.

TECH TIP

Use the Same Length Heater Hoses

Heater hoses are designed to supply warm coolant from the engine's cooling system to the small radiator called the heater core inside the vehicle. Because the heater hoses attach to the engine and the engine moves on its mounts during operation, the heater hoses are long enough to allow the engine to move without causing stress to be applied to the heater core. The extra length also helps to prevent engine vibration from being transmitted to the heater core and the interior of the vehicle. When replacing heater hoses, always use the old hoses as a guide and use the same length hoses. Also, route the replacement hoses in the same manner as originally designed, again, to help reduce the stress to the heater core.

TECH TIP

Check the Air Dam If Overheating Occurs

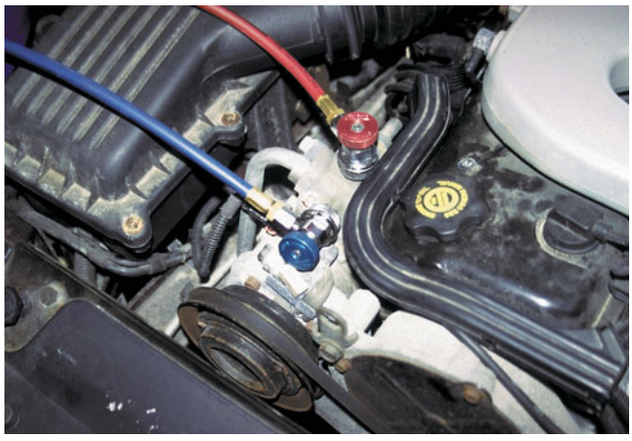
The **air dam** under the front of the vehicle is designed to force air to flow upward and through the radiator rather than travel underneath the vehicle. If this air dam is broken or damaged due to contact with a parking block or other object, the engine may overheat.

REFRIGERANT RECOVERY

Refrigerant should be recovered and not allowed to be discharged into the atmosphere. A refrigerant recovery unit should be used to remove the refrigerant from the vehicle, and it should be stored in a container until it can be recycled. ● **SEE FIGURES 65–2 AND 65–3.**



(a)



(b)

FIGURE 65–2 (a) A typical automotive air-conditioning service machine that is capable of handling both CFC-12 and HFC-134a systems. (b) HFC-134a systems use quick-disconnect fittings that are larger than those used for CFC-12 systems.

REFRIGERANT IDENTIFICATION

All refrigerant should be identified before it is recovered. Many also can detect sealers that may have been used in an attempt to stop a refrigerant leak. Sealers in refrigerant would contaminate the refrigerant and make it unsuitable for recycling.

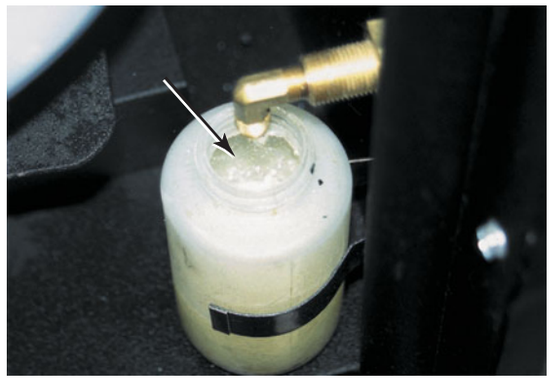
Always follow the operating instructions for machine being used.

Most recovery units are capable of drawing a slight vacuum on the system (about 5 in. Hg) to assure that all refrigerant is removed from the system. During the recovery process, any refrigerant oil removed is separated from the refrigerant and allowed to flow into a container where it can be measured. This is important because the correct total amount of lubricating refrigerant oil must be added to the system when recharged to protect the compressor.

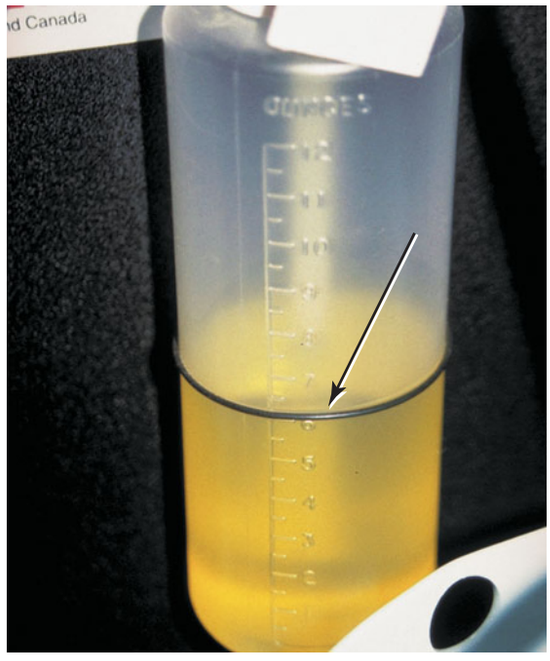
REPAIRS OR REPLACEMENT OF COMPONENTS

After all refrigerant has been removed from the system, repairs can be accomplished. For example, the evaporator can now be removed from the vehicle and replaced. If the system has been opened to the atmosphere for a length of time (over 24 hours), most experts recommend replacing the drier to help prevent the possibility of damaging moisture being trapped in the system. After all repairs are completed, the system should then be evacuated.

NOTE: Be sure to follow all instructions regarding the amount of oil that needs to be added to the system if components have been replaced.



(a)



(b)

FIGURE 65–3 (a) Refrigerant oil must be retrieved and measured when the refrigerant is recovered from the system. (b) A rubber O-ring is used to indicate the level of refrigerant oil already in the container. The exact same amount of refrigerant oil must be installed as was removed when the system is recharged.

REFRIGERANT LINE CONNECTIONS

Refrigerant lines have connections at each end so they can be removed during system repair. Refrigerant line connections must meet three requirements:

- The connection must be vapor tight.
- The connection must be easy to disconnect and reconnect.
- The seals must withstand rapid and extreme temperature changes.

The **O-ring seal,** ● **FIGURE 65–4,** is part of a fitting that holds the ends of two refrigerant lines or hoses together inside a connector. The O-ring forms the seal between the lines or hoses and the connector. The O-rings usually are made of highly saturated nitriles (HSN) or neoprene rubber and remain flexible over a wide range of temperatures. The O-ring must be lubricated with clean refrigerant oil before assembly to ensure a good seal. Be careful not to crimp the O-ring during installation.

Replace the O-ring seals at all connections when you retrofit a system to R-134a. This ensures any traces of R-12 or its oil

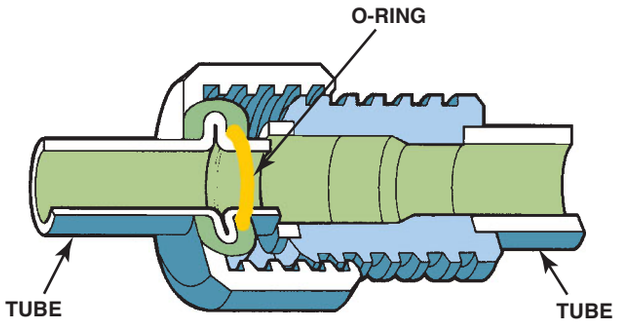


FIGURE 65–4 O-rings are usually made of neoprene rubber or highly saturated nitriles (HSN) to withstand high temperatures and flexing. O-rings should be changed during a retrofit procedure.

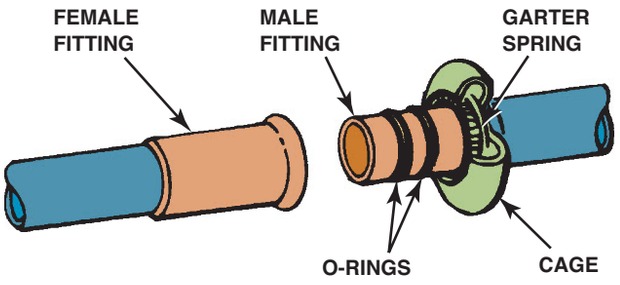


FIGURE 65–5 A Ford spring-lock coupling.

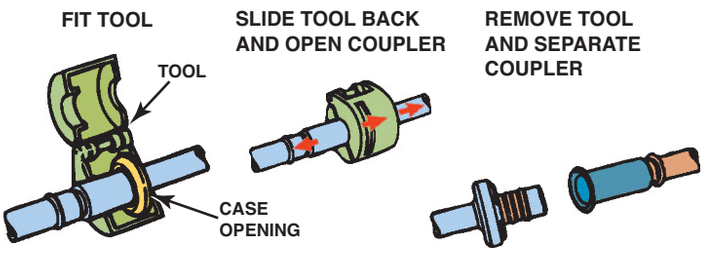


FIGURE 65–6 A special tool is needed to remove and install the Ford spring-lock coupling.

SAFETY TIP

Refrigerant Can Be Hazardous

Always wear safety glasses and protective gloves when servicing any automotive air-conditioning system. If any refrigerant escapes, it can cause skin to freeze or cause blindness if liquid refrigerant were to get into the eyes.

absorbed in the O-ring cannot enter the new system. Replace all gaskets as well.

A variation on the O-ring seal is Ford's spring-lock coupling. ● **SEE FIGURE 65–5.** It uses two O-rings mounted on the small end of the refrigeration line. The end of the joining refrigeration line is flared to slide over the two O-rings. A circular garter spring holds the connection together. You need a special tool to disconnect the coupling. ● **SEE FIGURE 65–6.**

SERVICE VALVES Service valves provide entry to the system when it is necessary to add or discharge refrigerant. The Schrader valve is used on R-12 systems. **Quick-disconnect valves** are used on R-134a systems. Each type of refrigerant has its own unique fitting. This prevents accidental use of the wrong service equipment and/or the introduction of the wrong refrigerant. Service valves are found almost anywhere on the system. They may be located on the receiver-drier, accumulator, compressor, muffler, or in the lines themselves.

All service valves have plastic coverings called **service caps.** ● **SEE FIGURE 65–7.** Along with preventing dirt from entering the system, service valve caps have O-rings which become the primary seal if a valve leaks. Always reattach the caps after any service has been performed, and replace them if you come across a system with missing service caps. Another built-in precaution is the refrigerant cut-off valve, which keeps the refrigerant in the service hose instead of allowing it to vent to the atmosphere. All service equipment hoses are required to have a cut-off valve within 12 inches of the end of the hose.

SCHRADER VALVES For years, R-12 systems have used the **Schrader valve.** A Schrader valve is similar to a tire valve. Internal pressure holds Schrader valves closed. There is also a small spring to keep the valve seated if the internal pressure becomes insufficient. When the service connection is made, the depressor in the end of the service hose or service coupling, presses on a small pin inside the valve, forcing the valve open. ● **SEE FIGURE 65–8.** The valve opens only when the service line connection is nearly complete, preventing contamination of the system or the unnecessary release of refrigerant.

The high-side service valve on R-12 systems is smaller and has different threads than the low-side service valve. This prevents incorrect connections that may result in damage to the system and to your service equipment. Some Ford systems use different sizes of quick-disconnect fittings, similar to an air-hose coupling. Adapters are available for use with standard manifold gauge sets.

EVACUATION PROCEDURES

Evacuation means that a vacuum will be applied to the system to vaporize any moisture that may be in the system. Although water boils at 212°F (100°C) at sea level, it can boil at much lower temperatures when the pressure is reduced. In other words, if a vacuum is applied to the air-conditioning system, the low pressure will cause any trapped moisture in the system to vaporize (boil). This water vapor is then removed from the system through the vacuum pump and released into the atmosphere. It is important to evacuate the system to at least 26 in. Hg of vacuum for at least 45 minutes to be assured that all of the moisture has been removed. For best results, the vacuum should be higher than 29 in. Hg. Just remember, the higher the vacuum and the longer that it is allowed to evacuate, the better.

NONCONDENSABLE GASES

Refrigerant should be checked for the presence of air, which is called a **noncondensable gas.** This means that the air will not condense into a liquid when pressurized like refrigerant. If air is present in the container of refrigerant, it is considered to be a contaminate and will reduce the cooling efficiency if installed into an air-conditioning

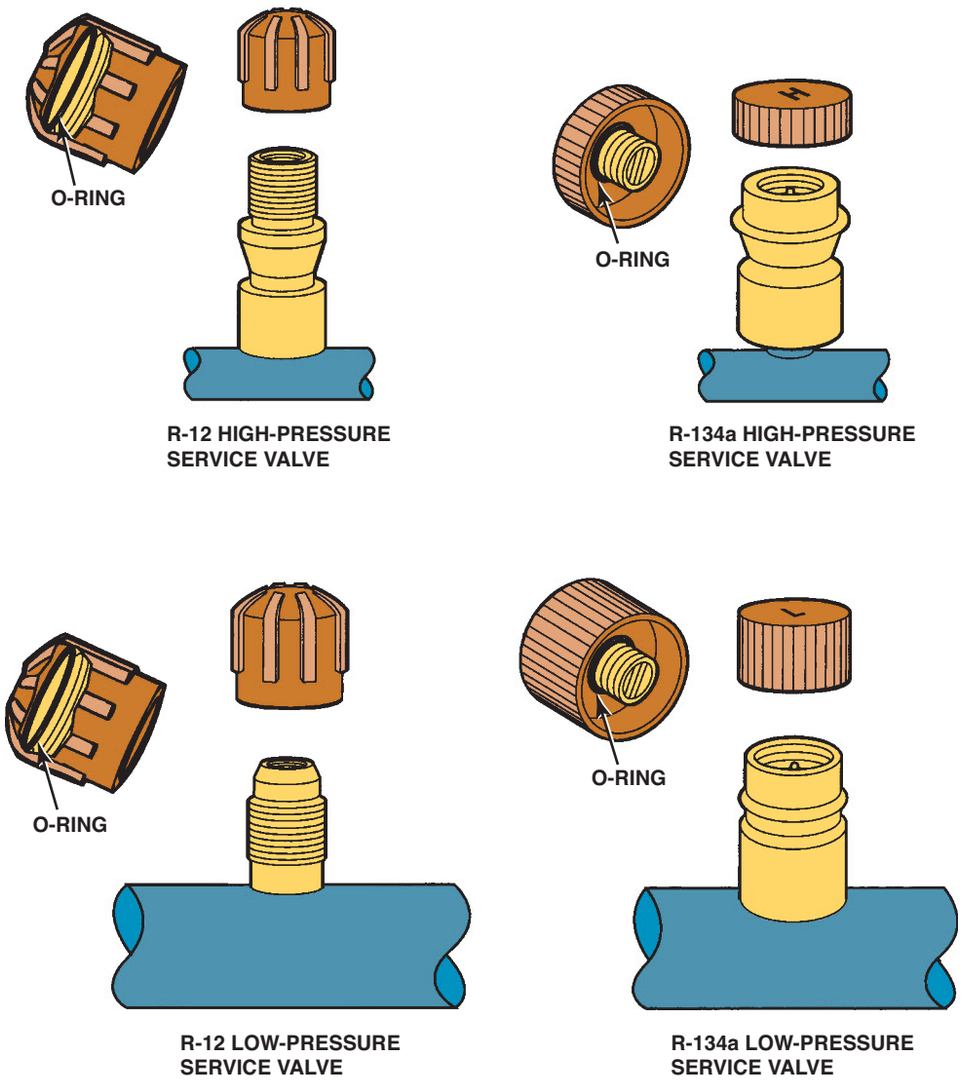


FIGURE 65–7 The service cap O-ring becomes the primary seal if the service valve leaks.

TECH TIP

Use a Micron Vacuum Gauge for Best Results

A typical vacuum gauge reads in inches of Mercury (in. Hg) and the recommended vacuum level needed to remove moisture from the system is considered to be 27 in. Hg or less. However, many experts recommend using a vacuum gauge that measures the amount of air remaining in the system. This type of gauge measures vacuum in microns. A micron is one millimeter of a meter and there are about 760,000 microns of air at atmospheric pressure. A vacuum reading of 29.72 in. Hg is about 5,000 microns. Many experts recommend that the micron level be 500 or less for best results. This is particularly important when evacuating a dual-climate control system where two evaporators are used and there are long lengths of refrigerant lines. ● **SEE FIGURE 65–9.**

system. There are two ways to determine if there is air (noncondensable gas) in the refrigerant, including:

- **Use a refrigerant identifier.** Most refrigerant identifiers will display the amount of air present.
- **Measure the temperature and pressure of the refrigerant.** Compare the measurement to a temperature/pressure chart.

If the only contaminate is air, it can be purged from the refrigerant. Always follow the instructions on the recycling machine for the procedure to follow.

REFRIGERANT RECYCLING

After refrigerant has been recovered, it needs to be recycled for further use. Most air-conditioning machines include the ability to recycle the refrigerant to the following SAE J1991 specification:

- **Moisture**—A maximum of 15 parts per million (ppm) by weight
- **Refrigerant oil**—A maximum of 4,000 parts per million (ppm) by weight
- **Noncondensable gases (air)**—A maximum of 330 parts per million (ppm) by weight

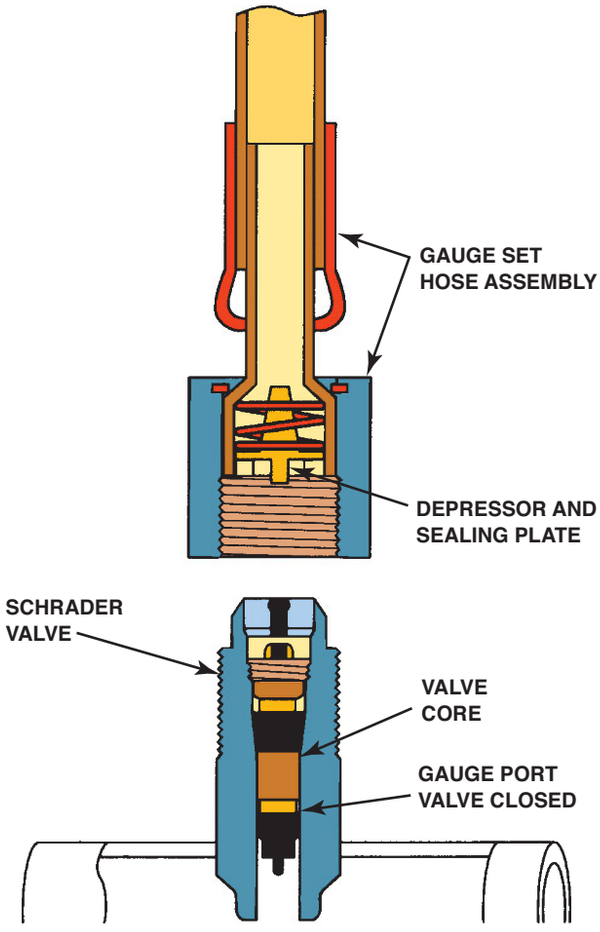


FIGURE 65–8 A depressor pin on the gauge set opens the Schrader valve when the connection is almost completely tightened. This prevents accidental refrigerant discharge.



FIGURE 65–9 An air-conditioning vacuum gauge that reads in microns.

RECHARGING A SYSTEM

After the system has been evacuated, it can be recharged with refrigerant. Most vehicles have a placard or sticker that indicates the correct amount of refrigerant to use. ● **SEE FIGURES 65–10 AND 65–11.** Follow the operating instructions for the equipment you are using.



FIGURE 65–10 A typical under-hood sticker that identifies the refrigerant and the amount needed to change the system in kilograms (0.96 kg is equal to 0.44 pounds).



FIGURE 65–11 A temperature and humidity gauge is a useful tool for air-conditioning work. The higher the relative humidity, the more difficult it is for the air-conditioning system to lower the temperature inside the vehicle.

REAL WORLD FIX

The Cadillac Story

When servicing an older Cadillac equipped with an automatic air-conditioning system (C-68), it was discovered that the compressor would not engage. The vehicle owner stated that a message had been warning him that the system was low on charge. The technician tightened a slightly loose Schrader valve and then added about one pound of R-12 to the system, yet the controller (computer) would not engage the clutch. The technician then remembered that if a diagnostic trouble code (DTC) has been set, the computer will not allow the compressor clutch to be engaged. This is a precaution to prevent possible compressor damage if the system is low on charge and not able to transfer the lubricating refrigerant oil through the system that the compressor needs for lubrication. The technician disconnected the negative (−) battery cable and waited several minutes and then reconnected it. After starting the engine and turning on the A/C controls, the compressor clutch engaged and the service technician was able to complete charging the system.

TECH TIP

Because It Fits, Does Not Mean It Is Correct!

Many air-conditioning systems use orifice tubes that look similar if not identical. They are usually color coded for identification. Always use the recommended orifice tube for the vehicle you are servicing. Some examples of the various colors and sizes available include:

Make	Color	Orifice Size (Inches)
Chrysler	purple	0.0605
Ford	red	0.0605
Ford	orange	0.0560
Ford	brown	0.0470
Ford	green	0.0505
GM	yellow	0.0605

NOTE: Always use the specified amount of refrigerant. Reduced cooling can occur if the system is either undercharged or overcharged. Air-conditioning service is definitely not a situation where "more is better."

RETROFITTING A CFC-12 SYSTEM TO A HFC-134A SYSTEM

Due to environmental and cost concerns, many service technicians are retrofitting (adapting) CFC-12 systems to HFC-134a systems. Whenever making the change, several tasks have to be performed, including:

- Specific service fittings must be installed.
- Retrofit labels must be attached to the vehicle in a visible location.
- PAG or ester oil must be used instead of the mineral oil in a CFC-12 system.
- A high-pressure shutoff switch must be installed that opens the compressor clutch circuit if the pressure exceeds 410 PSI.

Other changes that may or may not be necessary include:

- Replacing hoses
- Replacing O-rings
- Replacing the receiver-drier or accumulator
- Replacing pressure switches and calibrating them for use with an HFC-134a system
- Replacing the condenser or compressor as required by some vehicle manufacturers

All of the required parts necessary to retrofit a particular vehicle are often included in a kit for easy use. **SEE FIGURE 65–12.** When the system is recharged, the amount of HFC-134a is usually 90% of the CFC-12 amount minus 4 ounces. In other words, if 30 ounces is the normal charge of CFC-12, then 23 ounces of HFC-134a should be used (30 ounces × 90% = 27 ounces minus 4 ounces = 23 ounces).



(a)



(b)

FIGURE 65–12 (a) When a system is retrofitted from CFC-12 to HFC-134a, the proper service fittings have to be used to help assure that cross-contamination does not occur. (b) An underhood sticker is also installed indicating that the system was retrofitted to HFC-134a and when it was done and by whom.

COMPRESSOR SERVICE

COMPRESSOR DRIVE BELT Always check the compressor drive belt(s) whenever servicing the air-conditioning system and replace as needed. If some chunks are missing from the belt ribs or pieces of rubber are embedded in the pulleys, a noise that is often misinterpreted as coming from a defective compressor can occur.

COMPRESSOR CLUTCH SERVICE If the compressor clutch has been slipping, it will be blue, indicating that excessive heat has



FIGURE 65–13 A special tool is needed to remove and install the magnetic clutch on the air-conditioning compressor.

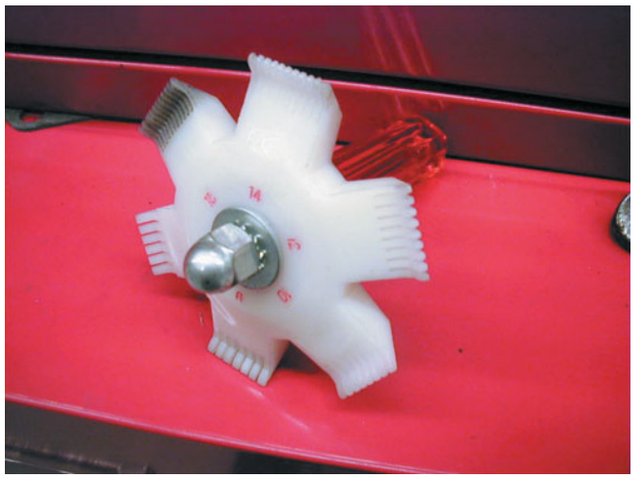


FIGURE 65–14 A fin comb is used to straighten the fins on the condenser to help increase airflow and heat transfer.

TECH TIP

An Additional Filter Is Insurance

If the air-conditioning compressor is found to be damaged mechanically, many experts recommend that an additional filter be installed in the refrigerant line to trap any debris that may have gotten into the system. This additional filter will help prevent the new compressor from being harmed by the debris as it circulates through the system.

TECH TIP

Might as Well Do It Now

Whenever an evaporator is being replaced, many service technicians also recommend that the heater core also be replaced. This is especially true if the vehicle had a neglected cooling system. Most heater cores are close to or even have to be removed to replace an evaporator. The only additional cost to the vehicle owner is the cost of the heater core itself.

been generated by the slipping clutch. Replace the clutch and adjust the air gap according to service information instructions. ● **SEE FIGURE 65–13.**

If replacement is needed, determine the quantity of oil that may be trapped in the old unit so that the proper amount can be added to the system after the new compressor has been installed.

COMPRESSOR REMOVAL If testing indicates that the air-conditioning compressor has failed, it should be removed from the vehicle after all of the refrigerant has been evacuated from the system. The steps specified by service information usually include the following:

STEP 1 Remove the refrigerant from the system.

STEP 2 Disconnect the compressor drive belt.

STEP 3 Disconnect sensors and compressor clutch wiring connections and label them if needed.

STEP 4 Disconnect the suction and discharge hoses.

STEP 5 Seal the hoses to help keep moisture and dirt from entering the system.

STEP 6 Remove the compressor mounting fasteners.

STEP 7 Drain and measure the refrigerant oil from the compressor.

STEP 8 Inspect the hoses, lines, fittings, O-rings, seals, muffler, and service valves for proper operation and repair or replace as needed as part of the compressor service.

CONDENSER SERVICE

Inspect the condenser for airflow restriction and clean as needed. Often a **"fin comb"** is needed to straighten the fins of the condenser, which may have been bent by road debris. ● **SEE FIGURE 65–14.**

If replacement is needed, determine the quantity of oil that may be trapped in the old unit so that the proper amount can be added to the system after the new condenser has been installed.

EVAPORATOR SERVICE

If the evaporator has been tested and found to be clogged or leaking, it has to be replaced. In most vehicles this is a major job involving disassembly of the dash.

RECEIVER/DRIER OR ACCUMULATOR/ DRIER SERVICE

Most experts recommend that the receiver/drier or accumulator/drier be replaced anytime the refrigerant system is opened and other repairs or services are being performed. Before replacing



FIGURE 65–15 Always be sure that the service valves are snug before evacuating the system. They are a common place for small refrigerant leaks.

the receiver/drier or accumulator/drier, determine the quantity of refrigerant oil so that the proper amount can be added to the system when it is recharged. Always follow the vehicle manufacturer's recommended service and repair procedures. ● **SEE FIGURE 65–15.**

ORIFICE TUBE/EXPANSION VALVE SERVICE

If the orifice tube is found to be clogged or the expansion valve has been determined to be not operating correctly, they will require replacement. Always follow the vehicle manufacturer's recommended replacement procedures and adhere to all precautions.

REVIEW QUESTIONS

1. What components should be checked if a blower motor resistor is found to be defective?
2. Why could a broken air dam in the front of a vehicle cause an engine to overheat?
3. Why should a refrigerant identifier be used before evacuating the refrigerant?
4. Why should the receiver/drier or accumulator/drier be replaced if the refrigerant system is opened for a repair?
5. What steps and procedures are required to retrofit an older R-12 system to a R-134a system?

CHAPTER QUIZ

1. A customer complains that the heater works sometimes, but sometimes only cold air comes out while driving. Technician A says that the water pump is defective. Technician B says that the cooling system could be low on coolant. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
2. Two technicians are discussing replacing heater hoses. Technician A says that the replacement hoses should be the same length as the original hoses. Technician B says that the replacement hoses should be cut as short as possible to allow more coolant to flow through the heater core faster. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. A defective thermostat can cause *the engine* to operate _____.
   a. Too cold **c.** Either a or b
   b. Too hot **d.** Neither a nor b
4. O-rings are usually made from _____.
   a. HSN **c.** Neoprene
   b. Natural rubber **d.** Either a or c
5. What type of service valves are used with R-134a?
   a. Schrader valves **c.** Quick-disconnect valves
   b. Gate valves **d.** Saddle valves
6. Which reading represents the lowest vacuum reading?
   a. 27 in. Hg **c.** 29 in. Hg
   b. 28 in. Hg **d.** 500 microns
7. What is a noncondensable gas?
   a. Air **c.** Ozone
   b. R-12 **d.** R-134a
8. Technician A says that all orifice tubes on all vehicles use the same orifice size. Technician B says that orifice tubes vary the orifice size by application. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. Which part *must* be used when refitting a vehicle from R-12 to R-134a refrigerant?
   a. A new (larger) condenser
   b. A new service fitting and a retrofit label
   c. A high-pressure cut-off switch
   d. Both a and b
10. When replacing a compressor clutch, what is the critical measurement?
    a. Air gap
    b. Current (ampere) draw
    c. Voltage drop
    d. High-pressure pressure

SECTION IX Engine Performance

66 Gasoline
67 Alternative Fuels
68 Diesel and Biodiesel Fuels
69 Ignition System Components and Operation
70 Ignition System Diagnosis and Service
71 Computer Fundamentals
72 Temperature Sensors
73 Throttle Position Sensors
74 MAP/BARO Sensors
75 Mass Air Flow Sensors
76 Oxygen Sensors
77 Fuel Pumps, Lines, and Filters
78 Fuel Injection Components and Operation
79 Gasoline Direct Injection Systems
80 Electronic Throttle Control Systems
81 Fuel Injection System Diagnosis and Service
82 Vehicle Emission Standards and Testing
83 Evaporative Emission Control Systems
84 Exhaust Gas Recirculation (EGR) Systems
85 Positive Crankcase Ventilation (PCV) and Secondary Air Injection (SAI) Systems
86 Catalytic Converters
87 On-Board Diagnosis
88 Scan Tools and Engine Performance Diagnosis

chapter 66 GASOLINE

OBJECTIVES: **After studying Chapter 66, the reader should be able to:** • Describe how the proper grade of gasoline affects engine performance. • List gasoline purchasing hints. • Discuss how volatility affects driveability. • Explain how oxygenated fuels can reduce CO exhaust emissions. • Discuss safety precautions when working with gasoline.

KEY TERMS: Air-fuel ratio 757 • American Society for Testing and Materials (ASTM) 756 • Antiknock index (AKI) 759 • British thermal unit (BTU) 757 • Catalytic cracking 755 • Cracking 755 • Detonation 758 • Distillation 755 • Distillation curve 756 • Driveability index (DI) 756 • E10 761 • Ethanol 761 • Fungible 756 • Gasoline 754 • Hydrocracking 755 • Octane rating 758 • Oxygenated fuels 760 • Petroleum 755 • Ping 758 • Reformulated gasoline (RFG) 762 • Reid vapor pressure (RVP) 756 • Spark knock 758 • Stoichiometric 758 • Tetraethyl lead (TEL) 757 • Vapor lock 756 • Volatility 756 • World Wide Fuel Charter (WWFC) 763

GASOLINE

DEFINITION **Gasoline** is a term used to describe a complex mixture of various hydrocarbons refined from crude petroleum oil for use as a fuel in engines. Gasoline and air burns in the cylinder of the engine and produces heat and pressure, which is converted to rotary motion inside the engine and eventually powers the drive wheels of a vehicle. When combustion occurs, carbon dioxide and water are produced if the process is perfect and all of the air and all of the fuel are consumed in the process.

CHEMICAL COMPOSITION Gasoline is a combination of hydrocarbon molecules that have between five and 12 carbon atoms. The names of these various hydrocarbons are based on the number of carbon atoms and include:

- **Methane**—one carbon atom
- **Ethane**—two carbon atoms
- **Propane**—three carbon atoms
- **Butane**—four carbon atoms
- **Pentane**—five carbon atoms
- **Hexane**—six carbon atoms

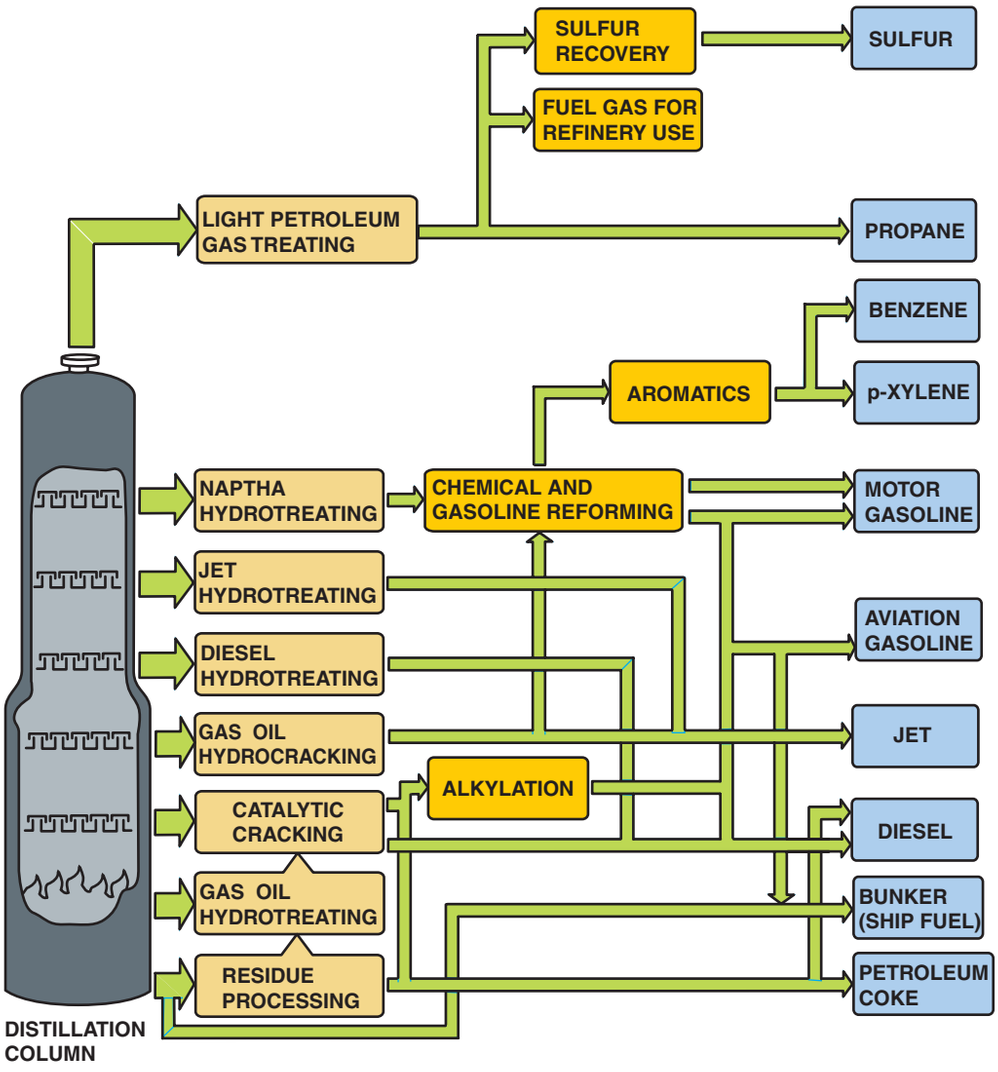


FIGURE 66–1 The crude oil refining process showing most of the major steps and processes.

- **Heptane**—seven carbon atoms (Used to test octane rating–has an octane rating of zero)
- **Octane**—eight carbon atoms (A type of octane is used as a basis for antiknock rating)

REFINING

TYPES OF CRUDE OIL

Refining is a complex combination of interdependent processing units that can separate crude oil into useful products such as gasoline and diesel fuel. As it comes out of the ground, **petroleum** (meaning "rock oil") crude can be as thin and light colored as apple cider or as thick and black as melted tar. A barrel of crude oil is 42 gallons, not 55 gallons as commonly used for industrial barrels. Typical terms used to describe the type of crude oil include:

- Thin crude oil has a high American Petroleum Institute (API) gravity, and therefore, is called *high-gravity* crude.
- Thick crude oil is called *low-gravity* crude. High-gravity-type crude contains more natural gasoline and its lower sulfur and nitrogen content makes it easier to refine.
- Low-sulfur crude oil is also known as "sweet" crude.
- High-sulfur crude oil is also known as "sour" crude.

DISTILLATION

In the late 1800s, crude was separated into different products by boiling in a process called **distillation.** Distillation works because crude oil is composed of hydrocarbons with a broad range of boiling points.

In a distillation column, the vapor of the lowest-boiling hydrocarbons, propane and butane, rises to the top. The straight-run gasoline (also called naphtha), kerosene, and diesel fuel cuts are drawn off at successively lower positions in the column.

CRACKING

Cracking is the process where hydrocarbons with higher boiling points could be broken down (cracked) into lower-boiling hydrocarbons by treating them to very high temperatures. This process, called *thermal cracking*, was used to increase gasoline production starting in 1913.

Instead of high heat, today cracking is performed using a catalyst and is called **catalytic cracking.** A catalyst is a material that speeds up or otherwise facilitates a chemical reaction without undergoing a permanent chemical change itself. Catalytic cracking produces gasoline of higher quality than thermal cracking.

Hydrocracking is similar to catalytic cracking in that it uses a catalyst, but the catalyst is in a hydrogen atmosphere. Hydrocracking can break down hydrocarbons that are resistant to catalytic cracking alone, and it is used to produce diesel fuel rather than gasoline.

Other types of refining processes include:

- Reforming
- Alkylation
- Isomerization
- Hydrotreating
- Desulfurization

SEE FIGURE 66–1.



FIGURE 66–2 A gasoline testing kit, including an insulated container where water at 100°F is used to heat a container holding a small sample of gasoline. The reading on the pressure gauge is the Reid vapor pressure (RVP).

SHIPPING The gasoline is transported to regional storage facilities by railway tank car or by pipeline. In the pipeline method, all gasoline from many refiners is often sent through the same pipeline and can become mixed. All gasoline is said to be **fungible,** meaning that it is capable of being interchanged because each grade is created to specification so there is no reason to keep the different gasoline brands separated except for grade. Regular grade, mid-grade, and premium grades are separated in the pipeline and the additives are added at the regional storage facilities and then shipped by truck to individual gas stations.

VOLATILITY

DEFINITION OF VOLATILITY

Volatility describes how easily the gasoline evaporates (forms a vapor). The definition of volatility assumes that the vapors will remain in the fuel tank or fuel line and will cause a certain pressure based on the temperature of the fuel.

REID VAPOR PRESSURE (RVP)

Reid vapor pressure (RVP) is the pressure of the vapor above the fuel when the fuel is at 100°F (38°C). Increased vapor pressure permits the engine to start in cold weather. Gasoline without air will not burn. Gasoline must be vaporized (mixed with air) to burn in an engine. ● **SEE FIGURE 66–2.**

SEASONAL BLENDING

Cold temperatures reduce the normal vaporization of gasoline; therefore, winter-blended gasoline is specially formulated to vaporize at lower temperatures for proper starting and driveability at low ambient temperatures. The **American Society for Testing and Materials (ASTM)** standards for winter-blend gasoline allow volatility of up to 15 pounds per square inch (PSI) RVP.

At warm ambient temperatures, gasoline vaporizes easily. However, the fuel system (fuel pump, carburetor, fuel-injector nozzles, etc.) is designed to operate with liquid gasoline. The volatility of summer-grade gasoline should be about 7.0 PSI RVP. According to ASTM standards, the maximum RVP should be 10.5 PSI for summer-blend gasoline.

DISTILLATION CURVE

Besides Reid vapor pressure, another method of classifying gasoline volatility is the **distillation curve.** A curve on a graph is created by plotting the temperature at which the various percentage of the fuel evaporates. A typical distillation curve is shown in ● **FIGURE 66–3.**

? FREQUENTLY ASKED QUESTION

Why Do I Get Lower Gas Mileage in the Winter?

Several factors cause the engine to use more fuel in the winter than in the summer, including:

- Gasoline that is blended for use in cold climates is designed for ease of starting and contains fewer heavy molecules, which contribute to fuel economy. The heat content of winter gasoline is lower than summer-blended gasoline.
- In cold temperatures, all lubricants are stiff, causing more resistance. These lubricants include the engine oil, as well as the transmission and differential gear lubricants.
- Heat from the engine is radiated into the outside air more rapidly when the temperature is cold, resulting in longer run time until the engine has reached normal operating temperature.
- Road conditions, such as ice and snow, can cause tire slippage or additional drag on the vehicle.

DRIVEABILITY INDEX

A distillation curve shows how much of a gasoline evaporates at what temperature range. To predict cold-weather driveability, an index was created called the **driveability index,** also called the *distillation index*, and abbreviated **DI**.

The DI was developed using the temperature for the evaporated percentage of 10% (labeled T10), 50% (labeled T50), and 90% (labeled T90). The formula for DI is:

$$\mathbf{DI = 1.5 \times T10 + 3 \times T50 + T90}$$

The total DI is a temperature and usually ranges from 1,000°F to 1,200°F. The lower values of DI generally result in good cold-start and warm-up performance. A high DI number is less volatile than a low DI number.

NOTE: Most premium-grade gasoline has a higher (worse) DI than regular-grade or midgrade gasoline, which could cause poor cold-weather driveability. Vehicles designed to operate on premium-grade gasoline are programmed to handle the higher DI, but engines designed to operate on regular-grade gasoline may not be able to provide acceptable cold-weather driveability.

VOLATILITY-RELATED PROBLEMS

At higher temperatures, liquid gasoline can easily vaporize, which can cause **vapor lock.** Vapor lock is a *lean* condition caused by vaporized fuel in the fuel system. This vaporized fuel takes up space normally occupied by liquid fuel. Bubbles that form in the fuel cause vapor lock, preventing proper operation of the fuel-injection system.

Heat causes some fuel to evaporate, thereby causing bubbles. Sharp bends cause the fuel to be restricted at the bend. When the fuel flows past the bend, the fuel can expand to fill the space after the bend. This expansion drops the pressure, and bubbles form in the fuel lines. When the fuel is full of bubbles, the engine is not being supplied with enough fuel and the engine runs lean. A lean engine will stumble during acceleration, will run rough, and may stall. Warm weather and alcohol-blended fuels both tend to increase vapor lock and engine performance problems.

If winter-blend gasoline (or high-RVP fuel) is used in an engine during warm weather, the following problems may occur:

1. Rough idle
2. Stalling
3. Hesitation on acceleration
4. Surging

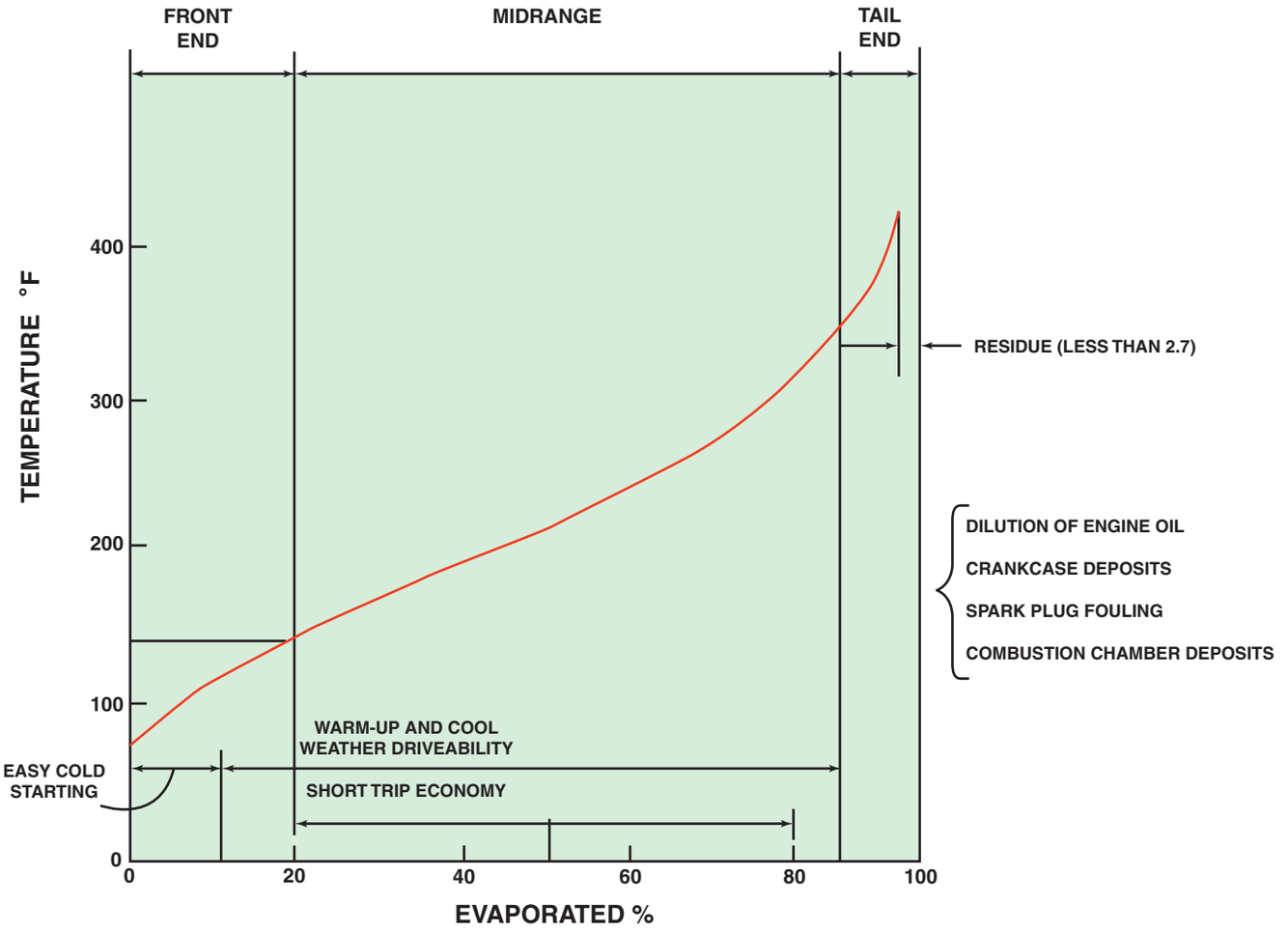


FIGURE 66–3 A typical distillation curve. Heavier molecules evaporate at higher temperatures and contain more heat energy for power, whereas the lighter molecules evaporate easier for starting.

GASOLINE COMBUSTION PROCESS

CHEMICAL REACTIONS

The combustion process involves the chemical combination of oxygen (O_2) from the air (about 21% of the atmosphere) with the hydrogen and carbon from the fuel. In a gasoline engine, a spark starts the combustion process, which takes about 3 ms (0.003 sec) to be completed inside the cylinder of an engine. The chemical reaction that takes place can be summarized as follows: hydrogen (H) plus carbon (C) plus oxygen (O_2) plus nitrogen (N) plus spark equals heat plus water (H_2O) plus carbon monoxide (CO) (if incomplete combustion) plus carbon dioxide (CO_2) plus hydrocarbons (HC) plus oxides of nitrogen (NO_X) plus many other chemicals. In an equation format it looks like this:

$$\mathbf{H + C + O_2 + N + Spark = Heat + CO_2 + HC + NO_x}$$

HEAT ENERGY

The heat produced by the combustion process is measured in **British thermal units (BTUs).** One BTU is the amount of heat required to raise one pound of water one Fahrenheit degree. The metric unit of heat is the *calorie* (cal). One calorie is the amount of heat required to raise the temperature of one gram (g) of water one Celsius degree:

Gasoline—About 130,000 BTUs per gallon

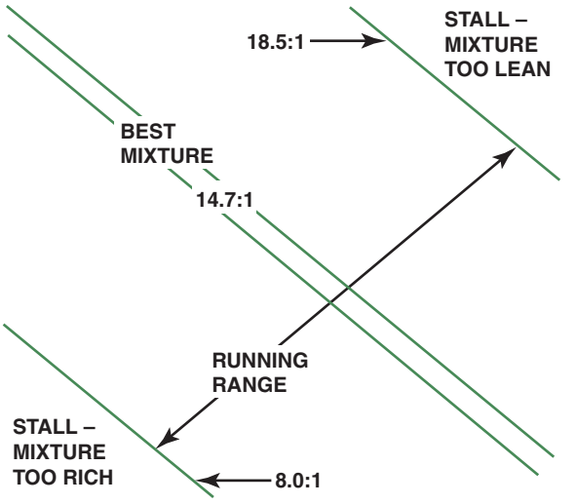


FIGURE 66–4 An engine will not run if the air-fuel mixture is either too rich or too lean.

AIR-FUEL RATIOS

Fuel burns best when the intake system turns it into a fine spray and mixes it with air before sending it into the cylinders. In fuel-injected engines, the fuel becomes a spray and mixes with the air in the intake manifold. There is a direct relationship between engine airflow and fuel requirements; this is called the **air-fuel ratio.**

The air-fuel ratio is the proportion by weight of air and gasoline that the injection system mixes as needed for engine combustion. The mixtures, with which an engine can operate without stalling, range from 8 to 1 to 18.5 to 1. ● **SEE FIGURE 66–4.**

These ratios are usually stated by weight, such as:

- 8 parts of air by weight combined with 1 part of gasoline by weight (8:1), which is the richest mixture that an engine can tolerate and still fire reliably.
- 18.5 parts of air mixed with 1 part of gasoline (18.5:1), which is the leanest practical ratio. Richer or leaner air-fuel ratios cause the engine to misfire badly or not run at all.

STOICHIOMETRIC AIR-FUEL RATIO The ideal mixture or ratio at which all of the fuel combines with all of the oxygen in the air and burns completely is called the **stoichiometric** ratio, a chemically perfect combination. In theory, this ratio for gasoline is an air-fuel mixture of 14.7 to 1. ● **SEE FIGURE 66–5.**

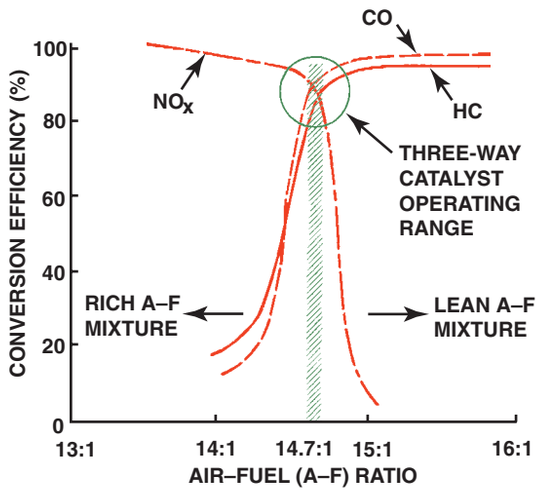


FIGURE 66–5 With a three-way catalytic converter, emission control is most efficient with an air-fuel ratio between 14.65 to 1 and 14.75 to 1.

In reality, the exact ratio at which perfect mixture and combustion occurs depends on the molecular structure of gasoline, which can vary. The stoichiometric ratio is a compromise between maximum power and maximum economy.

NORMAL AND ABNORMAL COMBUSTION

The **octane rating** of gasoline is the measure of its antiknock properties. *Engine knock* (also called **detonation, spark knock,** or **ping**) is a metallic noise an engine makes, usually during acceleration, resulting from abnormal or uncontrolled combustion inside the cylinder.

Normal combustion occurs smoothly and progresses across the combustion chamber from the point of ignition. ● **SEE FIGURE 66–6.**

Normal flame-front combustion travels between 45 and 90 mph (72 and 145 km/h). The speed of the flame front depends on the air-fuel ratio, combustion chamber design (determining amount of turbulence), and temperature.

During periods of spark knock (detonation), the combustion speed increases by up to 10 times to near the speed of sound. The increased combustion speed also causes increased temperatures and pressures, which can damage pistons, gaskets, and cylinder heads. ● **SEE FIGURE 66–7.**

One of the first additives used in gasoline was **tetraethyl lead (TEL).** TEL was added to gasoline in the early 1920s to reduce the tendency to knock. It was often called ethyl or high-test gasoline.

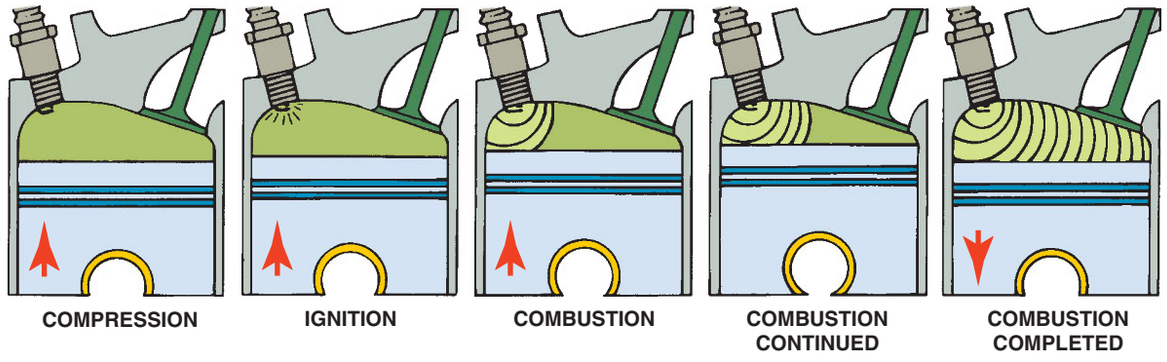


FIGURE 66–6 Normal combustion is a smooth, controlled burning of the air-fuel mixture.

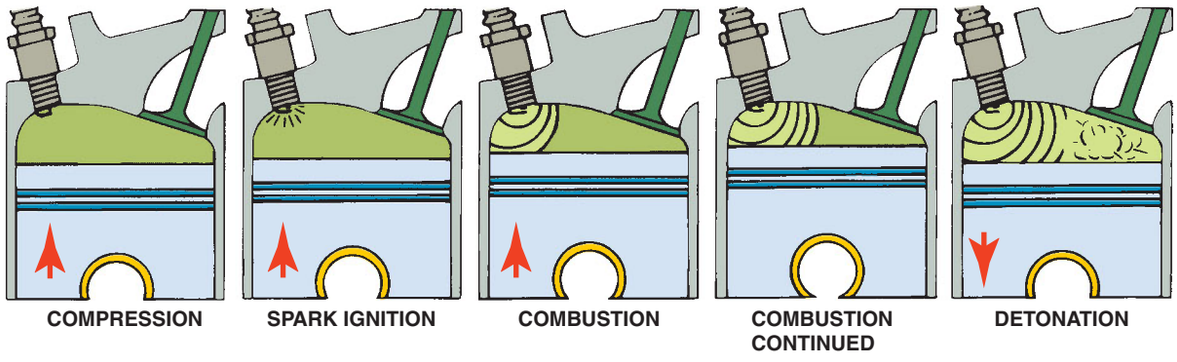


FIGURE 66–7 Detonation is a secondary ignition of the air-fuel mixture. It is also called spark knock or pinging.

FREQUENTLY ASKED QUESTION

What Grade of Gasoline Does the EPA Use When Testing Engines?

Due to the various grades and additives used in commercial fuel, the government (EPA) uses a liquid called indolene. Indolene has a research octane number of 96.5 and a motor method octane rating of 88, which results in an R + M ÷ 2 rating of 92.25.

TECH TIP

Horsepower and Fuel Flow

To produce 1 hp, the engine must be supplied with 0.50 lb of fuel per hour (lb/hr). Fuel injectors are rated in pounds per hour. For example, a V-8 engine equipped with 25 lb/hr fuel injectors could produce 50 hp per cylinder (per injector) or 400 hp. Even if the cylinder head or block is modified to produce more horsepower, the limiting factor may be the injector flow rate.

The following are flow rates and resulting horsepower for a V-8 engine:

30 lb/hr: 60 hp per cylinder or 480 hp
35 lb/hr: 70 hp per cylinder or 560 hp
40 lb/hr: 80 hp per cylinder or 640 hp

Of course, injector flow rate is only one of many variables that affect power output. Installing larger injectors without other major engine modification could decrease engine output and drastically increase exhaust emissions.

OCTANE RATING

The antiknock standard or basis of comparison is the knock-resistant hydrocarbon isooctane, chemically called trimethylpentane (C_8H_{18}), also known as 2-2-4 trimethylpentane. If a gasoline tested had the exact same antiknock characteristics as isooctane, it was rated as 100-octane gasoline. If the gasoline tested had only 85% of the antiknock properties of isooctane, it was rated as 85 octane. Remember, octane rating is only a comparison test.

The two basic methods used to rate gasoline for antiknock properties (octane rating) are the *research method* and the *motor method*. Each uses a model of the special cooperative fuel research (CFR) single-cylinder engine. The research method and the motor method vary as to temperature of air, spark advance, and other parameters. The research method typically results in readings that are 6 to 10 points higher than those of the motor method. For example, a fuel with a research octane number (RON) of 93 might have a motor octane number (MON) of 85.

The octane rating posted on pumps in the United States is the average of the two methods and is referred to as (R + M) ÷ 2, meaning that, for the fuel used in the previous example, the rating posted on the pumps would be

$$\frac{\text{RON} + \text{MON}}{2} = \frac{93 + 85}{2} = 89$$

The pump octane is called the **antiknock index (AKI).**



FIGURE 66–8 A pump showing regular with a pump octane of 87, plus rated at 89, and premium rated at 93. These ratings can vary with brand as well as in different parts of the country.

GASOLINE GRADES AND OCTANE NUMBER The posted octane rating on gasoline pumps is the rating achieved by the average of the research and the motor methods. ● **SEE FIGURE 66–8.**

Except in high-altitude areas, the grades and octane ratings are as follows:

Grades	Octane rating
Regular	87
Midgrade (also called Plus)	89
Premium	91 or higher

HIGH-ALTITUDE OCTANE REQUIREMENTS

As the altitude increases, atmospheric pressure drops. The air is less dense because a pound of air takes more volume. The octane rating of fuel does not need to be as high because the engine cannot take in as much air. This process will reduce the combustion (compression) pressures inside the engine. In mountainous areas, gasoline (R + M) ÷ 2 octane ratings are two or more numbers lower than normal (according to the SAE, about one octane number lower per 1,000 ft or 300 m in altitude). ● **SEE FIGURE 66–9.**

A secondary reason for the lowered octane requirement of engines running at higher altitudes is the normal enrichment of the air-fuel ratio and lower engine vacuum with the decreased air density. Some problems, therefore, may occur when driving out of high-altitude areas into lower-altitude areas where the octane rating must be higher. Most computerized engine control systems can compensate for changes in altitude and modify air-fuel ratio and ignition timing for best operation.

Because the combustion burn rate slows at high altitude, the ignition (spark) timing can be advanced to improve power. The amount of timing advance can be about 1 degree per 1,000 ft over 5,000 ft. Therefore, if driving at 8,000 ft of altitude, the ignition timing can be advanced 3 degrees.

High altitude also allows fuel to evaporate more easily. The volatility of fuel should be reduced at higher altitudes to prevent vapor from forming in sections of the fuel system, which can cause driveability and stalling problems. The extra heat generated in climbing



FIGURE 66–9 The posted octane rating in most high-altitude areas shows regular at 85 instead of the usual 87.

? FREQUENTLY ASKED QUESTION

Can Regular-Grade Gasoline Be Used If Premium Is the Recommended Grade?

Maybe. It is usually possible to use regular-grade or midgrade (plus) gasoline in most newer vehicles without danger of damage to the engine. Most vehicles built since the 1990s are equipped with at least one knock sensor. If a lower octane gasoline than specified is used, the engine ignition timing setting will usually cause the engine to spark knock, also called detonation or ping. This spark knock is detected by the knock sensor(s), which sends a signal to the computer. The computer then retards the ignition timing until the spark knock stops.

NOTE: Some scan tools will show the "estimated octane rating" of the fuel being used, which is based on knock sensor activity.

As a result of this spark timing retardation, the engine torque is reduced. While this reduction in power is seldom noticed, it will reduce fuel economy, often by 4 to 5 miles per gallon. If premium gasoline is then used, the PCM will gradually permit the engine to operate at the more advanced ignition timing setting. Therefore, it may take several tanks of premium gasoline to restore normal fuel economy. For best overall performance, use the grade of gasoline recommended by the vehicle manufacturer.

to higher altitudes plus the lower atmospheric pressure at higher altitudes combine to cause vapor lock problems as the vehicle goes to higher altitudes.

GASOLINE ADDITIVES

DYE Dye is usually added to gasoline at the distributor to help identify the grade and/or brand of fuel. In many countries, fuels are required to be colored using a fuel-soluble dye. In the United States and Canada, diesel fuel used for off-road use and not taxed is required to be dyed red for identification. Gasoline sold for off-road use in Canada is dyed purple.

? FREQUENTLY ASKED QUESTION

What Is Meant by "Phase Separation?"

All alcohols absorb water, and the alcohol–water mixture can separate from the gasoline and sink to the bottom of the fuel tank. This process is called *phase separation*. To help avoid engine performance problems, try to keep at least a quarter tank of fuel at all times, especially during seasons when there is a wide temperature span between daytime highs and nighttime lows. These conditions can cause moisture to accumulate in the fuel tank as a result of condensation of the moisture in the air.

OCTANE IMPROVER ADDITIVES When gasoline companies, under federal EPA regulations, removed tetraethyl lead from gasoline, other methods were developed to help maintain the antiknock properties of gasoline. Octane improvers (enhancers) can be grouped into three broad categories:

1. Aromatic hydrocarbons (hydrocarbons containing the benzene ring) such as xylene and toluene
2. Alcohols such as ethanol (ethyl alcohol), methanol (methyl alcohol), and tertiary butyl alcohol (TBA)
3. Metallic compounds such as methylcyclopentadienyl manganese tricarbonyl (MMT)

NOTE: MMT has been proven to be harmful to catalytic converters and can cause spark plug fouling. However, MMT is currently one of the active ingredients commonly found in octane improvers available to the public and in some gasoline sold in Canada. If an octane boost additive has been used that contains MMT, the spark plug porcelain will be rust colored around the tip.

Propane and butane, which are volatile by-products of the refinery process, are also often added to gasoline as octane improvers. The increase in volatility caused by the added propane and butane often leads to hot-weather driveability problems.

OXYGENATED FUEL ADDITIVES **Oxygenated fuels** contain oxygen in the molecule of the fuel itself. Examples of oxygenated fuels include methanol, ethanol, methyl tertiary butyl ether (MTBE), tertiary-amyl methyl ether (TAME), and ethyl tertiary butyl ether (ETBE).

Oxygenated fuels are commonly used in high-altitude areas to reduce carbon monoxide (CO) emissions. The extra oxygen in the fuel itself is used to convert harmful CO into carbon dioxide (CO_2). The extra oxygen in the fuel helps ensure that there is enough oxygen to convert all CO into CO_2 during the combustion process in the engine or catalytic converter.

METHYL TERTIARY BUTYL ETHER (MTBE). MTBE is manufactured by means of the chemical reaction of methanol and isobutylene. Unlike methanol, MTBE does not increase the volatility of the fuel and is not as sensitive to water as are other alcohols. The maximum allowable volume level, according to the EPA, is 15% but is currently being phased out because of health concerns, as well as MTBE contamination of drinking water if spilled from storage tanks.



FIGURE 66–10 This refueling pump indicates that the gasoline is blended with 10% ethanol (ethyl alcohol) and can be used in any gasoline vehicle. E85 contains 85% ethanol and can be used only in vehicles specifically designed to use it.



FIGURE 66–11 A container with gasoline containing alcohol. Notice the separation line where the alcohol–water mixture separated from the gasoline and sank to the bottom.

TERTIARY-AMYL METHYL ETHER. Tertiary-amyl methyl ether (TAME) contains an oxygen atom bonded to two carbon atoms and is added to gasoline to provide oxygen to the fuel. It is slightly soluble in water, very soluble in ethers and alcohol, and soluble in most organic solvents including hydrocarbons.

ETHYL TERTIARY BUTYL ETHER. ETBE is derived from ethanol. The maximum allowable volume level is 17.2%. The use of ETBE is the cause of much of the odor from the exhaust of vehicles using reformulated gasoline.

ETHANOL. **Ethanol,** also called *ethyl alcohol* is drinkable alcohol and is usually made from grain. Adding 10% ethanol (ethyl alcohol or grain alcohol) increases the (R + M) ÷ 2 octane rating by three points. The alcohol added to the base gasoline, however, also raises the volatility of the fuel about 0.5 PSI. Most automobile manufacturers permit up to 10% ethanol if driveability problems are not experienced.

The oxygen content of a 10% blend of ethanol in gasoline, called **E10,** is 3.5% oxygen by weight. ● **SEE FIGURE 66–10.**

Keeping the fuel tank full reduces the amount of air and moisture in the tank. ● **SEE FIGURE 66–11.**

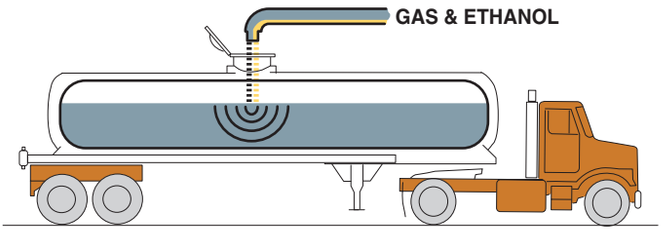


FIGURE 66–12 In-line blending is the most accurate method for blending ethanol with gasoline because computers are used to calculate the correct ratio.

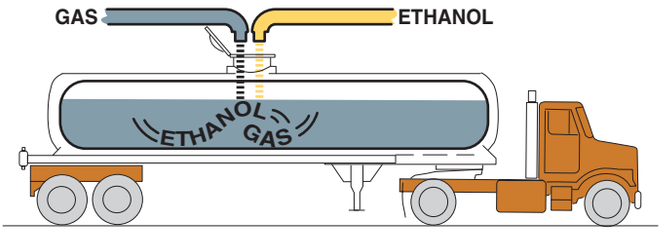


FIGURE 66–13 Sequential blending uses a computer to calculate the correct ratio as well as the prescribed order in which the products are loaded.

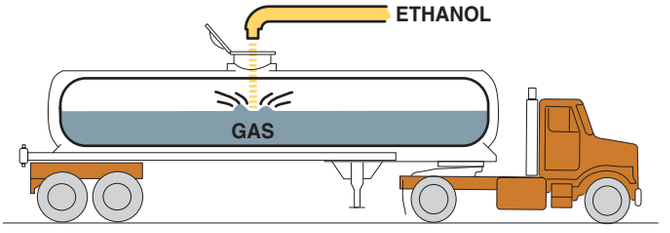


FIGURE 66–14 Splash blending occurs when the ethanol is added to a tanker with gasoline and is mixed as the truck travels to the retail outlet.

GASOLINE BLENDING

Gasoline additives, such as ethanol and dyes, are usually added to the fuel at the distributor. Adding ethanol to gasoline is a way to add oxygen to the fuel itself. Gasoline containing an addition that has oxygen is called *oxygenated fuel*. There are three basic methods used to blend ethanol with gasoline to create E10 (10% ethanol, 90% gasoline):

1. **In-line blending.** Gasoline and ethanol are mixed in a storage tank or in the tank of a transport truck while it is being filled. Because the quantities of each can be accurately measured, this method is most likely to produce a well-mixed blend of ethanol and gasoline. ● **SEE FIGURE 66–12.**
2. **Sequential blending.** This method is usually performed at the wholesale terminal and involves adding a measured amount of ethanol to a tank truck followed by a measured amount of gasoline. ● **SEE FIGURE 66–13.**
3. **Splash blending.** Splash blending can be done at the retail outlet or distributor and involves separate purchases of ethanol and gasoline. In a typical case, a distributor can purchase gasoline, and then drive to another supplier and purchase ethanol. The ethanol is then added (splashed) into the tank of gasoline. This method is the least-accurate method of blending and can result in ethanol concentration for E10 that should be 10% to range from 5% to over 20% in some cases. ● **SEE FIGURE 66–14.**

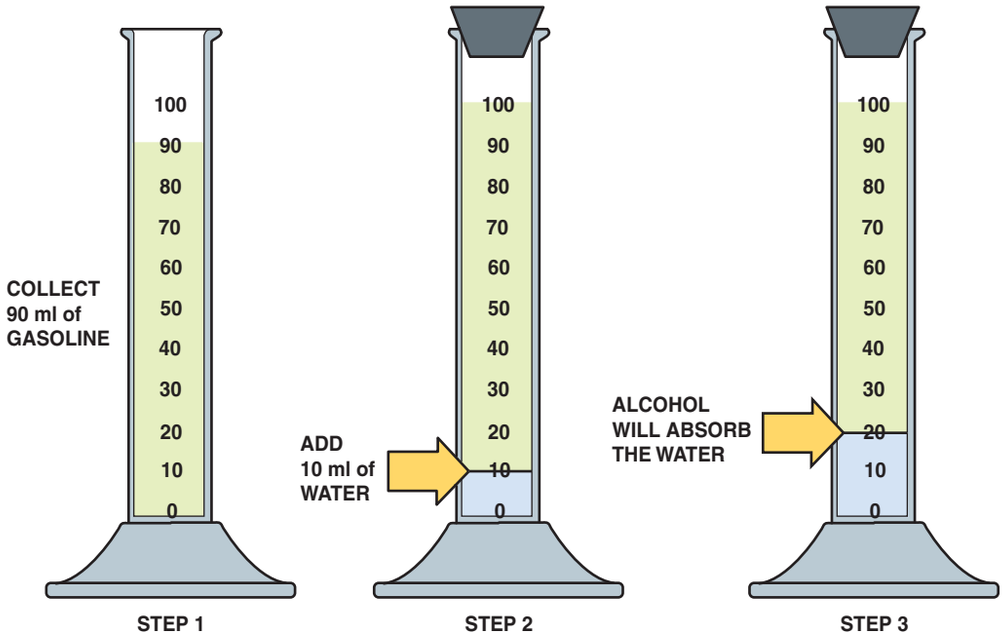


FIGURE 66–15 Checking gasoline for alcohol involves using a graduated cylinder and adding water to check if the alcohol absorbs the water.

FREQUENTLY ASKED QUESTION

Is Water Heavier Than Gasoline?

Yes. Water weighs about 8.3 pounds per gallon, whereas gasoline weighs about 6 pounds per gallon. The density as measured by specific gravity includes:

Water = 1.000 (the baseline for specific gravity)
Gasoline = 0.730 to 0.760

This means that any water that gets into the fuel tank will sink to the bottom.

REFORMULATED GASOLINE

Reformulated gasoline (RFG) is manufactured to help reduce emissions. The gasoline refiners reformulate gasoline by using additives that contain at least 2% oxygen by weight and reducing the additive benzene to a maximum of 1% by volume. Two other major changes done at the refineries are as follows:

1. **Reduce light compounds.** Refineries eliminate butane, pentane, and propane, which have a low boiling point and evaporate easily. These unburned hydrocarbons are released into the atmosphere during refueling and through the fuel tank vent system, contributing to smog formation. Therefore, reducing the light compounds from gasoline helps reduce evaporative emissions.
2. **Reduce heavy compounds.** Refineries eliminate heavy compounds with high boiling points such as aromatics and olefins. The purpose of this reduction is to reduce the amount of unburned hydrocarbons that enter the catalytic converter, which makes the converter more efficient, thereby reducing emissions.

Because many of the heavy compounds are eliminated, a drop in fuel economy of about 1 mpg has been reported in areas where reformulated gasoline is being used. Formaldehyde is formed when RFG is burned, and the vehicle exhaust has a unique smell when reformulated gasoline is used.

TESTING GASOLINE FOR ALCOHOL CONTENT

Take the following steps when testing gasoline for alcohol content:

WARNING

Do not smoke or run the test around sources of ignition!

1. Pour suspect gasoline into a graduated cylinder.
2. Carefully fill the graduated cylinder to the 90-mL mark.
3. Add 10 mL of water to the graduated cylinder by counting the number of drops from an eyedropper.
4. Put the stopper in the cylinder and shake vigorously for 1 minute. Relieve built-up pressure by occasionally removing the stopper. Alcohol dissolves in water and will drop to the bottom of the cylinder.
5. Place the cylinder on a flat surface and let it stand for 2 minutes.
6. Take a reading near the bottom of the cylinder at the boundary between the two liquids.
7. For percent of alcohol in gasoline, subtract 10 from the reading.

   For example,

   The reading is 20 mL: 20 − 10 = 10% alcohol

If the increase in volume is 0.2% or less, it may be assumed that the test gasoline contains no alcohol. ● **SEE FIGURE 66–15.** Alcohol content can also be checked using an electronic tester. See the step-by-step sequence at the end of the chapter.



FIGURE 66–16 The gas cap on a Ford vehicle notes that BP fuel is recommended.

TECH TIP

The Sniff Test

Problems can occur with stale gasoline from which the lighter parts of the gasoline have evaporated. Stale gasoline usually results in a no-start situation. If stale gasoline is suspected, sniff it. If it smells rancid, replace it with fresh gasoline.

NOTE: If storing a vehicle, boat, or lawnmower over the winter, put some gasoline stabilizer into the gasoline to reduce the evaporation and separation that can occur during storage. Gasoline stabilizer is frequently available at lawnmower repair shops or marinas.

FREQUENTLY ASKED QUESTION

How Does Alcohol Content in the Gasoline Affect Engine Operation?

In most cases, the use of gasoline containing 10% or less of ethanol (ethyl alcohol) has little or no effect on engine operation. However, because the addition of 10% ethanol raises the volatility of the fuel slightly, occasional rough idle or stalling may be noticed, especially during warm weather. The rough idle and stalling may also be noticeable after the engine is started, driven, then stopped for a short time. Engine heat can vaporize the alcohol-enhanced fuel causing bubbles to form in the fuel system. These bubbles in the fuel prevent the proper operation of the fuel injection system and result in a hesitation during acceleration, rough idle, or in severe cases repeated stalling until all the bubbles have been forced through the fuel system, replaced by cooler fuel from the fuel tank.

FREQUENTLY ASKED QUESTION

Why Should I Keep the Fuel Gauge Above One-Quarter Tank?

The fuel pickup inside the fuel tank can help keep water from being drawn into the fuel system unless water is all that is left at the bottom of the tank. Over time, moisture in the air inside the fuel tank can condense, causing liquid water to drop to the bottom of the fuel tank (water is heavier than gasoline–about 8 lb per gallon for water and about 6 lb per gallon for gasoline). If alcohol-blended gasoline is used, the alcohol can absorb the water and the alcohol–water combination can be burned inside the engine. However, when water combines with alcohol, a separation layer occurs between the gasoline at the top of the tank and the alcohol–water combination at the bottom. When the fuel level is low, the fuel pump will draw from this concentrated level of alcohol and water. Because alcohol and water do not burn as well as pure gasoline, severe driveability problems can occur such as stalling, rough idle, hard starting, and missing.

FREQUENTLY ASKED QUESTION

What Is "Top-Tier" Gasoline?

Top-tier gasoline is gasoline that has specific standards for quality, including enough detergent to keep all intake valves clean. Four automobile manufacturers, including BMW, General Motors, Honda, and Toyota, developed the standards. Top-tier gasoline exceeds the quality standards developed by the **World Wide Fuel Charter (WWFC)** that was established in 2002 by vehicle and engine manufacturers. The gasoline companies that agreed to make fuel that matches or exceeds the standards as a top-tier fuel include Shell, ChevronTexaco and ConocoPhillips. Ford has specified that BP fuel, sold in many parts of the country, is the recommended fuel to use in Ford vehicles. ● **SEE FIGURE 66–16.**

GENERAL GASOLINE RECOMMENDATIONS

The fuel used by an engine is a major expense in the operation cost of the vehicle. The proper operation of the engine depends on clean fuel of the proper octane rating and vapor pressure for the atmospheric conditions.

To help ensure proper engine operation and keep fuel costs to a minimum, follow these guidelines:

1. Purchase fuel from a busy station to help ensure that it is fresh and less likely to be contaminated with water or moisture.
2. Keep the fuel tank above one-quarter full, especially during seasons in which the temperature rises and falls by more than 20°F between daytime highs and nighttime lows. This helps to reduce condensed moisture in the fuel tank and could prevent gas line freeze-up in cold weather.

TECH TIP

Do Not Overfill the Fuel Tank

Gasoline fuel tanks have an expansion volume area at the top. The volume of this expansion area is equal to 10% to 15% of the volume of the tank. This area is normally not filled with gasoline, but rather is designed to provide a place for the gasoline to expand into, if the vehicle is parked in the hot sun and the gasoline expands. This prevents raw gasoline from escaping from the fuel system. A small restriction is usually present to control the amount of air and vapors that can escape the tank and flow to the charcoal canister.

This volume area could be filled with gasoline if the fuel is slowly pumped into the tank. Since it can hold an extra 10% (2 gallons in a 20-gallon tank), some people deliberately try to fill the tank completely. When this expansion volume is filled, liquid fuel (rather than vapors) can be drawn into the charcoal canister. When the purge valve opens, liquid fuel can be drawn into the engine, causing an excessively rich air-fuel mixture. Not only can this liquid fuel harm vapor recovery parts, but overfilling the gas tank could also cause the vehicle to fail an exhaust emission test, particularly during an enhanced test when the tank could be purged while on the rollers.

NOTE: Gas line freeze-up occurs when the water in the gasoline freezes and forms an ice blockage in the fuel line.

3. Do not purchase fuel with a higher octane rating than is necessary. Most newer engines are equipped with a detonation (knock) sensor that signals the vehicle computer to retard the ignition timing when spark knock occurs. Therefore, an operating difference may not be noticeable to the driver when using a low-octane fuel, except for a decrease in power and fuel economy. In other words, the engine with a knock sensor will tend to operate knock free on regular fuel, even if premium, higher-octane fuel is specified. Using premium fuel may result in more power and greater fuel economy. The increase in fuel economy, however, would have to be substantial to justify the increased cost of high-octane premium fuel. Some drivers find a good compromise by using midgrade (plus) fuel to benefit from the engine power and fuel economy gains without the cost of using premium fuel all the time.
4. Avoid using gasoline with alcohol in warm weather, even though many alcohol blends do not affect engine driveability. If warm-engine stumble, stalling, or rough idle occurs, change brands of gasoline.
5. Do not purchase fuel from a retail outlet when a tanker truck is filling the underground tanks. During the refilling procedure, dirt, rust, and water may be stirred up in the underground tanks. This undesirable material may be pumped into your vehicle's fuel tank.
6. Do not overfill the gas tank. After the nozzle clicks off, add just enough fuel to round up to the next dime. Adding additional gasoline will cause the excess to be drawn into the charcoal canister. This can lead to engine flooding and excessive exhaust emissions.
7. Be careful when filling gasoline containers. Always fill a gas can on the ground to help prevent the possibility of static electricity buildup during the refueling process. ● **SEE FIGURE 66–17.**



FIGURE 66–17 Many gasoline service stations have signs posted warning customers to place plastic fuel containers on the ground while filling. If placed in a trunk or pickup truck bed equipped with a plastic liner, static electricity could build up during fueling and discharge from the container to the metal nozzle, creating a spark and possible explosion. Some service stations have warning signs not to use cell phones while fueling to help avoid the possibility of an accidental spark creating a fire hazard.

FREQUENTLY ASKED QUESTION

What Are the Pump Nozzle Sizes?

Unleaded gasoline nozzles are smaller than those used for diesel fuel to help prevent fueling errors. However, it is still possible to fuel a diesel vehicle with gasoline. ● **SEE CHART 66–1** for the sizes and colors used for fuel pump nozzles.

Fuel	Nozzle Diameter	Pump Handle Color (Varies—no established standard)
Gasoline	13/16 in. (21 mm)	Black, red, white, green, or blue
E10	13/16 in. (21 mm)	Black, red, white, green, or blue
E85	13/16 in. (21 mm)	Yellow or black
Diesel fuel	15/16 in. (24 mm)	Yellow, green, or black
Biodiesel	15/16 in. (24 mm)	Green
Truckstop diesel	1 1/14 or 1 1/2 in. (32 or 38 mm)	Varies

CHART 66–1

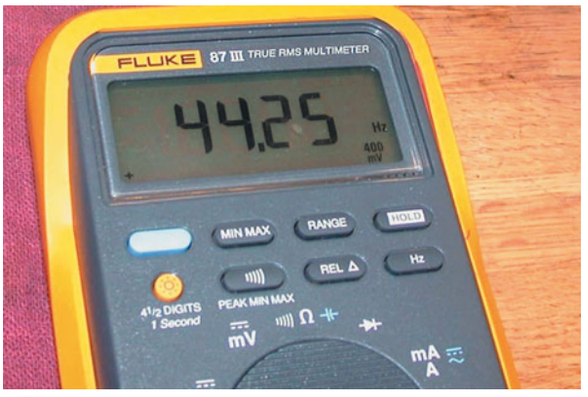
Fuel pump nozzle size is standardized except for use by over-the-road truck stops where high fuel volumes and speedy refills require larger nozzle sizes compared to passenger vehicle filling station nozzles.



1 A fuel composition tester (SPX Kent-Moore J-44175) is the recommended tool, by General Motors, to use to test the alcohol content of gasoline.



2 This battery-powered tester uses light-emitting diodes (LEDs), meter lead terminals, and two small openings for the fuel sample.



3 The first step is to verify the proper operation of the tester by measuring the air frequency by selecting AC hertz on the meter. The air frequency should be between 35 and 48 Hz.



4 After verifying that the tester is capable of correctly reading the air frequency, gasoline is poured into the testing cell of the tool.



5 Record the AC frequency as shown on the meter and subtract 50 from the reading. (e.g., 60.50 − 50.00 = 10.5). This number (10.5) is the percentage of alcohol in the gasoline sample.



6 Adding additional amounts of ethyl alcohol (ethanol) increases the frequency reading.

REVIEW QUESTIONS

1. What is the difference between summer-blend and winter-blend gasoline?
2. What is Reid vapor pressure?
3. What is vapor lock?
4. What does the (R + M) ÷ 2 gasoline pump octane rating indicate?
5. What are the octane improvers that may be used during the refining process?
6. What is stoichiometric?

CHAPTER QUIZ

1. Winter-blend gasoline _____.
   a. Vaporizes more easily than summer-blend gasoline
   b. Has a higher RVP
   c. Can cause engine driveability problems if used during warm weather
   d. All of the above
2. Vapor lock can occur _____.
   a. As a result of excessive heat near fuel lines
   b. If a fuel line is restricted
   c. During both a and b
   d. During neither a nor b
3. Technician A says that spark knock, ping, and detonation are different names for abnormal combustion. Technician B says that any abnormal combustion raises the temperature and pressure inside the combustion chamber and can cause severe engine damage. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
4. Technician A says that the research octane number is higher than the motor octane number. Technician B says that the octane rating posted on fuel pumps is an average of the two ratings. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
5. Technician A says that in going to high altitudes, engines produce lower power. Technician B says that most engine control systems can compensate the air-fuel mixture for changes in altitude. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. Which method of blending ethanol with gasoline is the most accurate?
   a. In-line
   b. Sequential
   c. Splash
   d. All of the above are equally accurate methods
7. What can be used to measure the alcohol content in gasoline?
   a. Graduated cylinder **c.** Scan tool
   b. Electronic tester **d.** Either a or b
8. To avoid problems with the variation of gasoline, all government testing uses _____ as a fuel during testing procedures.
   a. MTBE (methyl tertiary butyl ether)
   b. Indolene
   c. Xylene
   d. TBA (tertiary butyl alcohol)
9. Avoid topping off the fuel tank because _____.
   a. It can saturate the charcoal canister
   b. The extra fuel simply spills onto the ground
   c. The extra fuel increases vehicle weight and reduces performance
   d. The extra fuel goes into the expansion area of the tank and is not used by the engine
10. Using ethanol-enhanced or reformulated gasoline can result in reduced fuel economy.
    a. True
    b. False

chapter 67

ALTERNATIVE FUELS

OBJECTIVES: After studying Chapter 67, the reader should be able to: • Describe how alternative fuels affect engine performance. • List alternatives to gasoline. • Discuss how alternative fuels affect driveability. • Explain how alternative fuels can reduce CO exhaust emissions. • Discuss safety precautions when working with alternative fuels.

KEY TERMS: AFV 768 • Anhydrous ethanol 767 • Biomass 772 • Cellulose ethanol 767 • Cellulosic biomass 767 • Coal to liquid (CTL) 775 • Compressed natural gas (CNG) 772 • E85 768 • Ethanol 767 • Ethyl alcohol 767 • FFV 768 • Fischer-Tropsch 775 • Flex fuels 768 • FTD 775 • Fuel compensation sensor 768 • Gas to liquid (GTL) 775 • Grain alcohol 767 • Liquid petroleum gas (LPG) 772 • LP-gas 772 • M85 772 • Methanol 771 • Methanol to gasoline (MTG) 776 • NGV 772 • Propane 772 • Switchgrass 768 • Syncrude 776 • Syn-gas 772 • Synthetic fuel 774 • Underground coal gasification (UCG) 776 • V-FFV 771 • Variable fuel sensor 768

ETHANOL

ETHANOL TERMINOLOGY

Ethanol is also called **ethyl alcohol** or **grain alcohol,** because it is usually made from grain and is the type of alcohol found in alcoholic drinks such as beer, wine, and distilled spirits like whiskey. Ethanol is composed of two carbon atoms and six hydrogen atoms with one added oxygen atom. **SEE FIGURE 67–1.**

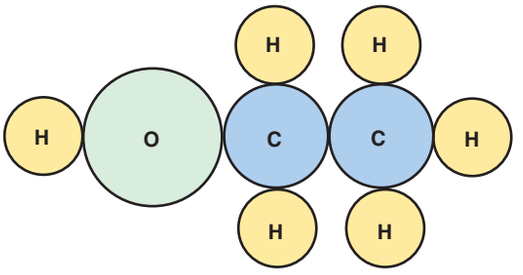


FIGURE 67–1 The ethanol molecule showing two carbon atoms, six hydrogen atoms, and one oxygen atom.

ETHANOL PRODUCTION

Conventional ethanol is derived from grains, such as corn, wheat, or soybeans. Corn, for example, is converted to ethanol in either a dry or wet milling process. In dry milling operations, liquefied cornstarch is produced by heating cornmeal with water and enzymes. A second enzyme converts the liquefied starch to sugars, which are fermented by yeast into ethanol and carbon dioxide. Wet milling operations separate the fiber, germ (oil), and protein from the starch before it is fermented into ethanol.

The majority of the ethanol in the United States is made from:

- Corn
- Grain
- Sorghum
- Wheat
- Barley
- Potatoes

In Brazil, the world's largest ethanol producer, it is made from sugarcane. Ethanol can be made by the dry mill process in which the starch portion of the corn is fermented into sugar and then distilled into alcohol.

The major steps in the dry mill process include:

1. **Milling.** The feedstock passes through a hammer mill that turns it into a fine powder called *meal*.
2. **Liquefaction.** The meal is mixed with water and then passed through cookers where the starch is liquefied. Heat is applied at this stage to enable liquefaction. Cookers use a high-temperature stage of about 250°F to 300°F (120°C to 150°C) to reduce bacteria levels and then a lower temperature of about 200°F (95°C) for a holding period.
3. **Saccharification.** The mash from the cookers is cooled and a secondary enzyme is added to convert the liquefied starch to fermentable sugars (dextrose).
4. **Fermentation.** Yeast is added to the mash to ferment the sugars to ethanol and carbon dioxide.
5. **Distillation.** The fermented mash, now called beer, contains about 10% alcohol plus all the nonfermentable solids from the corn and yeast cells. The mash is pumped to the continuous-flow, distillation system where the alcohol is removed from the solids and the water. The alcohol leaves the top of the final column at about 96% strength, and the residue mash, called *silage*, is transferred from the base of the column to the co-product processing area.

? FREQUENTLY ASKED QUESTION

Does Ethanol Production Harm the Environment?

The production of ethanol is referred to as being carbon neutral because the amount of CO_2 released during production is equal to the amount of CO_2 that would be released if the corn or other products were left to decay.

6. **Dehydration.** The alcohol from the top of the column passes through a dehydration system where the remaining water will be removed. The alcohol product at this stage is called **anhydrous ethanol** (pure, no more than 0.5% water).
7. **Denaturing.** Ethanol that will be used for fuel must be denatured, or made unfit for human consumption, with a small amount of gasoline (2% to 5%), methanol, or denatonium benzoate. This is done at the ethanol plant.

CELLULOSE ETHANOL

TERMINOLOGY

Cellulose ethanol can be produced from a wide variety of cellulose biomass feedstock, including:

- Agricultural plant wastes (corn stalks, cereal straws)
- Plant wastes from industrial processes (sawdust, paper pulp)
- Energy crops grown specifically for fuel production.

These nongrain products are often referred to as **cellulosic biomass.** Cellulosic biomass is composed of cellulose and lignin, with smaller amounts of proteins, lipids (fats, waxes, and oils), and ash. About two-thirds of cellulosic materials are present as cellulose, with lignin making up the bulk of the remaining dry mass.

REFINING CELLULOSE BIOMASS

As with grains, processing cellulose biomass involves extracting fermentable sugars from the feedstock. But the sugars in cellulose are locked in complex carbohydrates called polysaccharides (long chains of simple sugars). Separating these complex structures into fermentable sugars

? FREQUENTLY ASKED QUESTION

What Is Switchgrass?

Switchgrass (*Panicum virgatum*) can be used to make ethanol and is a summer perennial grass that is native to North America. It is a natural component of the tall-grass prairie, which covered most of the Great Plains, but was also found on the prairie soils in the Black Belt of Alabama and Mississippi. Switchgrass is resistant to many pests and plant diseases, and is capable of producing high yields with very low applications of fertilizer. This means that the need for agricultural chemicals to grow switchgrass is relatively low. Switchgrass is also very tolerant of poor soils, flooding, and drought, which are widespread agricultural problems in the Southeast.

There are two main types of switchgrass:

- **Upland types**—usually grow 5 to 6 feet tall
- **Lowland types**—grow up to 12 feet tall and are typically found on heavy soils in bottomland sites

Better energy efficiency is gained because less energy is used to produce ethanol from switchgrass.

is needed to achieve the efficient and economic production of cellulose ethanol.

Two processing options are employed to produce fermentable sugars from cellulose biomass:

- Acid hydrolysis is used to break down the complex carbohydrates into simple sugars.
- Enzymes are employed to convert the cellulose biomass to fermentable sugars. The final step involves microbial fermentation, yielding ethanol and carbon dioxide.

NOTE: Cellulose ethanol production substitutes biomass for fossil fuels. The greenhouse gases produced by the combustion of biomass are offset by the CO_2 absorbed by the biomass as it grows in the field.

E85

WHAT IS E85? Vehicle manufacturers have available vehicles that are capable of operating on gasoline plus ethanol or a combination of gasoline and ethanol called **E85.** E85 is composed of 85% ethanol and 15% gasoline.

Pure ethanol has an octane rating of about 113. E85, which contains 35% oxygen by weight, has an octane rating of about 100 to 105. This compares to a regular unleaded gasoline, which has a rating of 87. ● **SEE FIGURE 67–2.**

NOTE: The octane rating of E85 depends on the exact percent of ethanol used, which can vary from 81% to 85%. It also depends on the octane rating of the gasoline used to make E85.

HEAT ENERGY OF E85 E85 has less heat energy than gasoline.

Gasoline = 114,000 BTUs per gallon

E85 = 87,000 BTUs per gallon



FIGURE 67–2 Some retail stations offer a variety of fuel choices, such as this station in Ohio where E10 and E85 are available.

This means that the fuel economy is reduced by 20% to 30% if E85 is used instead of gasoline.

Example: A Chevrolet Tahoe 5.3-liter V-8 with an automatic transmission has an EPA rating of 15 mpg in the city and 20 mpg on the highway when using gasoline. If this same vehicle was fueled with E85, the EPA fuel economy rating drops to 11 mpg in the city and 15 mpg on the highway.

ALTERNATIVE-FUEL VEHICLES

The 15% gasoline in this blend helps the engine start, especially in cold weather. Vehicles equipped with this capability are commonly referred to as **alternative-fuel vehicles (AFVs), flex fuels,** and **flexible fuel vehicles,** or **FFVs.** Using E85 in a flex-fuel vehicle can result in a power increase of about 5%. For example, an engine rated at 200 hp using gasoline or E10 could produce 210 hp if using E85.

NOTE: E85 may test as containing less than 85% ethanol if tested in cold climates because it is often blended according to outside temperature. A lower percentage of ethanol with a slightly higher percentage of gasoline helps engines start in cold climates.

These vehicles are equipped with an electronic sensor in the fuel supply line that detects the presence and percentage of ethanol. The PCM then adjusts the fuel injector on-time and ignition timing to match the needs of the fuel being used.

E85 contains less heat energy, and therefore will use more fuel, but the benefits include a lower cost of the fuel and the environmental benefit associated with using an oxygenated fuel.

General Motors, Ford, Chrysler, Mazda, and Honda are a few of the manufacturers offering E85 compatible vehicles. E85 vehicles use fuel system parts designed to withstand the additional alcohol content, modified driveability programs that adjust fuel delivery and timing to compensate for the various percentages of ethanol fuel, and a **fuel compensation sensor** that measures both the percentage of ethanol blend and the temperature of the fuel. This sensor is also called a **variable fuel sensor.** ● **SEE FIGURES 67–3 AND 67–4.**

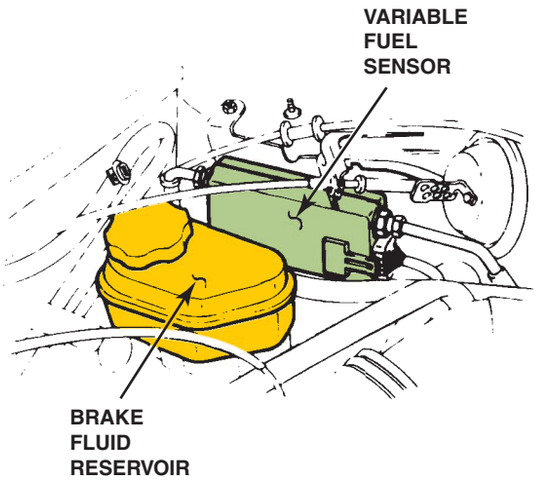


FIGURE 67–3 The location of the variable fuel sensor can vary, depending on the make and model of vehicle, but it is always in the fuel line between the fuel tank and the fuel injectors.



FIGURE 67–5 A pump for E85 (85% ethanol and 15% gasoline). E85 is available in more locations every year.

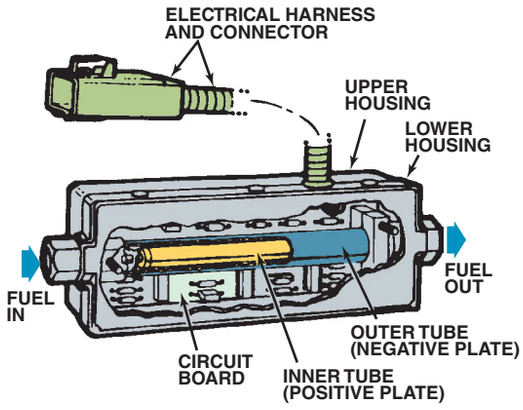


FIGURE 67–4 A cutaway view of a typical variable fuel sensor.

TECH TIP

Purchase a Flex-Fuel Vehicle

If purchasing a new or used vehicle, try to find a flex-fuel vehicle. Even though you may not want to use E85, a flex-fuel vehicle has a more robust fuel system than a conventional fuel system designed for gasoline or E10. The enhanced fuel system components and materials usually include:

- Stainless steel fuel rail
- Graphite commutator bars instead of copper in the fuel pump motor (ethanol can oxidize into acetic acid, which can corrode copper)
- Diamond-like carbon (DLC) corrosion-resistant fuel injectors
- Alcohol-resistant O-rings and hoses

The cost of a flex-fuel vehicle compared with the same vehicle designed to operate on gasoline is a no-cost or a low-cost option.

E85 FUEL SYSTEM REQUIREMENTS

Most E85 vehicles are very similar to non-E85 vehicles. Fuel system components may be redesigned to withstand the effects of higher concentrations of ethanol. In addition, since the stoichiometric point for ethanol is 9:1 instead of 14.7:1 as for gasoline, the air-fuel mixture has to be adjusted for the percentage of ethanol present in the fuel tank. In order to determine this percentage of ethanol in the fuel tank, a compensation sensor is used. The fuel compensation sensor is the only additional piece of hardware required on some E85 vehicles. The fuel compensation sensor provides both the ethanol percentage and the fuel temperature to the PCM. The PCM uses this information to adjust both the ignition timing and the quantity of fuel delivered to the engine. The fuel compensation sensor uses a microprocessor to measure both the ethanol percentage and the fuel temperature. This information is sent to the PCM on the signal circuit. The compensation sensor produces a square wave frequency and pulse width signal. The normal frequency range of the fuel compensation sensor is 50 hertz, which represents 0% ethanol and 150 hertz, which represents 100% ethanol. The pulse width of the signal varies from 1 millisecond to 5 milliseconds. One millisecond would represent a fuel temperature of −40°F (−40°C), and 5 milliseconds would represent a fuel temperature of 257°F (125°C). Since the PCM knows both the fuel temperature and the ethanol percentage of the fuel, it can adjust fuel quantity and ignition timing for optimum performance and emissions.

The benefits of E85 vehicles are less pollution, less CO_2 production, and less dependence on oil. ● **SEE FIGURE 67–5.**

Ethanol-fueled vehicles generally produce the same pollutants as gasoline vehicles; however, they produce less CO and CO_2 emissions. While CO_2 is not considered a pollutant, it is thought to lead to global warming and is called a greenhouse gas.

FLEX-FUEL VEHICLE IDENTIFICATION

Flexible fuel vehicles (FFVs) can be identified by:

- Emblems on the side, front, and/or rear of the vehicle
- Yellow fuel cap showing E85/gasoline (● **SEE FIGURE 67–6**)
- Vehicle emission control information (VECI) label under the hood (● **SEE FIGURE 67–7**)
- Vehicle identification number (VIN)



FIGURE 67–6 A flex-fuel vehicle often has a yellow gas cap, which is labeled E85/gasoline.



FIGURE 67–7 A vehicle emission control information (VECI) sticker on a flexible fuel vehicle indicating that it can use ethanol from 0 to 85%.

Vehicles that are flexible fuel include:

Chrysler

2004+
- 4.7L Dodge Ram Pickup 1500 Series
- 2.7L Dodge Stratus Sedan
- 2.7L Chrysler Sebring Sedan
- 3.3L Caravan and Grand Caravan SE

2003–2004
- 2.7L Dodge Stratus Sedan
- 2.7L Chrysler Sebring Sedan

2003
- 3.3L Dodge Cargo Minivan

2000–2003
- 3.3L Chrysler Voyager Minivan
- 3.3L Dodge Caravan Minivan 3.3L Chrysler Town and Country Minivan

1998–1999
- 3.3L Dodge Caravan Minivan
- 3.3L Plymouth Voyager Minivan
- 3.3L Chrysler Town & Country Minivan

Ford Motor Company

*Ford offers the flex fuel capability as an option on select vehicles—see the owner's manual.

2004+
- 4.0L Explorer Sport Trac
- 4.0L Explorer (4-door)
- 3.0L Taurus Sedan and Wagon

2002–2004
- 4.0L Explorer (4-door)
- 3.0L Taurus Sedan and Wagon

2002–2003
- 3.0L Supercab Ranger Pickup 2WD

2001
- 3.0L Supercab Ranger Pickup 2WD
- 3.0L Taurus LX, SE, and SES Sedan

1999–2000
- 3.0L Ranger Pickup 4WD and 2WD

General Motors

*Select vehicles only—see your owner's manual.

2005+
- 5.3L Vortec-Engine Avalanche
- 5.3L Vortec-Engine Police Package Tahoe

2003–2005
- 5.3L V8 Chevy Silverado* and GMC Sierra* Half-Ton Pickups 2WD and 4WD
- 5.3L Vortec-Engine Suburban, Tahoe, Yukon, and Yukon XL

2002
- 5.3L V8 Chevy Silverado* and GMC Sierra* Half-Ton Pickups 2WD and 4WD
- 5.3L Vortec-Engine Suburban, Tahoe, Yukon, and Yukon XL
- 2.2L Chevy S10 Pickup 2WD
- 2.2L Sonoma GMC Pickup 2WD

2000–2001
- 2.2L Chevy S10 Pickup 2WD
- 2.2L GMC Sonoma Pickup 2WD

Isuzu

2000–2001
- 2.2L Hombre Pickup 2WD

Mazda

1999–2003
- 3.0L Selected B3000 Pickups

Mercedes-Benz

2005+
- 2.6L C240 Luxury Sedan and Wagon

2003
- 3.2L C320 Sport Sedan and Wagon

Mercury

2002–2004
- 4.0L Selected Mountaineers

2000–2004
- 3.0L Selected Sables

Nissan

2005+
- 5.6L DOHC V8 Engine

*Select vehicles only—see the owner's manual or VECI sticker under the hood.

FREQUENTLY ASKED QUESTION

How Does a Sensorless Flex-Fuel System Work?

Many General Motors flex-fuel vehicles do not use a fuel compensation sensor and instead use the oxygen sensor to detect the presence of the lean mixture and the extra oxygen in the fuel.

The powertrain control module (PCM) then adjusts the injector pulse-width and the ignition timing to optimize engine operation to the use of E85. This type of vehicle is called a **virtual flexible fuel vehicle,** abbreviated **V-FFV.** The virtual flexible fuel vehicle can operate on pure gasoline or blends up to 85% ethanol.

HOW TO READ A VEHICLE IDENTIFICATION NUMBER

The vehicle identification number (VIN) is required by federal regulation to contain specific information about the vehicle. The following chart shows the character in the eighth position of the VIN number from Ford Motor Company, General Motors, and Chrysler that designates their vehicles as flexible fuel vehicles.

Ford Motor Company

Vehicle	8th Character
Ford Crown Victoria	V
Ford F-150	V
Ford Explorer	K
Ford Ranger	V
Ford Taurus	2
Lincoln Town Car	V
Mercury Mountaineer	K
Mercury Sable	2
Mercury Grand Marquis	V

General Motors

Vehicle	8th Character
Chevrolet Avalanche	Z
Chevrolet Impala	K
Chevrolet Monte Carlo	K
Chevrolet S-10 Pickup	5
Chevrolet Sierra	Z
Chevrolet Suburban	Z
Chevrolet Tahoe	Z
GMC Yukon and Yukon XL	Z
GMC Silverado	Z
GMC Sonoma	5

Chrysler

Vehicle	8th Character
Chrysler Sebring	T
Chrysler Town & Country	E, G or 3
Dodge Caravan	E, G or 3
Dodge Cargo Minivan	E, G or 3
Dodge Durango	P
Dodge Ram	P
Dodge Stratus	T
Plymouth Voyageur	E, G or 3

TECH TIP

Avoid Resetting Fuel Compensation

Starting in 2006, General Motors vehicles designed to operate on E85 do not use a fuel compensation sensor, but instead use the oxygen sensor and refueling information to calculate the percentage of ethanol in the fuel. The PCM uses the fuel level sensor to sense that fuel has been added and starts to determine the resulting ethanol content by using the oxygen sensor. However, if a service technician were to reset fuel compensation by clearing long-term fuel trim, the PCM starts the calculation based on base fuel, which is gasoline with less than or equal to 10% ethanol (E10). If the fuel tank has E85, then the fuel compensation cannot be determined unless the tank is drained and refilled with base fuel. Therefore, avoid resetting the fuel compensation setting unless it is known that the fuel tank contains gasoline or E10 only.

FREQUENTLY ASKED QUESTION

How Long Can Oxygenated Fuel Be Stored Before All of the Oxygen Escapes?

The oxygen in oxygenated fuels, such as E10 and E85, is not in a gaseous state like the CO_2 in soft drinks. The oxygen is part of the molecule of ethanol or other oxygenates and does not bubble out of the fuel. Oxygenated fuels, just like any fuel, have a shelf life of about 90 days.

Mazda

Vehicle	8th Character
B3000 Pickup	V

Nissan

Vehicle	4th Character
Titan	B

Mercedes Benz

Check owner's manual or the VECI sticker under the hood.

NOTE: For additional information on E85 and for the location of E85 stations in your area, go to www.e85fuel.com.

METHANOL

METHANOL TERMINOLOGY

Methanol, also known as *methyl alcohol*, *wood alcohol*, or *methyl hydrate,* is a chemical compound formula that includes one carbon atom and four hydrogen atoms and one oxygen. ● **SEE FIGURE 67–8.**

Methanol is a light, volatile, colorless, tasteless, flammable, poisonous liquid with a very faint odor. It is used as an antifreeze, a solvent, and a fuel. Methanol burns in air, forming CO_2 (carbon dioxide)

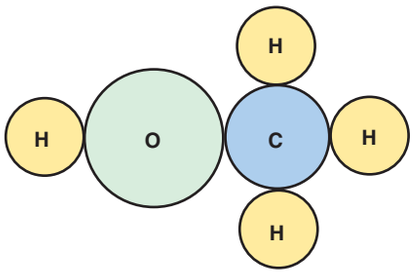


FIGURE 67–8 The molecular structure of methanol showing the one carbon atom, four hydrogen atoms, and one oxygen atom.



FIGURE 67–9 Sign on methanol pump shows that methyl alcohol is a poison and can cause skin irritation and other personal injury. Methanol is used in industry as well as being a fuel.

and H_2O (water). A methanol flame is almost colorless. Because of its poisonous properties, methanol is also used to denature ethanol. Methanol is often called wood alcohol because it was once produced chiefly as a by-product of the destructive distillation of wood. ● **SEE FIGURE 67–9.**

PRODUCTION OF METHANOL The biggest source of methanol in the United States is coal. Using a simple reaction between coal and steam, a gas mixture called **syn-gas** (*synthesis gas*) is formed. The components of this mixture are carbon monoxide and hydrogen, which, through an additional chemical reaction, are converted to methanol.

Natural gas can also be used to create methanol and is reformed or converted to synthesis gas, which is later made into methanol.

Biomass can be converted to synthesis gas by a process called partial oxidation, and later converted to methanol. **Biomass** is organic material, such as:

- Urban wood wastes
- Primary mill residues
- Forest residues
- Agricultural residues
- Dedicated energy crops (e.g., sugarcane and sugar beets) that can be made into fuel

Electricity can be used to convert water into hydrogen, which is then reacted with carbon dioxide to produce methanol.

Methanol is toxic and can cause blindness and death. It can enter the body by ingestion, inhalation, or absorption through the skin. Dangerous doses will build up if a person is regularly exposed to fumes or handles liquid without skin protection. If methanol has been ingested, a doctor should be contacted immediately. The usual fatal dose is 4 fl oz (100 to 125 mL).



FIGURE 67–10 Propane fuel storage tank in the trunk of a Ford taxi.

M85 Some flexible fuel vehicles are designed to operate on 85% methanol and 15% gasoline called **M85.** Methanol is very corrosive and requires that the fuel system components be constructed of stainless steel and other alcohol-resistant rubber and plastic components. The heat content of M85 is about 60% of that of gasoline.

PROPANE

Propane is the most widely used of all of the alternative fuels. Propane is normally a gas but is easily compressed into a liquid and stored in inexpensive containers. When sold as a fuel, it is also known as **liquefied petroleum gas (LPG)** or **LP-gas** because the propane is often mixed with about 10% of other gases such as butane, propylene, butylenes, and mercaptan to give the colorless and odorless propane a smell. Propane is nontoxic, but if inhaled can cause asphyxiation through lack of oxygen. Propane is heavier than air and lays near the floor if released into the atmosphere. Propane is commonly used in forklifts and other equipment used inside warehouses and factories because the exhaust from the engine using propane is not harmful. Propane is a by-product of petroleum refining of natural gas. In order to liquefy the fuel, it is stored in strong tanks at about 300 PSI (2,000 kPa). The heating value of propane is less than that of gasoline; therefore, more is required, which reduces the fuel economy. ● **SEE FIGURE 67–10.**

COMPRESSED NATURAL GAS

CNG VEHICLE DESIGN Another alternative fuel that is often used in fleet vehicles is **compressed natural gas,** or **CNG,** and vehicles using this fuel are often referred to as **natural gas vehicles (NGVs).** Look for the blue CNG label on vehicles designed to operate on compressed natural gas. ● **SEE FIGURE 67–11.**

Natural gas has to be compressed to about 3,000 PSI (20,000 kPa) or more, so that the weight and the cost of the



FIGURE 67–11 The blue sticker on the rear of this vehicle indicates that it is designed to use compressed natural gas.



FIGURE 67–12 A CNG storage tank from a Honda Civic GX shown with the fixture used to support it while it is being removed or installed in the vehicle. Honda specifies that three technicians be used to remove or install the tank through the rear door of the vehicle due to the size and weight of the tank.

storage container is a major factor when it comes to preparing a vehicle to run on CNG. The tanks needed for CNG are typically constructed of 0.5-inch-thick (3 mm) aluminum reinforced with fiberglass. ● **SEE FIGURE 67–12.** The octane rating of CNG is about 130 and the cost per gallon is about half of the cost of gasoline. However, the heat value of CNG is also less, and therefore more is required to produce the same power and the miles per gallon is less.

CNG COMPOSITION Compressed natural gas is made up of a blend of:

- Methane
- Propane
- Ethane
- N-butane
- Carbon dioxide
- Nitrogen

Once it is processed, it is at least 93% methane. Natural gas is nontoxic, odorless, and colorless in its natural state. It is odorized during processing, using ethyl mercaptan (“skunk”), to allow for easy leak detection. Natural gas is lighter than air and will rise when released into the air. Since CNG is already a vapor, it does not need heat to vaporize before it will burn, which improves cold start-up and

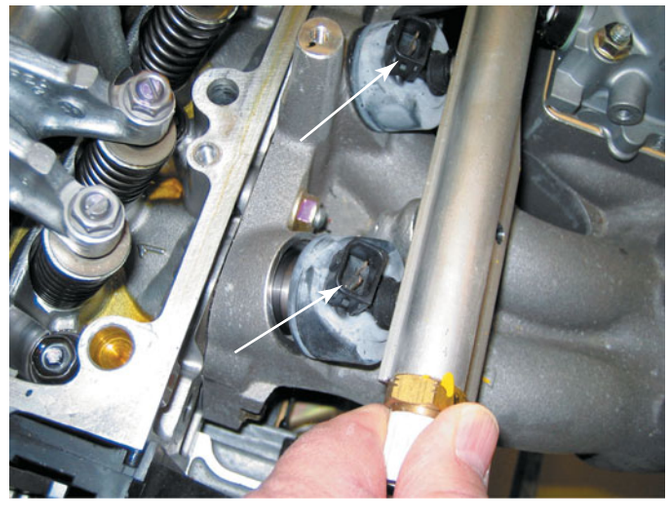


FIGURE 67–13 The fuel injectors used on this Honda Civic GX CNG engine are designed to flow gaseous fuel instead of liquid fuel and cannot be interchanged with any other type of injector.

? FREQUENTLY ASKED QUESTION

What Is the Amount of CNG Equal to in Gasoline?

To achieve the amount of energy of one gallon of gasoline, 122 cubic feet of compressed natural gas (CNG) is needed. While the octane rating of CNG is much higher than gasoline (130 octane), using CNG instead of gasoline in the same engine would result in a reduction of 10% to 20% of power due to the lower heat energy that is released when CNG is burned in the engine.

results in lower emissions during cold operation. However, because it is already in a gaseous state, it does displace some of the air charge in the intake manifold. This leads to about a 10% reduction in engine power as compared to an engine operating on gasoline. Natural gas also burns slower than gasoline; therefore, the ignition timing must be advanced more when the vehicle operates on natural gas. The stoichiometric ratio, the point at which all the air and fuel is used or burned is 16.5:1 compared to 14.7:1 for gasoline. This means that more air is required to burn one pound of natural gas than is required to burn one pound of gasoline. ● **SEE FIGURE 67–13.**

The CNG engine is designed to include:

- Increased compression ratio
- Strong pistons and connecting rods
- Heat-resistant valves
- Fuel injectors designed for gaseous fuel instead of liquid fuel

CNG FUEL SYSTEMS When completely filled, the CNG tank has 3,600 PSI of pressure in the tank. When the ignition is turned on, the alternate fuel electronic control unit activates the high-pressure lock-off, which allows high-pressure gas to pass to the high-pressure regulator. The high-pressure regulator reduces the high-pressure CNG to approximately 170 PSI and sends it to the low-pressure lock-off. The low-pressure lock-off is also controlled by the alternate fuel electronic control unit and is activated at the same time that the high-pressure lock-off is activated. From the low-pressure lock-off, the CNG is directed to the low-pressure regulator. This is a two-stage regulator that first reduces the pressure to approximately 4 to 6 PSI in the first stage and then to 4.5 to 7 inches



FIGURE 67–14 This CNG pump is capable of supplying compressed natural gas at either 3,000 PSI or 3,600 PSI. The price per gallon is higher for the higher pressure.

of water in the second stage. Twenty-eight inches of water is equal to 1 PSI, therefore, the final pressure of the natural gas entering the engine is very low. From here, the low-pressure gas is delivered to the gas mass sensor/mixture control valve. This valve controls the air-fuel mixture. The CNG gas distributor adapter then delivers the gas to the intake stream.

CNG vehicles are designed for fleet use that usually have their own refueling capabilities. One of the drawbacks to using CNG is the time that it takes to refuel a vehicle. The ideal method of refueling is the slow fill method. The slow filling method compresses the natural gas as the tank is being fueled. This method ensures that the tank will receive a full charge of CNG; however, this method can take three to five hours to accomplish. If more than one vehicle needs filling, the facility will need multiple CNG compressors to refuel the vehicles.

There are three commonly used CNG refilling station pressures:

P24—2,400 PSI

P30—3,000 PSI

P36—3,600 PSI

Try to find and use a station with the highest refilling pressure. Filling at lower pressures will result in less compressed natural gas being installed in the storage tank, thereby reducing the driving range. ● **SEE FIGURE 67–14.**

The fast fill method uses CNG that is already compressed. However, as the CNG tank is filled rapidly, the internal temperature of the tank will rise, which causes a rise in tank pressure. Once the temperature drops in the CNG tank, the pressure in the tank also drops, resulting in an incomplete charge in the CNG tank. This refueling method may take only about five minutes; however, it will result in an incomplete charge to the CNG tank, reducing the driving range.

LIQUEFIED NATURAL GAS

Natural gas can be turned into a liquid if cooled to below −260°F (−127°C). The natural gas condenses into a liquid at normal atmospheric pressure and the volume is reduced by about 600 times. This means that the natural gas can be more efficiently transported over long distances where no pipelines are present when liquefied.

Because the temperature of liquefied natural gas (LNG) must be kept low, it is only practical for use in short haul trucks where they can be refueled from a central location.

COMPOSITION OF P-SERIES FUELS (BY VOLUME)

COMPONENT	REGULAR GRADE	PREMIUM GRADE	COLD WEATHER
Pentanes plus	32.5%	27.5%	16.0%
MTHF	32.5%	17.5%	26.0%
Ethanol	35.0%	55.0%	47.0%
Butane	0.0%	0.0%	11.0%

CHART 67–1

P-series fuel varies in composition, depending on the octane rating and temperature.

? FREQUENTLY ASKED QUESTION

What Is a Tri-Fuel Vehicle?

In Brazil, most vehicles are designed to operate on ethanol or gasoline or any combination of the two. In this South American country, ethanol is made from sugarcane, is commonly available, and is lower in price than gasoline. Compressed natural gas (CNG) is also being made available so many vehicle manufacturers in Brazil, such as General Motors and Ford, are equipping vehicles to be capable of using gasoline, ethanol, or CNG. These vehicles are called tri-fuel vehicles.

P-SERIES FUELS

P-series alternative fuel is patented by Princeton University and is a non-petroleum- or natural gas-based fuel suitable for use in flexible fuel vehicles or any vehicle designed to operate on E85 (85% ethanol, 15% gasoline). P-series fuel is recognized by the United States Department of Energy as being an alternative fuel, but is not yet available to the public. P-series fuels are blends of the following:

- Ethanol (ethyl alcohol)
- Methyltetrahydrofuron, abbreviated MTHF
- Natural gas liquids, such as pentanes
- Butane

The ethanol and MTHF are produced from renewable feedstocks, such as corn, waste paper, biomass, agricultural waste, and wood waste (scraps and sawdust). The components used in P-type fuel can be varied to produce regular grade, premium grade, or fuel suitable for cold climates. ● **SEE CHART 67–1** for the percentages of the ingredients based on fuel grade.

● **SEE CHART 67–2** for a comparison of the most frequently used alternative fuels.

SYNTHETIC FUELS

Synthetic fuels can be made from a variety of products, using several different processes. Synthetic fuel must, however, make these alternatives practical only when conventional petroleum products are either very expensive or not available.

ALTERNATIVE FUEL COMPARISON CHART

CHARACTERISTIC	PROPANE	CNG	METHANOL	ETHANOL	REGULAR UNLEADED GAS
Octane	104	130	100	100	87–93
BTU per gallon	91,000	N.A.	70,000	83,000	114,000–125,000
Gallon equivalent	1.15	122 cubic feet—1 gallon of gasoline	1.8	1.5	1
On-board fuel storage	Liquid	Gas	Liquid	Liquid	Liquid
Miles/gallon as compared to gas	85%	N.A.	55%	70%	100%
Relative tank size required to yield driving range equivalent to gas	Tank is 1.25 times larger	Tank is 3.5 times larger	Tank is 1.8 times larger	Tank is 1.5 times larger	
Pressure	200 PSI	3,000–3,600 PSI	N.A.	N.A.	N.A.
Cold weather capability	Good	Good	Poor	Poor	Good
Vehicle power	5–10% power loss	10–20% power loss	4% power increase	5% power increase	Standard
Toxicity	Nontoxic	Nontoxic	Highly toxic	Toxic	Toxic
Corrosiveness	Noncorrosive	Noncorrosive	Corrosive	Corrosive	Minimally corrosive
Source	Natural gas/petroleum refining	Natural gas/crude oil	Natural gas/coal	Sugar and starch crops/biomass	Crude oil

CHART 67–2

The characteristics of alternative fuels compared to regular unleaded gasoline shows that all have advantages and disadvantages.

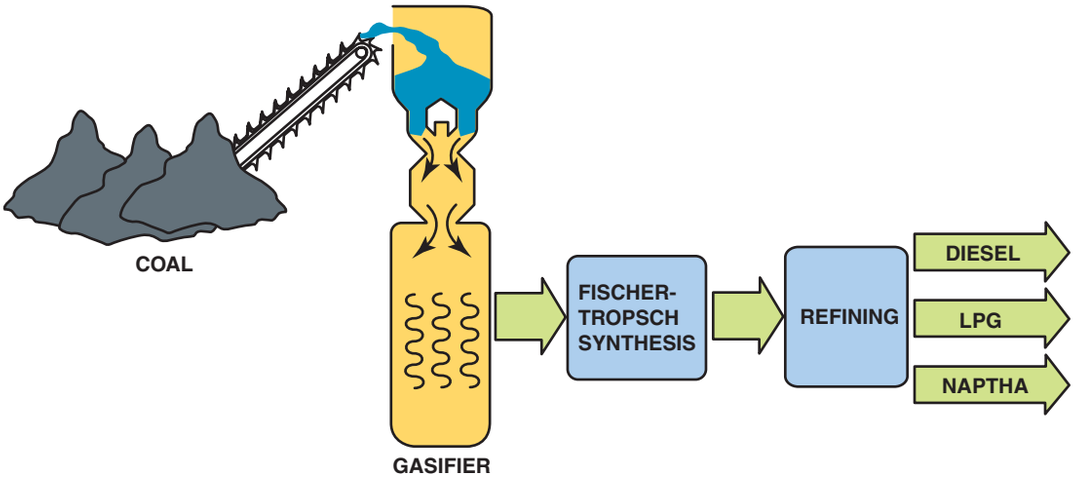


FIGURE 67–15 A Fischer-Tropsch processing plant is able to produce a variety of fuels from coal.

FISCHER-TROPSCH

Synthetic fuels were first developed using the **Fischer-Tropsch** method and have been in use since the 1920s to convert coal, natural gas, and other fossil fuel products into a fuel that is high in quality and clean-burning. The process for producing Fischer-Tropsch fuels was patented by two German scientists, Franz Fischer and Hans Tropsch, during World War I. The Fischer-Tropsch method uses carbon monoxide and hydrogen (the same synthesis gas used to produce hydrogen fuel) to convert coal and other hydrocarbons to liquid fuels in a process similar to hydrogenation, another method for hydrocarbon conversion. The process using natural gas, also called **gas-to-liquid (GTL)** technology, uses a catalyst, usually iron or cobalt, and incorporates steam re-forming to give off the by-products of carbon dioxide, hydrogen, and carbon monoxide. ● **SEE FIGURE 67–15.**

Whereas traditional fuels emit environmentally harmful particulates and chemicals, namely sulfur compounds, Fischer-Tropsch fuels combust with no soot or odors and emit only low levels of toxins. Fischer-Tropsch fuels can also be blended with traditional transportation fuels with little equipment modification, as they use the same engine and equipment technology as traditional fuels.

The fuels contain a very low sulfur and aromatic content and they produce virtually no particulate emissions. Researchers also expect reductions in hydrocarbon and carbon monoxide emissions. Fischer-Tropsch fuels do not differ in fuel performance from gasoline and diesel. At present, Fischer-Tropsch fuels are very expensive to produce on a large scale, although research is under way to lower processing costs. Diesel fuel created using the Fischer-Tropsch diesel (**FTD**) process is often called *GTL diesel*. GTL diesel can also be combined with petroleum diesel to produce a GTL blend. This fuel product is currently being sold in Europe and plans are in place to introduce it in North America.

COAL TO LIQUID (CTL)

Coal is very abundant in the United States and coal can be converted to a liquid fuel through a process called **coal to liquid (CTL).** The huge cost is the main obstacle to these plants. The need to invest $1.4 billion per plant before it can make

product is the reason no one has built a CTL plant yet in the United States. Investors need to be convinced that the cost of oil is going to remain high in order to get them to commit this kind of money.

A large plant might be able to produce 120,000 barrels of liquid fuel a day and would consume about 50,000 tons of coal per day. However, such a plant would create about 6,000 tons of CO_2 per day. These CO_2 emissions, which could contribute to global warming, and the cost involved make CTL a technology that is not likely to expand.

Two procedures can be used to convert coal-to-liquid fuel:

1. **Direct.** In the direct method, coal is broken down to create liquid products. First the coal is reacted with hydrogen (H_2) at high temperatures and pressure with a catalyst. This process creates a synthetic crude, called **syncrude,** which is then refined to produce gasoline or diesel fuel.
2. **Indirect.** In the indirect method, coal is first turned into a gas and the molecules are reassembled to create the desired product. This process involves turning coal into a gas called syn-gas. The syn-gas is then converted into liquid, using the Fischer-Tropsch (FT) process.

Russia has been using CTL by injecting air into the underground coal seams. Ignition is provided and the resulting gases are trapped and converted to liquid gasoline and diesel fuel through the Fischer-Tropsch process. This underground method is called **underground coal gasification (UCG).**

METHANOL TO GASOLINE

Exxon Mobil has developed a process for converting methanol (methyl alcohol) into gasoline in a process called **methanol-to-gasoline (MTG).** The MTG process was discovered by accident when a gasoline additive made from methanol was being created. The process instead created olefins (alkenes), paraffins (alkenes), and aromatic compounds, which in combination are known as gasoline. The process uses a catalyst and is currently being produced in New Zealand.

FUTURE OF SYNTHETIC FUELS

Producing gasoline and diesel fuels by other methods besides refining from crude oil has usually been more expensive. With the increasing cost of crude oil, alternative methods are now becoming economically feasible. Whether or not the diesel fuel or gasoline is created from coal, natural gas, or methanol, or created by refining crude oil, the transportation and service pumps are already in place. Compared to using compressed natural gas or other similar alternative fuels, synthetic fuels represent the lowest cost.

SAFETY PROCEDURES WHEN WORKING WITH ALTERNATIVE FUELS

All fuels are flammable and many are explosive under certain conditions. Whenever working around compressed gases of any kind (CNG, LNG, propane, or LPG), always wear personal protective equipment (PPE), including at least the following items:

1. Safety glasses and/or face shield.
2. Protective gloves.
3. Long-sleeved shirt and pants to help protect bare skin from the freezing effects of gases under pressure in the event that the pressure is lost.
4. If any fuel gets on the skin, the area should be washed immediately.
5. If fuel spills on clothing, change into clean clothing as soon as possible.
6. If fuel spills on a painted surface, flush the surface with water and air dry. If simply wiped off with a dry cloth, the paint surface could be permanently damaged.
7. As with any fuel-burning vehicle, always vent the exhaust to the outside. If methanol fuel is used, the exhaust contains *formaldehyde*, which has a sharp odor and can cause severe burning of the eyes, nose, and throat.



WARNING

Do not smoke or have an open flame in the area when working around or refueling any vehicle.

REVIEW QUESTIONS

1. Ethanol is also known by what other terms?
2. The majority of ethanol in the United States is made from what farm products?
3. How is a flexible fuel vehicle identified?
4. Methanol is also known by what other terms?
5. What other gases are often mixed with propane?
6. Why is it desirable to fill a compressed natural gas (CNG) vehicle with the highest pressure available?
7. P-series fuel is made of what products?
8. The Fischer-Tropsch method can be used to change what into gasoline?

CHAPTER QUIZ

1. Ethanol can be produced from what products?
   a. Switchgrass
   b. Corn
   c. Sugarcane
   d. Any of the above
2. E85 means that the fuel is made from _____.
   a. 85% gasoline, 15% ethanol
   b. 85% ethanol, 15% gasoline
   c. Ethanol that has 15% water
   d. Pure ethyl alcohol

3. A flex-fuel vehicle can be identified by _____.
   a. Emblems on the side, front, and/or rear of the vehicle
   b. VECI
   c. VIN
   d. Any of the above
4. Methanol is also called _____.
   a. Methyl alcohol **c.** Methyl hydrate
   b. Wood alcohol **d.** All of the above
5. Which alcohol is dangerous (toxic)?
   a. Methanol **c.** Both ethanol and methanol
   b. Ethanol **d.** Neither ethanol nor methanol
6. Which is the most widely used alternative fuel?
   a. E85 **c.** CNG
   b. Propane **d.** M85
7. Liquefied petroleum gas (LPG) is also called _____.
   a. E85 **c.** Propane
   b. M85 **d.** P-series fuel
8. How much compressed natural gas (CNG) does it require to achieve the energy of one gallon of gasoline?
   a. 130 cubic feet **c.** 105 cubic feet
   b. 122 cubic feet **d.** 91 cubic feet
9. When refueling a CNG vehicle, why is it recommended that the tank be filled to a high pressure?
   a. The range of the vehicle is increased
   b. The cost of the fuel is lower
   c. Less of the fuel is lost to evaporation
   d. Both a and c
10. Producing liquid fuel from coal or natural gas usually uses which process?
    a. Syncrude **c.** Fischer-Tropsch
    b. P-series **d.** Methanol to gasoline (MTG)

chapter 68 DIESEL AND BIODIESEL FUELS

OBJECTIVES: **After studying Chapter 68, the reader should be able to:** • Explain diesel fuel specifications. • List the advantages and disadvantages of biodiesel. • Discuss API gravity. • Explain E-diesel specifications.

KEY TERMS: API gravity 778 • ASTM 778 • B20 780 • Biodiesel 779 • Cetane number 777 • Cloud point 777 • Diesohol 780 • E-diesel 780 • Petrodiesel 780 • PPO 780 • SVO 780 • UCO 780 • ULSD 779 • WVO 780

DIESEL FUEL

FEATURES OF DIESEL FUEL

Diesel fuel must meet an entirely different set of standards than gasoline. Diesel fuel contains 12% more heat energy than the same amount of gasoline. The fuel in a diesel engine is not ignited with a spark, but is ignited by the heat generated by high compression. The pressure of compression (400 to 700 PSI or 2,800 to 4,800 kPa) generates temperatures of 1,200°F to 1,600°F (700°C to 900°C), which speeds the preflame reaction to start the ignition of fuel injected into the cylinder.

DIESEL FUEL REQUIREMENTS

All diesel fuel must have the following characteristics:

- **Cleanliness.** It is imperative that the fuel used in a diesel engine be clean and free from water. Unlike the case with gasoline engines, the fuel is the lubricant and coolant for the diesel injector pump and injectors. Good-quality diesel fuel contains additives such as oxidation inhibitors, detergents, dispersants, rust preventatives, and metal deactivators.
- **Low-temperature fluidity.** Diesel fuel must be able to flow freely at all expected ambient temperatures. One specification for diesel fuel is its "pour point," which is the temperature below which the fuel would stop flowing.
- **Cloud point** is another concern with diesel fuel at lower temperatures. **Cloud point** is the low-temperature point when the waxes present in most diesel fuels tend to form crystals that can clog the fuel filter. Most diesel fuel suppliers distribute fuel with the proper pour point and cloud point for the climate conditions of the area.

CETANE NUMBER

The cetane number for diesel fuel is the opposite of the octane number for gasoline. The **cetane number** is a measure of the ease with which the fuel can be ignited. The cetane rating of the fuel determines, to a great extent, its ability to start the engine at low temperatures and to provide smooth warm-up and even combustion. The cetane rating of diesel fuel should be between 45 and 50. The higher the cetane rating, the more easily the fuel is ignited.

SULFUR CONTENT

The sulfur content of diesel fuel is very important to the life of the engine. Sulfur in the fuel creates sulfuric



(a)



(b)

FIGURE 68–1 (a) Regular diesel fuel on the left has a clear or greenish tint, whereas fuel for off-road use is tinted red for identification. (b) A fuel pump in a farming area that clearly states the red diesel fuel is for off-road use only.

acid during the combustion process, which can damage engine components and cause piston ring wear. Federal regulations are getting extremely tight on sulfur content to less than 15 parts per million (ppm). High-sulfur fuel contributes to acid rain.

DIESEL FUEL COLOR

Diesel fuel intended for use on the streets and highways is clear or green in color. Diesel fuel to be used on farms and off-road use is dyed red. ● **SEE FIGURE 68–1.**

GRADES OF DIESEL FUEL

American Society for Testing Materials (ASTM) also classifies diesel fuel by volatility (boiling range) into the following grades:

GRADE #1 This grade of diesel fuel has the lowest boiling point and the lowest cloud and pour points, as well as a lower BTU content—less heat per pound of fuel. As a result, grade #1 is suitable for use during low-temperature (winter) operation. Grade #1 produces less heat per pound of fuel compared to grade #2 and may be specified for use in diesel engines involved in frequent changes in load and speed, such as those found in city buses and delivery trucks.

? FREQUENTLY ASKED QUESTION

How Can You Tell If Gasoline Has Been Added to the Diesel Fuel by Mistake?

If gasoline has been accidentally added to diesel fuel and is burned in a diesel engine, the result can be very damaging to the engine. The gasoline can ignite faster than diesel fuel, which would tend to increase the temperature of combustion. This high temperature can harm injectors and glow plugs, as well as pistons, head gaskets, and other major diesel engine components. If contaminated fuel is suspected, first smell the fuel at the filler neck. If the fuel smells like gasoline, then the tank should be drained and refilled with diesel fuel. If the smell test does not indicate a gasoline smell (or any rancid smell), then test a sample for proper API gravity.

NOTE: Diesel fuel designed for on-road use should be green in color. Red diesel fuel (high sulfur) should be found only in off-road or farm equipment.

GRADE #2 This grade has a higher boiling point, cloud point, and pour point as compared with grade #1. It is usually specified where constant speed and high loads are encountered, such as in long-haul trucking and automotive diesel applications. Most diesel is Grade #2.

DIESEL FUEL SPECIFIC GRAVITY TESTING

The density of diesel fuel should be tested whenever there is a driveability concern. The density or specific gravity of diesel fuel is measured in units of **API gravity.** API gravity is an arbitrary scale expressing the gravity or density of liquid petroleum products devised jointly by the American Petroleum Institute and the National Bureau of Standards. The measuring scale is calibrated in terms of degrees API. Oil with the least specific gravity has the highest API gravity. The formula for determining API gravity is as follows:

Degrees API gravity = (141.5 ÷ specific gravity at 60°F) − 131.5

The normal API gravity for #1 diesel fuel is 39 to 44 (typically 40). The normal API gravity for #2 diesel fuel is 30 to 39 (typically 35). A hydrometer calibrated in API gravity units should be used to test diesel fuel. ● **SEE FIGURE 68–2.**

● **SEE CHART 68–1** for a comparison among specific gravity, weight density, pounds per gallon, and API gravity of diesel fuel.

DIESEL FUEL HEATERS

Diesel fuel heaters, either coolant or electric, help prevent power loss and stalling in cold weather. The heater is placed in the fuel line between the tank and the primary filter. Some coolant heaters are thermostatically controlled, which allows fuel to bypass the heater once it has reached operating temperature. ● **SEE FIGURE 68–3.**

ULTRA-LOW-SULFUR DIESEL FUEL

Diesel fuel is used in diesel engines and is usually readily available throughout the United States, Canada, and Europe, where many more cars are equipped with diesel engines. Diesel engines manufactured to 2007 or newer standards must use ultra-low-sulfur diesel fuel containing less than 15 ppm of sulfur compared to the older, low-sulfur specification of 500 ppm. The purpose of the lower sulfur amount in diesel fuel is to

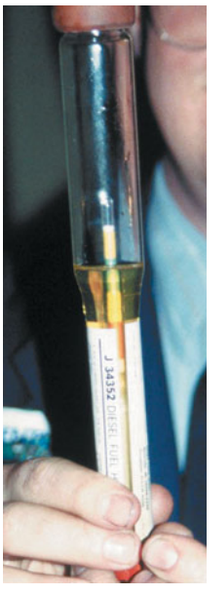


FIGURE 68–2 Testing the API viscosity of a diesel fuel sample using a hydrometer.

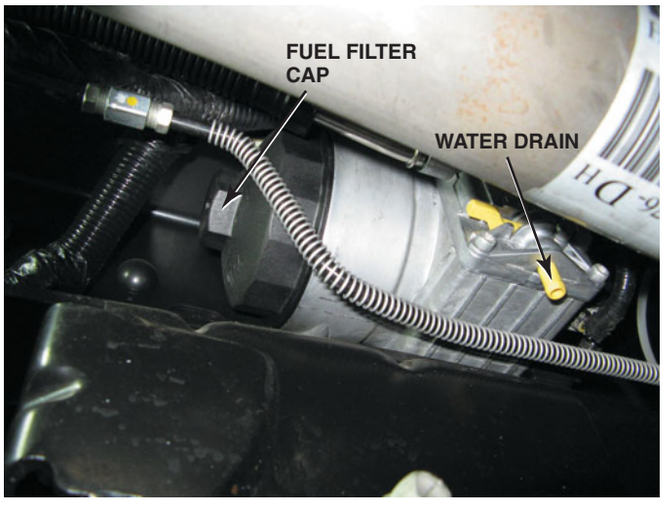


FIGURE 68–3 A fuel heater is part of the fuel filter and water separator located on the frame rail of a Ford pickup truck equipped with a PowerStroke 6.0 liter V-8 diesel engine.

reduce emissions of sulfur oxides (SO_x) and particulate matter (PM) from heavy-duty highway engines and vehicles that use diesel fuel. The emission controls used on 2007 and newer diesel engines require the use of **ultra-low-sulfur diesel (ULSD)** for reliable operation.

Ultra-low-sulfur diesel (ULSD) will eventually replace the current highway diesel fuel, low-sulfur diesel, which can have as much as 500 ppm of sulfur. ULSD is required for use in all model year 2007 and newer vehicles equipped with advanced emission control systems. ULSD looks lighter in color and has less smell than other diesel fuel.

BIODIESEL

DEFINITION OF BIODIESEL

Biodiesel is a domestically produced, renewable fuel that can be manufactured from vegetable oils, animal fats, or recycled restaurant greases. Biodiesel is safe, biodegradable, and reduces serious air pollutants such as particulate matter (PM), carbon monoxide, and hydrocarbons. Biodiesel is

API GRAVITY COMPARISON CHART

Values for API Scale Oil

API GRAVITY SCALE	SPECIFIC GRAVITY	WEIGHT DENSITY, LB/FT	POUNDS PER GALLON
0			
2			
4			
6			
8			
10	1.0000	62.36	8.337
12	0.9861	61.50	8.221
14	0.9725	60.65	8.108
16	0.9593	59.83	7.998
18	0.9465	59.03	7.891
20	0.9340	58.25	7.787
22	0.9218	57.87	7.736
24	0.9100	56.75	7.587
26	0.8984	56.03	7.490
28	0.8871	55.32	7.396
30	0.8762	54.64	7.305
32	0.8654	53.97	7.215
34	0.8550	53.32	7.128
36	0.8448	52.69	7.043
38	0.8348	51.06	6.960
40	0.8251	50.96	6.879
42	0.8155	50.86	6.799
44	0.8030	50.28	6.722
46	0.7972	49.72	6.646
48	0.7883	49.16	6.572
50	0.7796	48.62	6.499
52	0.7711	48.09	6.429
54	0.7628	47.57	6.359
56	0.7547	47.07	6.292
58	0.7467	46.57	6.225
60	0.7389	46.08	6.160
62	0.7313	45.61	6.097
64	0.7238	45.14	6.034
66	0.7165	44.68	5.973
68	0.7093	44.23	5.913
70	0.7022	43.79	5.854
72	0.6953	43.36	5.797
74	0.6886	42.94	5.741
76	0.6819	42.53	5.685
78	0.6754	41.12	5.631
80	0.6690	41.72	5.577
82	0.6628	41.33	5.526
84	0.6566	40.95	5.474
86	0.6506	40.57	5.424
88	0.6446	40.20	5.374
90	0.6388	39.84	5.326
92	0.6331	39.48	5.278
94	0.6275	39.13	5.231
96	0.6220	38.79	5.186
98	0.6116	38.45	5.141
100	0.6112	38.12	5.096

CHART 68–1

The API gravity scale is based on the specific gravity of the fuel.



FIGURE 68–4 A pump decal indicating that the biodiesel fuel is ultra-low-sulfur diesel (ULSD) and must be used in 2007 and newer diesel vehicles.

defined as mono-alkyl esters of long-chain fatty acids derived from vegetable oils or animal fats which conform to ASTM D6751 specifications for use in diesel engines. Biodiesel refers to the pure fuel before blending with diesel fuel. ● **SEE FIGURE 68–4.**

BIODIESEL BLENDS Biodiesel blends are denoted as "BXX" with "XX" representing the percentage of biodiesel contained in the blend (i.e., **B20** is 20% biodiesel, 80% petroleum diesel). Blends of 20% biodiesel with 80% petroleum diesel (B20) can generally be used in unmodified diesel engines; however, users should consult their OEM and engine warranty statement. Biodiesel can also be used in its pure form (B100), but it may require certain engine modifications to avoid maintenance and performance problems and may not be suitable for wintertime use. Most diesel engine or vehicle manufacturers of diesel vehicles allow the use of B5 (5% biodiesel). For example, Cummins, used in Dodge trucks, allows the use of B20 only if the optional extra fuel filter has been installed. Users should consult their engine warranty statement for more information on fuel blends of greater than 20% biodiesel.

In general, B20 costs 30 to 40 cents more per gallon than conventional diesel. Although biodiesel costs more than regular diesel fuel, often called **petrodiesel,** fleet managers can make the switch to alternative fuels without purchasing new vehicles, acquiring new spare parts inventories, rebuilding refueling stations, or hiring new service technicians.

FEATURES OF BIODIESEL Biodiesel has the following characteristics:

1. Purchasing biodiesel in bulk quantities decreases the cost of fuel.
2. Biodiesel maintains similar horsepower, torque, and fuel economy.
3. Biodiesel has a higher cetane number than conventional diesel, which increases the engine's performance.
4. It is nontoxic, which makes it safe to handle, transport, and store. Maintenance requirements for B20 vehicles and petrodiesel vehicles are the same.
5. Biodiesel acts as a lubricant and this can add to the life of the fuel system components.

NOTE: For additional information on biodiesel and the locations where it can be purchased, visit www.biodiesel.org.

? FREQUENTLY ASKED QUESTION

I Thought Biodiesel Was Vegetable Oil?

Biodiesel is vegetable oil with the glycerin component removed by means of reacting the vegetable oil with a catalyst. The resulting hydrocarbon esters are 16 to 18 carbon atoms in length, almost identical to the petroleum diesel fuel atoms. This allows the use of biodiesel fuel in a diesel engine with no modifications needed. Biodiesel-powered vehicles do not *need* a second fuel tank, whereas vegetable-oil-powered vehicles do. There are three main types of fuel used in diesel engines. These are:

- Petroleum diesel, a fossil hydrocarbon with a carbon chain length of about 16 carbon atoms.
- Biodiesel, a hydrocarbon with a carbon chain length of 16 to 18 carbon atoms.
- Vegetable oil is a triglyceride with a glycerin component joining three hydrocarbon chains of 16 to 18 carbon atoms each, called **straight vegetable oil (SVO).** Other terms used when describing vegetable oil include:
  - **Pure plant oil (PPO)**—a term most often used in Europe to describe SVO
  - **Waste vegetable oil (WVO)**—this oil could include animal or fish oils from cooking
  - **Used cooking oil (UCO)**—a term used when the oil may or may not be pure vegetable oil

Vegetable oil is not liquid enough at common ambient temperatures for use in a diesel engine fuel delivery system designed for the lower-viscosity petroleum diesel fuel. Vegetable oil needs to be heated to obtain a similar viscosity to biodiesel and petroleum diesel. This means that a heat source needs to be provided before the fuel can be used in a diesel engine. This is achieved by starting on petroleum diesel or biodiesel fuel until the engine heat can be used to sufficiently warm a tank containing the vegetable oil. It also requires purging the fuel system of vegetable oil with petroleum diesel or biodiesel fuel prior to stopping the engine to avoid the vegetable oil's thickening and solidifying in the fuel system away from the heated tank. The use of vegetable oil in its natural state does, however, eliminate the need to remove the glycerin component. Many vehicle and diesel engine fuel system suppliers permit the use of biodiesel fuel that is certified as meeting testing standards. None permit the use of vegetable oil in its natural state.

E-DIESEL FUEL

DEFINITION OF E-DIESEL **E-diesel,** also called **diesohol** outside of the United States, is standard No. 2 diesel fuel that contains up to 15% ethanol. While E-diesel can have up to 15% ethanol by volume, typical blend levels are from 8% to 10%.

CETANE RATING OF E-DIESEL The higher the cetane number, the shorter the delay between injection and ignition. Normal diesel fuel has a cetane number of about 50. Adding 15% ethanol lowers the cetane number. To increase the cetane number back

to that of conventional diesel fuel, a cetane-enhancing additive is added to E-diesel. The additive used to increase the cetane rating of E-diesel is ethylhexylnitrate or ditertbutyl peroxide.

E-diesel has better cold-flow properties than conventional diesel. The heat content of E-diesel is about 6% less than conventional diesel, but the particulate matter (PM) emissions are reduced by as much as 40%, 20% less carbon monoxide, and a 5% reduction in oxides of nitrogen (NOX).

Currently, E-diesel is considered to be experimental and can be used legally in off-road applications or in mass-transit buses with EPA approval. For additional information, visit www.e-diesel.org.

REVIEW QUESTIONS

1. What is meant by the cloud point?
2. What is ultra-low-sulfur diesel?
3. Biodiesel blends are identified by what designation?

CHAPTER QUIZ

1. What color is diesel fuel dyed if it is for off-road use only?
   a. Red **c.** Blue
   b. Green **d.** Yellow
2. What clogs fuel filters when the temperature is low on a vehicle that uses diesel fuel?
   a. Alcohol **c.** Wax
   b. Sulfur **d.** Cetane
3. The specific gravity of diesel fuel is measured in what units?
   a. Hydrometer units **c.** Grade number
   b. API gravity **d.** Cetane number
4. What rating of diesel fuel indicates how well a diesel engine will start?
   a. Specific gravity rating **c.** Cloud point
   b. Sulfur content **d.** Cetane rating
5. Ultra-low-sulfur diesel fuel has how much sulfur content?
   a. 15 ppm **c.** 500 ppm
   b. 50 ppm **d.** 1,500 ppm
6. E-diesel is diesel fuel with what additive?
   a. Methanol **c.** Ethanol
   b. Sulfur **d.** Vegetable oil
7. Biodiesel is regular diesel fuel with vegetable oil added.
   a. True **b.** False
8. B20 biodiesel has how much regular diesel fuel?
   a. 20% **c.** 80%
   b. 40% **d.** 100%
9. Most diesel fuel is what grade?
   a. Grade #1 **c.** Grade #3
   b. Grade #2 **d.** Grade #4
10. Most manufacturers of vehicles equipped with diesel engines allow what type of biodiesel?
    a. B100 **c.** B20
    b. B80 **d.** B5

chapter 69

IGNITION SYSTEM COMPONENTS AND OPERATION

OBJECTIVES: **After studying Chapter 69, the reader will be able to:** • Prepare for ASE Engine Performance (A8) certification test content area “B” (Ignition System Diagnosis and Repair). • Explain how ignition coils create 40,000 volts. • Discuss crankshaft position sensor and pickup coil operation. • Describe the operation of waste-spark and coil-on-plug ignition systems.

KEY TERMS: Bypass ignition 792 • Companion (paired) cylinder 787 • Compression-sensing ignition 788 • COP ignition 788 • Detonation 791 • DI 782 • DIS 787 • Dwell 792 • EI 782 • EMI 788 • EST 792 • Firing order 786 • Hall effect 784 • High voltage 786 • IC 792 • ICM 791 • Ion-sensing ignition 790 • Low voltage 786 • Knock sensors 791 • Magnetic sensor 784 • Optical sensors 785 • Paired cylinders 785 • Pickup coil 784 • Ping 791 • Primary winding 783 • Pulse generator 784 • Secondary winding 783 • Schmitt trigger 785 • Spark knock 791 • SPOUT 792 • Switching 783 • Transistor 784 • Trigger 784 • Turns ratio 783 • Up-integrated ignition 793

IGNITION SYSTEM

PURPOSE AND FUNCTION The ignition system includes components and wiring necessary to create and distribute a high voltage (up to 40,000 volts or more) and send to the spark plug at the correct time. A high-voltage arc occurs across the gap of a spark plug inside the combustion chamber. The spark raises the temperature of the air-fuel mixture and starts the combustion process inside the cylinder.

BACKGROUND All ignition systems apply battery voltage (close to 12 volts) to the positive side of the ignition coil(s) and pulse the negative side to ground on and off.

- **Early ignition systems.** Before the mid-1970s, ignition systems used a mechanically opened set of contact points to make and break the electrical connection to ground. A cam lobe, located in and driven by the distributor, opened the points. There was one lobe for each cylinder. The points used a rubbing block that was lubricated by applying a thin layer of grease on the cam lobe at each service interval. Each time the points opened, a spark was created in the ignition coil. The high-voltage spark then traveled to each spark plug through the distributor cap and rotor and the spark plug wires. The distributor was used twice in the creation of the spark.
  - First, it connected to the camshaft that rotated the distributor cam causing the points to open and close.
  - Second, it used a rotor to direct the high-voltage spark from the coil entering the center of the distributor cap to inserts connected to spark plug wires to each cylinder.

  SEE FIGURE 69–1.
- **Electronic ignition.** Since the mid-1970s, ignition systems have used sensors, such as a pickup coil and reluctor (trigger wheel), to trigger or signal an electronic module that switches the primary ground circuit of the ignition coil. **Distributor ignition (DI)** is the term specified by the Society of Automotive Engineers (SAE) for an ignition system that uses a distributor. **Electronic ignition (EI)** is the term specified by the SAE for an ignition system that does not use a distributor. Types of EI systems include:
  1. **Waste-spark system.** This type of system uses one ignition coil to fire the spark plugs for two cylinders at the same time.
  2. **Coil-on-plug system.** This type of system uses a single ignition coil for each cylinder with the coil placed above or near the spark plug.

IGNITION COIL OPERATION In an ignition coil there are two windings:

- Primary winding
- Secondary winding

All ignition systems use electromagnetic induction to produce a high-voltage spark from the ignition coil. Electromagnetic induction means that a current can be created in a conductor (coil winding) by a moving magnetic field. Current flowing through the primary winding of the coil produces the magnetic field in an ignition coil. An ignition coil is able to increase battery voltage to 40,000 volts or more in the following way.

- Battery voltage is applied to the primary winding.
- A ground is provided to the primary winding by the ignition control module (ICM), igniter, or powertrain control module (PCM).

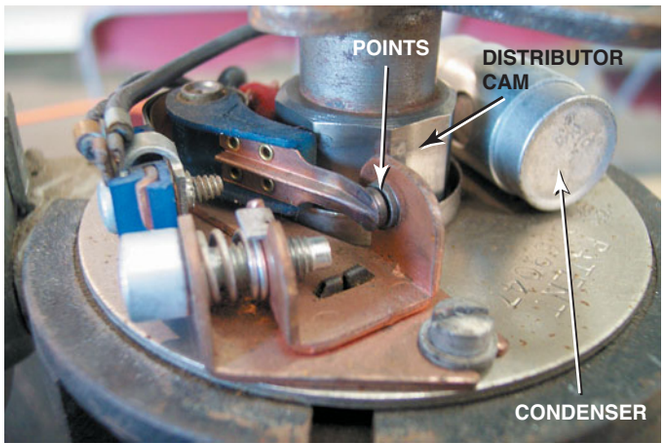


FIGURE 69–1 A point-type distributor from a hot rod being tested on a distributor machine.

- Current (approximately 2 to 6 amperes) flows in the primary coil creating a magnetic field.
- When the ground is opened by the ICM, the primary circuit is turned off and the built-up magnetic field in the secondary winding collapses.
- The movement of the collapsing magnetic field induces a voltage of 250 to 400 volts in the primary winding and 20,000 to 40,000 volts or more in the secondary winding with a current of 0.02 to 0.08 amperes (20 to 80 mA).
- The high voltage created in the secondary winding is high enough to jump the air gap at the spark plug.
- The electrical arc at the spark plug ignites the air-fuel mixture in the combustion chamber of the engine.
- For each spark that occurs, the coil must be charged with a magnetic field and then discharged.

WARNING

The spark from an ignition coil is strong enough to cause physical injury. Always follow the exact service procedure and avoid placing hands near the secondary ignition components when the engine is running.

The ignition components in the coil primary winding are known collectively as the primary ignition circuit.

- When the primary circuit is carrying current, the secondary circuit is off.
- When the primary circuit is turned off, the secondary circuit has high voltage.
- The components necessary to create and distribute the high voltage produced in the secondary windings of the coil are called the secondary ignition circuit. **SEE FIGURE 69–2.**

These circuits include the following components.

- Primary ignition circuit
  1. Battery
  2. Ignition switch
  3. Primary winding of coil
  4. Pickup coil (if distributor ignition)

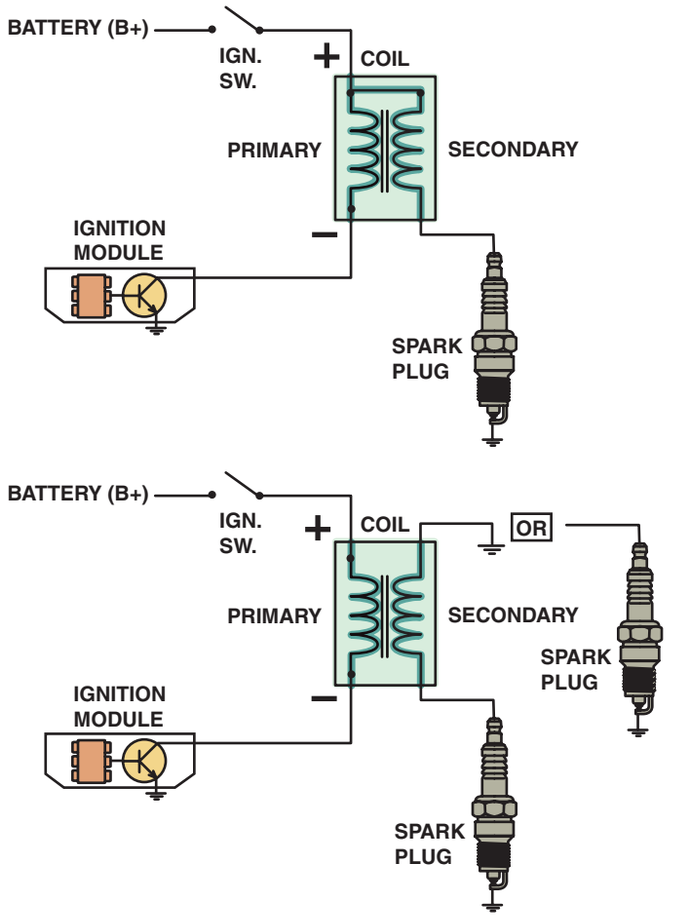


FIGURE 69–2 The primary ignition system is used to trigger and therefore create the secondary (high-voltage) spark from the ignition coil. Some ignition coils are electrically connected, called married (top figure) whereas others use separated primary and secondary windings, called divorced (lower figure).

5. Crankshaft position sensor (CKP)
6. Ignition control module (ICM) or igniter

- Secondary ignition circuit

1. Secondary winding of coil
2. Distributor cap and rotor (if the vehicle is so equipped)
3. Spark plug wires
4. Spark plugs

IGNITION COIL CONSTRUCTION Many ignition coils contain two separate but electrically connected windings of copper wire. Other coils are true transformers in which the primary and secondary windings are not electrically connected. ● **SEE FIGURE 69–3.**

The center of an ignition coil contains a core of laminated soft iron (thin strips of soft iron). This core increases the magnetic strength of the coil.

- **Secondary winding.** Surrounding the laminated core are approximately 20,000 turns of fine wire (approximately 42 gauge), which is smaller than a human hair. The winding is called the **secondary** coil winding.
- **Primary winding.** Surrounding the secondary windings are approximately 150 turns of heavy wire (approximately 21 gauge), which is about 0.028 inch in diameter. The winding is called the **primary** coil winding. The secondary winding has about 100 times the number of turns of the primary winding, referred to as the **turns ratio** (approximately 100:1).

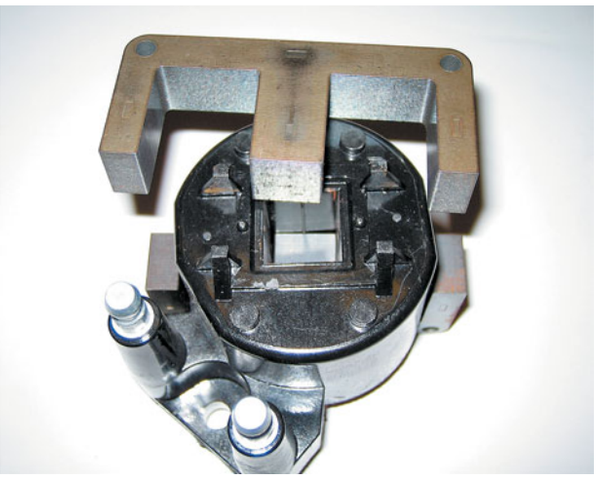


FIGURE 69–3 The steel laminations used in an E coil helps increase the magnetic field strength, which helps the coil produce higher energy output for a more complete combustion in the cylinders.

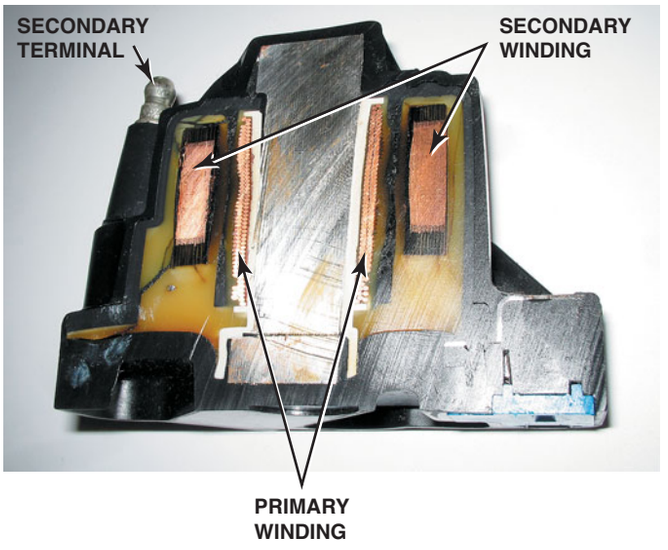


FIGURE 69–4 The primary windings are inside the secondary windings on this General Motors coil.

In older coils, these windings are surrounded with a thin metal shield and insulating paper and placed into a metal container filled with transformer oil to help cool the coil windings. Other coil designs use an air-cooled, epoxy-sealed E coil. The *E coil* is so named because the laminated, soft iron core is E shaped, with the coil wire turns wrapped around the center "finger" of the E and the primary winding wrapped inside the secondary winding. ● **SEE FIGURES 69–4 AND 69–5.**

IGNITION SWITCHING AND TRIGGERING

SWITCHING For any ignition system to function, the primary current must be turned on to charge the coil and off to allow the coil to discharge, creating a high-voltage spark. This turning on and off of the primary circuit is called **switching.** The unit that does the

switching is an electronic switch, such as a power transistor. This power transistor can be located in either of the following locations.

- In the ICM or igniter
- In the PCM (computer)

NOTE: On some coil-on-plug systems, the ICM is part of the ignition coil itself and is serviced as an assembly.

PRIMARY CIRCUIT OPERATION

The device that signals the switching of the coil on and off or just on in most instances is called the **trigger.** A trigger is typically a pickup coil in some distributor-type ignitions and a crankshaft position sensor (CKP) on electronic systems (waste-spark and coil-on-plug systems). To get a spark out of an ignition coil, the primary coil circuit must be turned on and off.

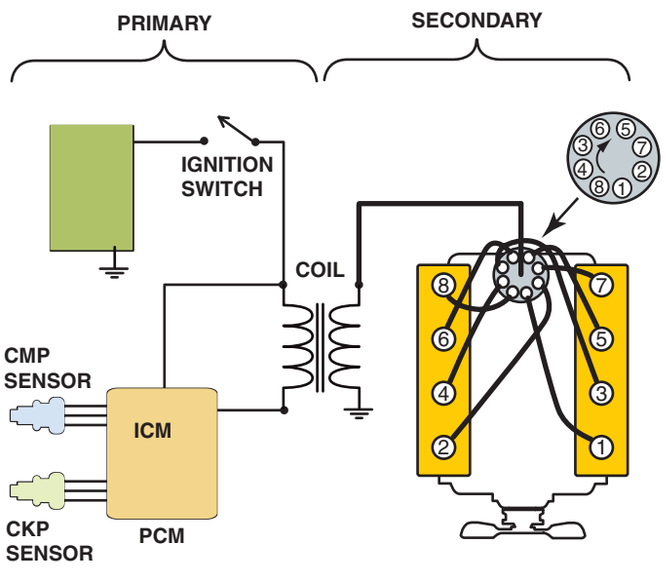


FIGURE 69–5 The primary ignition system is used to trigger and therefore create the secondary (high-voltage) spark from the ignition coil.

The primary circuit current switching is controlled by a **transistor** (electronic switch) inside the ignition module or igniter, and is controlled by one of the following devices.

- **Magnetic sensor.** A simple and common ignition electronic switching device is the magnetic pulse generator system. This type of magnetic sensor is often called a magnetic **pulse generator** or **pickup coil,** and is installed in the distributor housing. The pulse generator consists of a trigger wheel (reluctor) and a pickup coil. The pickup coil consists of an iron core wrapped with fine wire, in a coil at one end and attached to a permanent magnet at the other end. The center of the coil is called the pole piece. The pickup coil signal triggers the transistor inside the module and is also used by the computer for piston position information and engine speed (RPM). The reluctor is shaped so that the magnetic strength changes enough to create a usable varying signal for use by the module to trigger the coil. A magnetic pickup coil produces an analog AC signal. **SEE FIGURE 69–6.**

  Magnetic crankshaft position sensors use the changing strength of the magnetic field surrounding a coil of wire to signal the ICM and PCM. This signal is used by the electronics in the ignition module and computer to determine piston position and engine speed (RPM). This sensor operates similarly to the distributor magnetic pickup coil. The crankshaft position sensor uses the strength of the magnetic field surrounding a coil of wire to signal the ICM. The rotating crankshaft has notches cut into it that trigger the magnetic position sensor, which change the strength of the magnetic field as the notches pass by the position sensor, creating an AC analog signal. **SEE FIGURE 69–7.**

- **Hall-effect switch.** This switch also uses a stationary sensor and rotating trigger wheel (shutter). Unlike the magnetic pulse generator, the Hall-effect switch requires a small input voltage to generate an output or signal voltage. **Hall effect** has the ability to generate a voltage signal in semiconductor material (gallium arsenate crystal) by passing

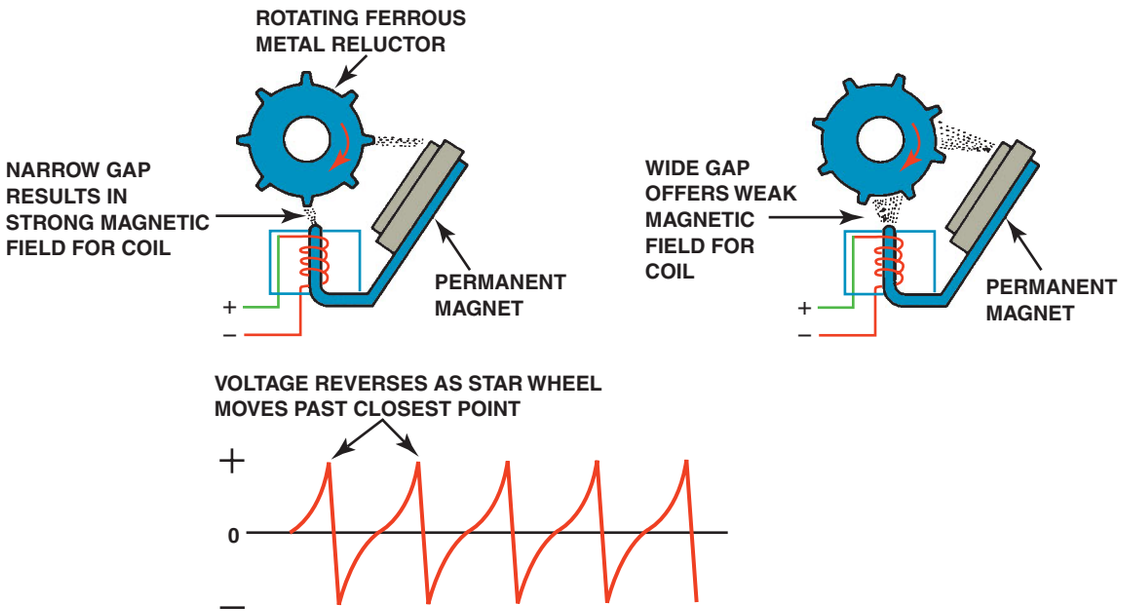


FIGURE 69–6 Operation of a typical pulse generator (pickup coil). At the bottom is a line drawing of a typical scope pattern of the output voltage of a pickup coil. The ICM receives this voltage from the pickup coil and opens the ground circuit to the ignition coil when the voltage starts down from its peak (just as the reluctor teeth start moving away from the pickup coil).

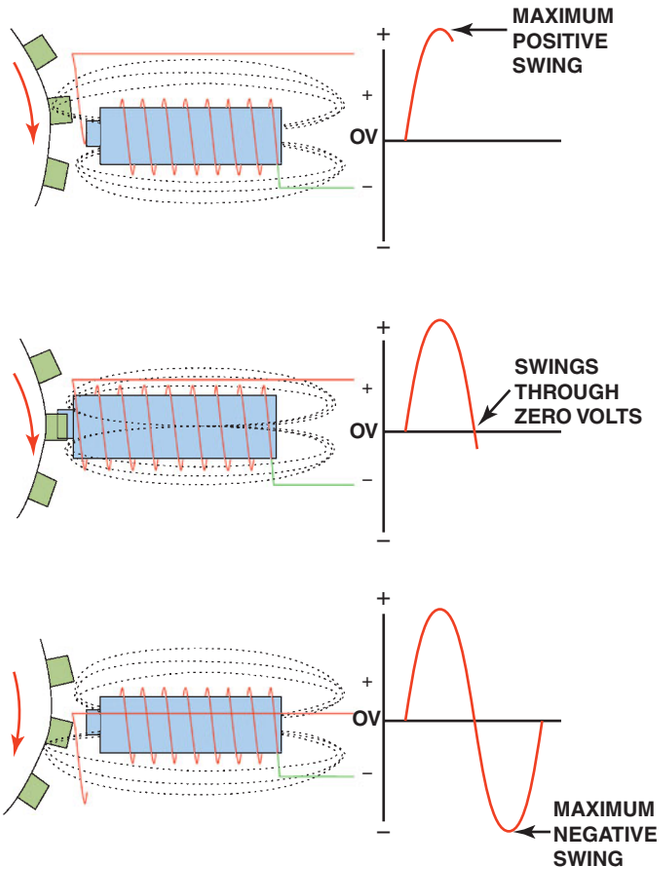


FIGURE 69–7 A magnetic sensor uses a permanent magnet surrounded by a coil of wire. The notches of the crankshaft (or camshaft) create a variable magnetic field strength around the coil. When a metallic section is close to the sensor, the magnetic field is stronger because metal is a better conductor of magnetic lines of force than air.

current through it in one direction and applying a magnetic field to it at a right angle to its surface. If the input current is held steady and the magnetic field fluctuates, an output voltage is produced that changes in proportion to field strength. Most Hall-effect switches used in distributors have the following:

1. Hall element or device
2. Permanent magnet
3. Rotating ring of metal blades (shutters) similar to a trigger wheel (Another method uses a stationary sensor with a rotating magnet.) ● **SEE FIGURE 69–8**.

Some blades are designed to hang down, typically found in Bosch and Chrysler systems; others may be on a separate ring on the distributor shaft, typically found in General Motors and Ford Hall-effect distributors.

- When the shutter blade enters the gap between the magnet and the Hall element, it creates a magnetic shunt that changes the field strength through the Hall element.
- This analog signal is sent to a **Schmitt trigger** inside the sensor itself, which converts the analog signal into a digital signal. A digital (on or off) voltage signal is created at a varying frequency to the ignition module or onboard computer. ● **SEE FIGURE 69–9.**
- **Optical sensors.** This type of sensor uses light from an LED and a phototransistor to signal the computer. An interrupter disc between the LED and the phototransistor has slits that allow the light from the LED to trigger the phototransistor on the other side of the disc. Most optical sensors (usually located inside the distributor) use two rows of slits to provide individual cylinder recognition (low-resolution) and precise distributor angle recognition (high-resolution) signals that are used for cylinder misfire detection. ● **SEE FIGURE 69–10.**

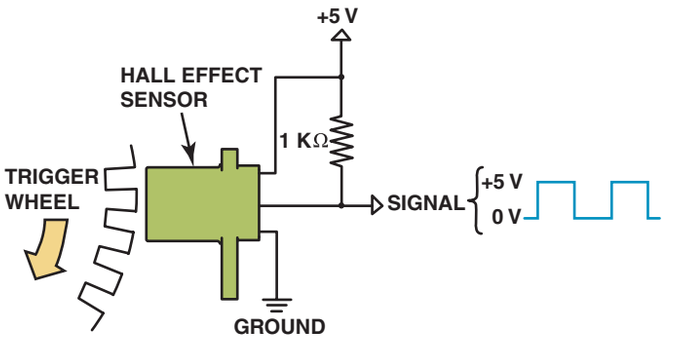


FIGURE 69–8 A Hall-effect sensor produces an on-off voltage signal whether it is used with a blade or a notched wheel.

TECH TIP

The Tachometer Trick

When diagnosing a no-start or intermediate misfiring condition, check the operation of the tachometer. If the tachometer does not indicate engine speed (no-start condition) or drops toward zero (engine missing), then the problem is due to a defect in the *primary* ignition circuit. The tachometer gets its signal from the pulsing of the primary winding of the ignition coil. The following components in the primary circuit could cause the tachometer to not work when the engine is cranking.

- Pickup coil
- Crankshaft position (CKP) sensor
- Ignition control module (ICM) or igniter
- Coil primary wiring

If the vehicle is not equipped with a tachometer, use a scan tool to look at engine RPM. Results:

- No or an unstable engine RPM reading means the problem is in the primary ignition circuit.
- A steady engine RPM reading means the problem is in the secondary ignition circuit or is a fuel-related problem.

DISTRIBUTOR IGNITION

PURPOSE AND FUNCTION The purpose of a distributor is to distribute the high-voltage spark from the secondary terminal of the ignition coil to the spark plugs for each cylinder. A gear or shaft that is part of the distributor is meshed with a gear on the camshaft. The distributor is driven at camshaft speed (one-half of crankshaft speed).

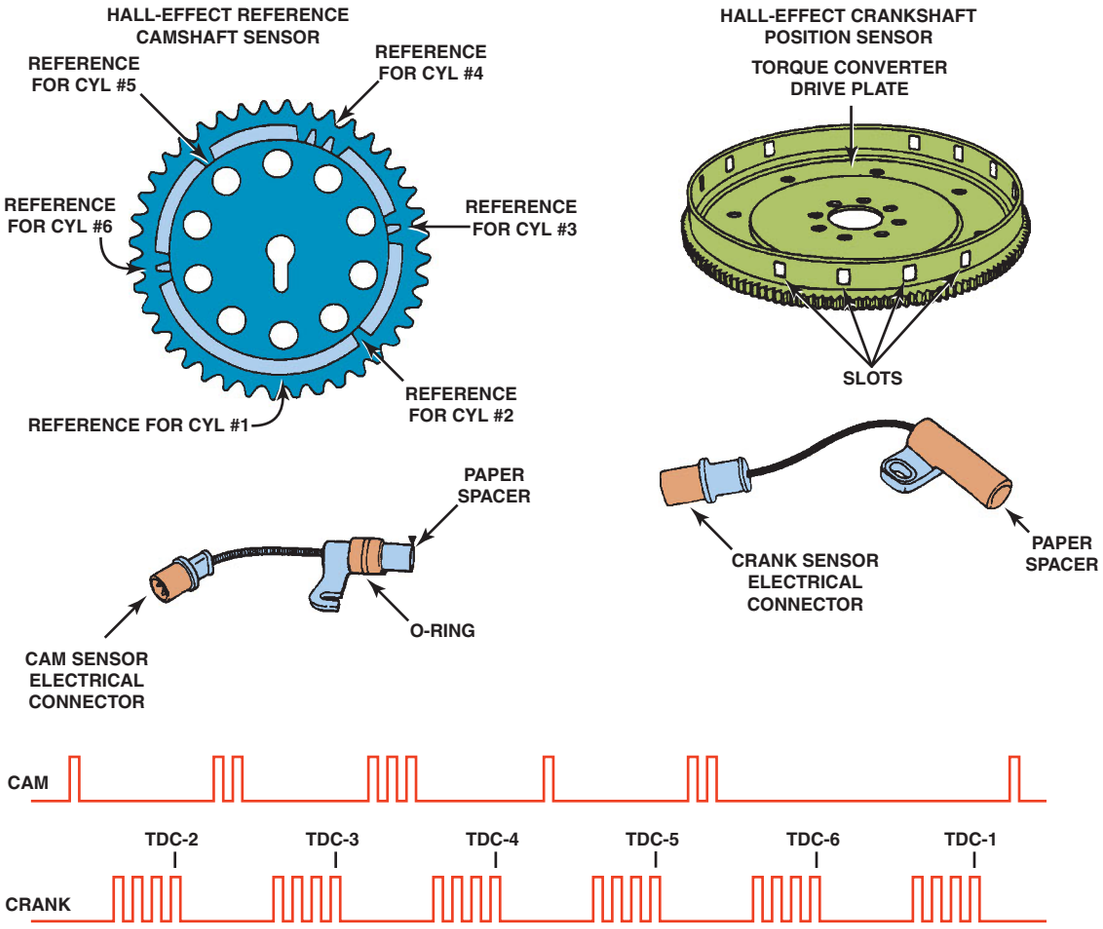


FIGURE 69–9 Some Hall-effect sensors look like magnetic sensors. This Hall-effect camshaft reference sensor and crankshaft position sensor have an electronic circuit built in that creates a 0 to 5 volt signal as shown at the bottom. These Hall-effect sensors have three wires: a power supply (8 volts) from the computer (controller), a signal (0 to 5 volts), and a signal ground.

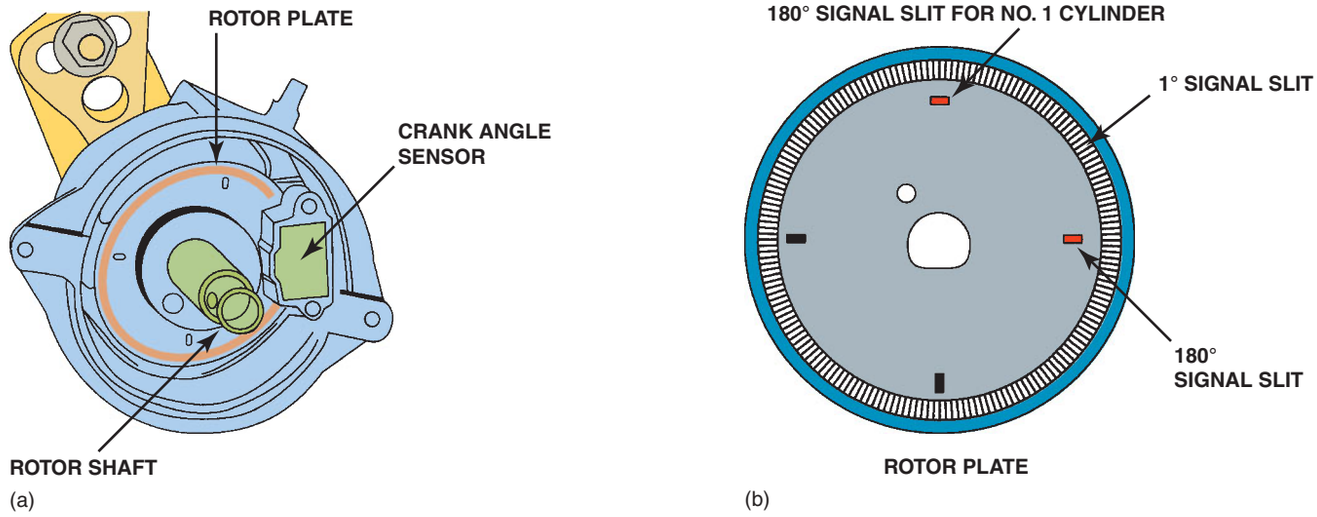


FIGURE 69–10 (a) Typical optical distributor. (b) Cylinder I slit signals the computer the piston position for cylinder I. The 1-degree slits provide accurate engine speed information to the PCM.

Most distributor ignition systems also use a sensor to trigger the ignition control module.

OPERATION OF DISTRIBUTOR IGNITION

The distributor is used twice in most ignition systems that use one.

- The first time is when the **low voltage** triggers the ignition control module (ICM) by the use of the rotating distributor shaft.
- The second time is when the **high voltage** is directed by rotating the rotor to distribute the high-voltage spark to the individual spark plugs.

FIRING ORDER

Firing order means the order that the spark is distributed to the correct spark plug at the right time. The firing order of an engine is determined by crankshaft and camshaft

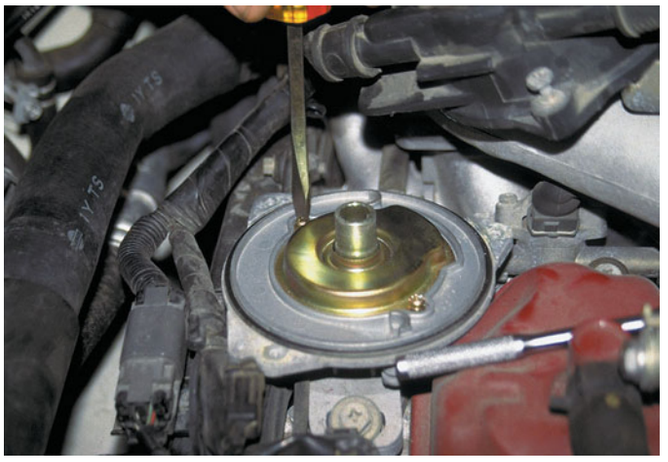


FIGURE 69–11 A light shield being installed before the rotor is attached.



FIGURE 69–12 The firing order is cast or stamped on the intake manifold on most engines that have a distributor ignition.

TECH TIP

Optical Distributors Do Not Like Light

Optical distributors use the light emitted from LEDs to trigger phototransistors. Most optical distributors use a shield between the distributor rotor and the optical interrupter ring. Sparks jump the gap from the rotor tip to the distributor cap inserts. This shield blocks the light from the electrical arcs from interfering with the detection of the light from the LEDs.

If this shield is not replaced during service, the light signals are reduced and the engine may not operate correctly. ● **SEE FIGURE 69–11.**

This can be difficult to detect because nothing looks wrong during a visual inspection. Remember that all optical distributors must be shielded between the rotor and the interrupter ring.

design and the location of the spark plug wires in the distributor cap of an engine equipped with a distributor. The firing order is often cast into the intake manifold for easy reference. ● **SEE FIGURE 69–12.**

Service information also shows the firing order and the direction of the distributor rotor rotation, engine cylinder numbering, and the location of the spark plug wires on the distributor cap.

CAUTION: Ford V-8s use two different firing orders depending on whether the engine is high output (HO) or standard. Using the incorrect firing order can cause the engine to backfire and could cause engine damage or personal injury. General Motors V-6 engines use different firing orders and different locations for cylinder 1 between the 60-degree V-6 and the 90-degree V-6. Using the incorrect firing order or cylinder number location chart could result in poor engine operation or a no-start condition. Firing order is also important for waste-spark-type ignition systems. The spark plug wire can often be installed on the wrong coil pack which can create a no-start condition or poor engine operation.

WASTE-SPARK IGNITION SYSTEMS

PARTS INVOLVED

Waste-spark ignition is another name for the **distributorless ignition system (DIS)** or electronic ignition (EI). Waste-spark ignition was introduced in the mid-1980s and uses the ignition control module (ICM) and/or the powertrain control module (PCM) to fire the ignition coils. A 4-cylinder engine uses two ignition coils and a 6-cylinder engine uses three ignition coils. Each coil is a true transformer because the primary winding and secondary winding are not electrically connected. A waste-spark coil has four terminals:

- Two primary (Bat + and − to ICM)
- Two secondary (each connected to a spark plug)

Each end of the secondary winding is connected to the spark plug of the cylinder exactly opposite the other in the firing order, called a **companion (paired) cylinder.** ● **SEE FIGURE 69–13.**

WASTE-SPARK SYSTEM OPERATION

Both spark plugs fire at the same time (within nanoseconds of each other).

- When one cylinder (for example, cylinder number 6) is on the compression stroke, the other cylinder (number 3) is on the exhaust stroke.
- The spark that occurs on the exhaust stroke is called the waste spark, because it does no useful work and is only used as a ground path for the secondary winding of the ignition coil. The voltage required to jump the spark plug gap on cylinder 3 (the exhaust stroke) is only 2 to 3 kV.
- The cylinder on the compression stroke uses the remaining coil energy.
- One spark plug of each pair always fires straight polarity (from the center electrode to the ground electrode of the spark plug) and the other cylinder always fires reverse polarity (from the ground electrode to the center electrode of the spark plug). Spark plug life is not greatly affected by the reverse polarity. If there is only one defective spark plug wire or spark plug, two cylinders may be affected.

The coil polarity is determined by the direction the coil is wound (left-hand rule for conventional current flow) and cannot be changed.

For example, if a V-6 engine has a firing order of 165432 when one cylinder is on compression, such as cylinder number 1, then the paired cylinder (number 4) is on the exhaust stroke. During the next

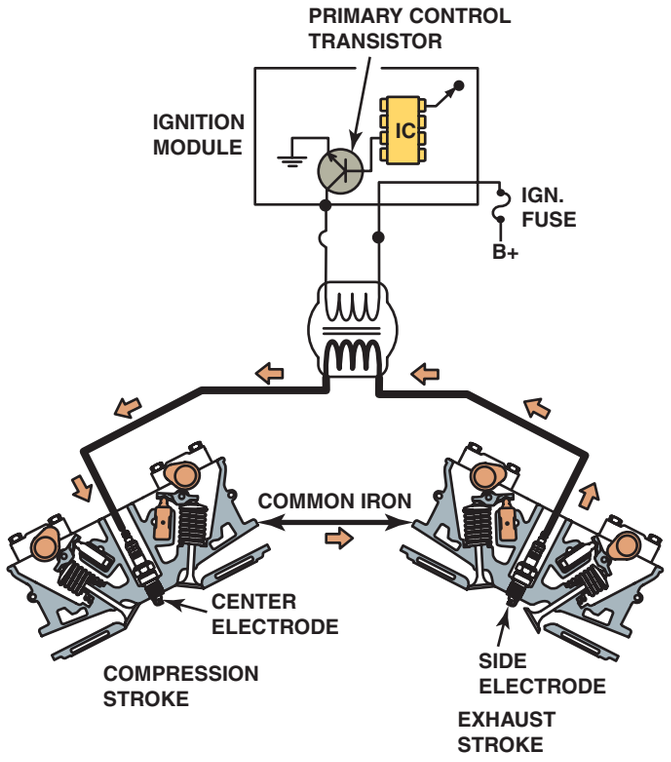


FIGURE 69–13 A waste-spark system fires one cylinder while its piston is on the compression stroke and into paired or companion cylinders while it is on the exhaust stroke. In a typical engine, it requires only about 2 to 3 kV to fire the cylinder on the exhaust stroke. The remaining coil energy is available to fire the spark plug under compression (typically about 8 to 12 kV).

rotation of the crankshaft, cylinder number 4 is on the compression stroke and cylinder number 1 is on the exhaust stroke.

Cylinder 1. Always fires straight polarity (from the center electrode to the ground electrode), one time requiring 10 to 12 kV, and one time requiring 3 to 4 kV.

Cylinder 4. Always fires reverse polarity (from the ground electrode to the center electrode), one time requiring 10 to 12 kV, and one time requiring 3 to 4 kV.

Waste-spark ignitions require a sensor (usually a crankshaft sensor) to trigger the coils at the correct time. ● **SEE FIGURE 69–14.**

The crankshaft sensor cannot be moved to adjust ignition timing, because ignition timing is not adjustable. The slight adjustment of the crankshaft sensor is designed to position the sensor exactly in the middle of the rotating metal disc for maximum clearance.

COMPRESSION-SENSING WASTE-SPARK IGNITION Some waste-spark ignition systems, such as on Saturns and others, use the voltage required to fire the cylinders to determine cylinder position. It requires a higher voltage to fire a spark plug under compression than it does when the spark plug is being fired on the exhaust stroke. The electronics in the coil and the PCM can detect which of the two companion (paired) cylinders that are fired at the same time requires the higher voltage, which indicates the cylinder that is on the compression stroke. For example, a typical 4-cylinder engine equipped with a waste-spark ignition system will fire both cylinders 1 and 4. If cylinder number 4 requires a higher voltage to fire, as determined by the electronics connected to the coil, then the PCM assumes that cylinder number 4 is on the compression stroke. Engines equipped with **compression-sensing ignition** systems do not require the use of a camshaft position sensor to determine specific cylinder numbers. ● **SEE FIGURE 69–15.**

FREQUENTLY ASKED QUESTION

How Can You Determine the Companion Cylinder?

Companion cylinders are two cylinders in the same engine that both reach top dead center at the same time.

- One cylinder is on the compression stroke.
- The other cylinder is on the exhaust stroke.

To determine which two cylinders are companion cylinders in the engine, follow these steps:

STEP 1 Determine the firing order (such as 165432 for a typical V-6 engine).

STEP 2 Write the firing order and then place the second half under the first half.

$$\frac{165}{432}$$

STEP 3 The cylinder numbers above and below each other are companion or paired cylinders.

In this case, 1 and 4, 6 and 3, and 5 and 2 are companion cylinders.

TECH TIP

Odds Fire Straight

Waste-spark ignition systems fire two spark plugs at the same time. Most vehicle manufacturers use a waste-spark system that fires the odd number cylinders (1, 3, and 5) by straight polarity (current flow from the top of the spark plug through the gap and to the ground electrode). The even number cylinders (2, 4, and 6) are fired reverse polarity, meaning that the spark jumps from the side electrode to the center electrode. Some vehicle manufacturers equip their vehicles with platinum plugs, with the expensive platinum alloy only on one electrode as follows:

- On odd number cylinders (1, 3, 5), the platinum is on the center electrode.
- On even number cylinders (2, 4, 6), the platinum is on the ground electrode.

Replacement spark plugs use platinum on both electrodes (double platinum) and, therefore, can be placed in any cylinder location.

COIL-ON-PLUG IGNITION

TERMINOLOGY **Coil-on-plug (COP) ignition** uses one ignition coil for each spark plug. This system is also called *coil-by-plug, coil-near-plug,* or *coil-over-plug* ignition. ● **SEE FIGURES 69–16 AND 69–17.**

ADVANTAGES The coil-on-plug system eliminates the spark plug wires that are often the source of **electromagnetic interference (EMI)** that can cause problems to some computer signals. The vehicle computer controls the timing of the spark. Ignition

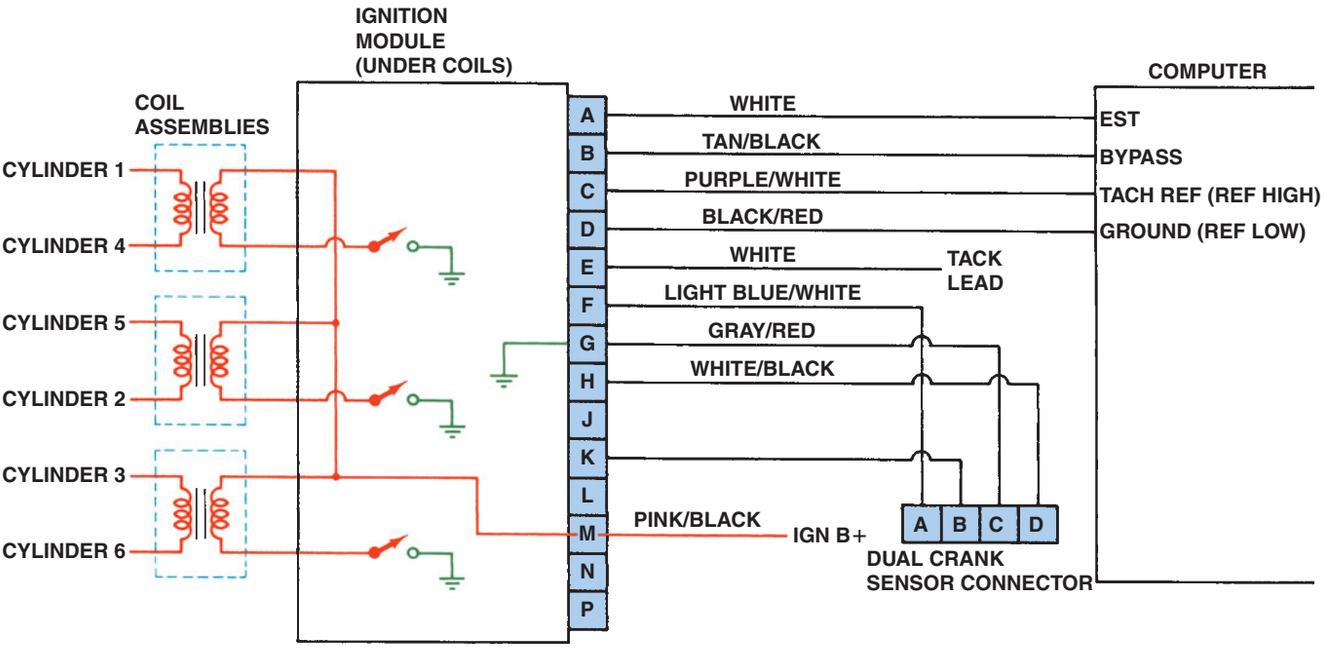


FIGURE 69–14 Typical wiring diagram of a V-6 waste-spark ignition system. The computer (PCM) is in control of the ignition timing based on information from various engine sensors including engine speed (RPM), MAP and engine coolant temperature (ECT). The timing signal is sent to the module through the electronic spark timing (EST) wire in this example.

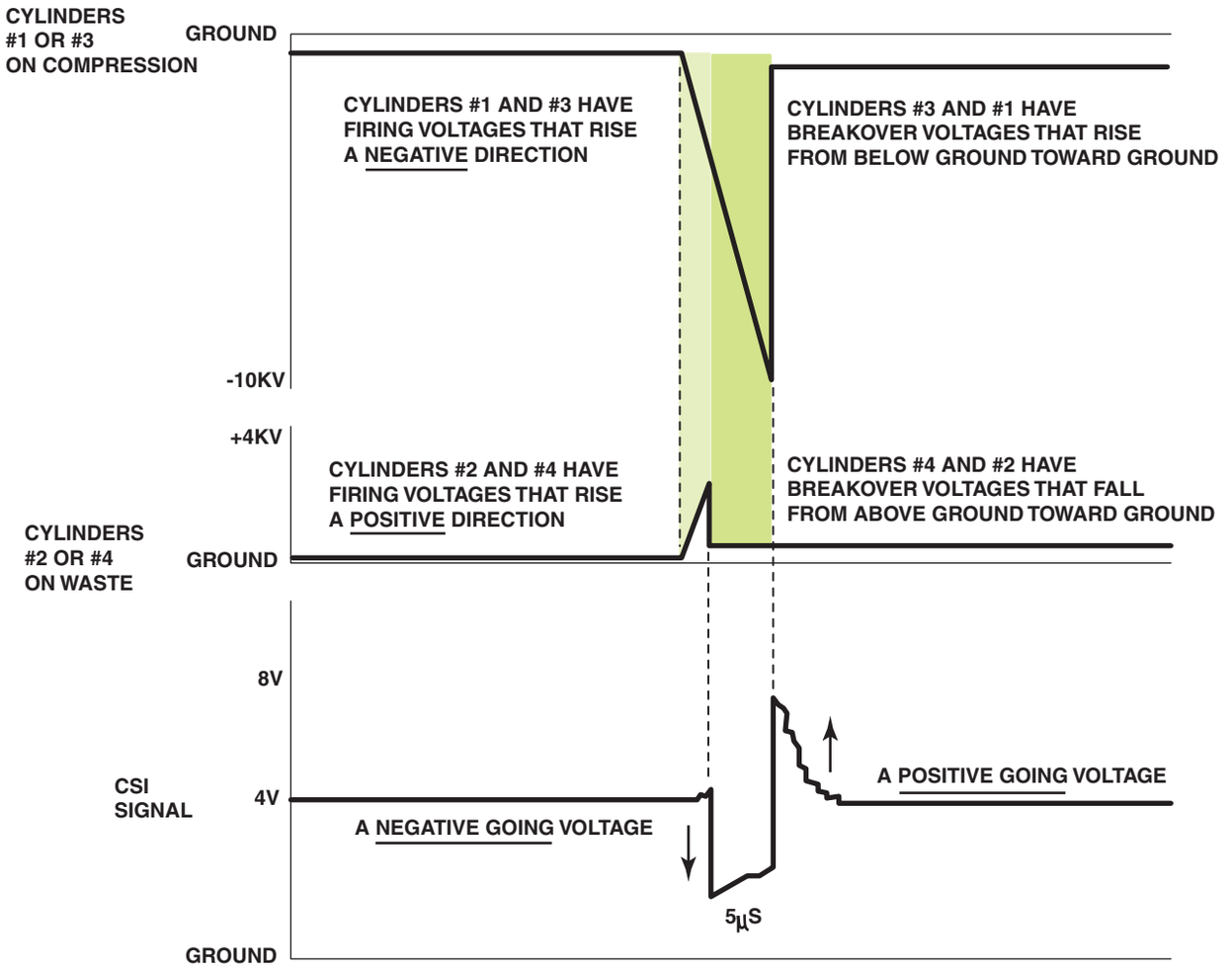


FIGURE 69–15 The slight (5 microsecond) difference in the firing of the companion cylinders is enough time to allow the PCM to determine which cylinder is firing on the compression stroke. The compression sensing ignition (CSI) signal is then processed by the PCM which then determines which cylinder is on the compression stroke.

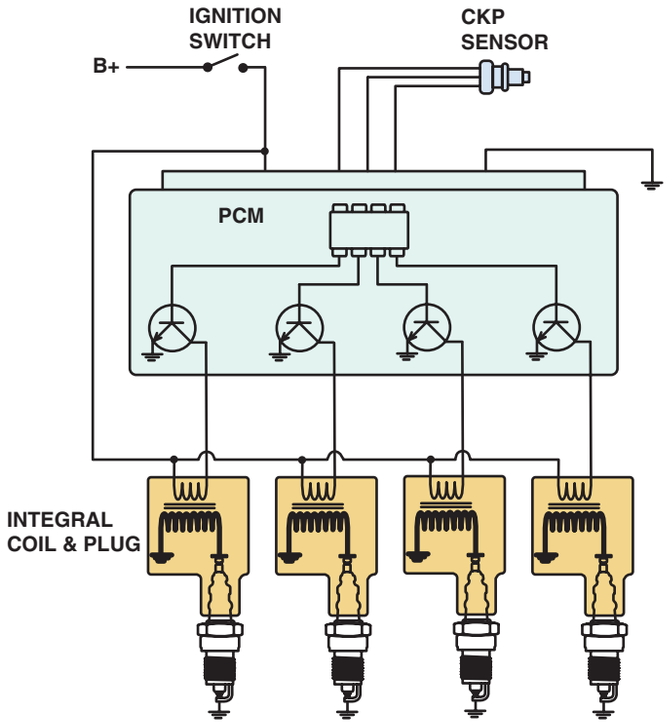


FIGURE 69–16 A typical coil-on-plug ignition system showing the triggering and the switching being performed by the PCM via input from the crankshaft position sensor.

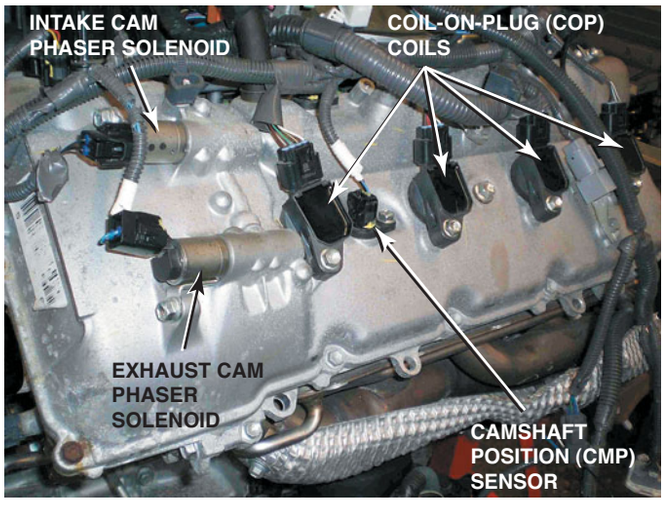


FIGURE 69–17 An overhead camshaft engine equipped with variable valve timing on both the intake and exhaust camshafts and the coil-on-plug ignition.

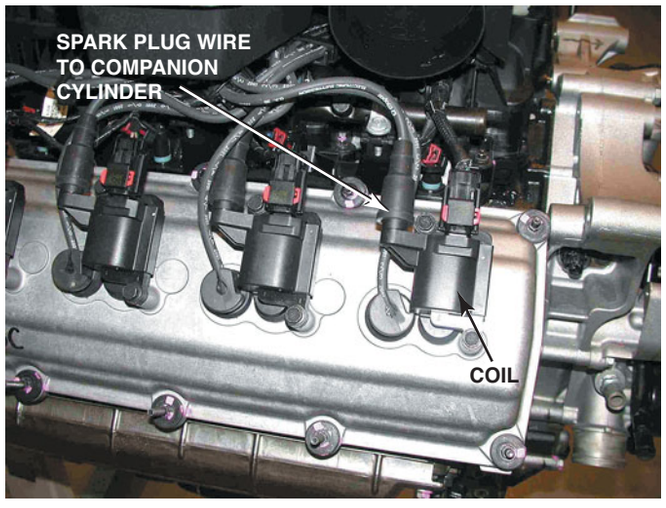


FIGURE 69–18 A Chrysler Hemi V-8 that has two spark plugs per cylinder. The coil on top of one spark plug fires that plug and, through a spark plug wire, fires a plug in the companion cylinder.

SAFETY TIP

Never Disconnect a Spark Plug Wire When the Engine Is Running!

Ignition systems produce a high-voltage pulse necessary to ignite a lean air-fuel mixture. If you disconnect a spark plug wire when the engine is running, this high-voltage spark could cause personal injury or damage to the ignition coil and/or ignition module.

timing also can be changed (retarded or advanced) on a cylinder-by-cylinder basis for maximum performance and to respond to knock sensor signals.

TYPES OF COP SYSTEMS

There are two basic types of coil-on-plug ignition.

- **Two primary wires.** This design uses the vehicle computer to control the firing of the ignition coil. The two wires include ignition voltage feed and the pulse ground wire, which is controlled by the PCM. The ignition control module (ICM) is located in the PCM, which handles all ignition timing and coil on-time control.
- **Three primary wires.** This design includes an ignition module at each coil. The three wires include:
  - Ignition voltage
  - Ground
  - Pulse from the PCM to the built-in ignition module

Vehicles use a variety of coil-on-plug-type ignition systems, such as the following:

- Many General Motors V-8 engines use a coil-near-plug system with individual coils and modules for each individual cylinder placed on the valve covers. Short secondary ignition spark plug wires are used to connect the output terminal of the ignition coil to the spark plug, which explains why this system is called a *coil-near-plug* system.
- A combination of coil-on-plug and waste-spark systems fires a spark plug attached to the coil and uses a spark plug wire attached to the other secondary terminal of the coil to fire another spark plug of the companion cylinder. This type of system is used in some Chrysler Hemi V-8 and Toyota V-6 engines. ● **SEE FIGURE 69–18.**

Most new engines use coil-over-plug-type ignition systems. Each coil is controlled by the PCM, which can vary the ignition timing separately for each cylinder based on signals the PCM receives from the knock sensor(s). For example, if the knock sensor detects that a spark knock has occurred after firing cylinder 3, then the PCM will continue to monitor cylinder 3 and retard timing on just this one cylinder if necessary to prevent engine damaging detonation.

ION-SENSING IGNITION

In an **ion-sensing ignition** system, the spark plug itself becomes a sensor. An ion-sensing ignition uses

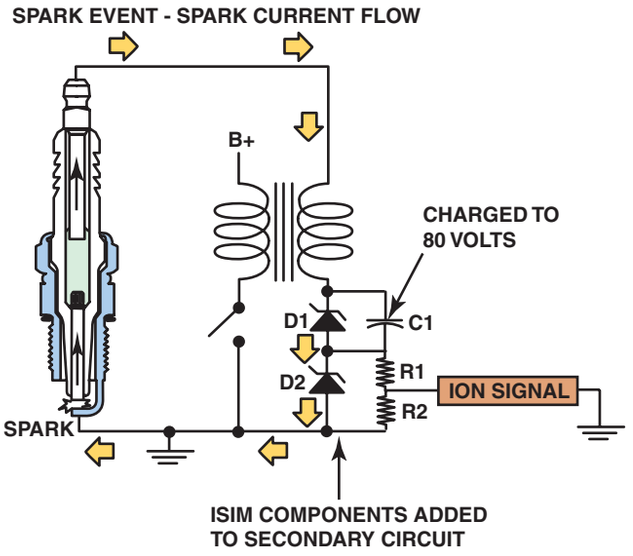


FIGURE 69–19 A DC voltage is applied across the spark plug gap after the plug fires and the circuit can determine if the correct air-fuel ratio was present in the cylinder and if knock occurred. The applied voltage for ion sensing does not jump the spark plug gap but rather determines the conductivity of the ionized gases left over from the combustion process.

a coil-on-plug design where the **ignition control module (ICM)** applies a DC voltage across the spark plug gap *after* the ignition event to sense the ionized gases (called plasma) inside the cylinder. Ion-sensing ignition is used in the General Motors EcoTec 4-cylinder engines. ● **SEE FIGURE 69–19.**

The secondary coil discharge voltage (10 to 15 kV) is electrically isolated from the ion-sensing circuit. The combustion flame is ionized and will conduct some electricity, which can be accurately measured at the spark plug gap. The purpose of this circuit includes:

- Misfire detection (required by OBD-II regulations)
- Knock detection (eliminates the need for a knock sensor)
- Ignition timing control (to achieve the best spark timing for maximum power with lowest exhaust emissions)
- Exhaust gas recirculation (EGR) control
- Air-fuel ratio control on an individual cylinder basis

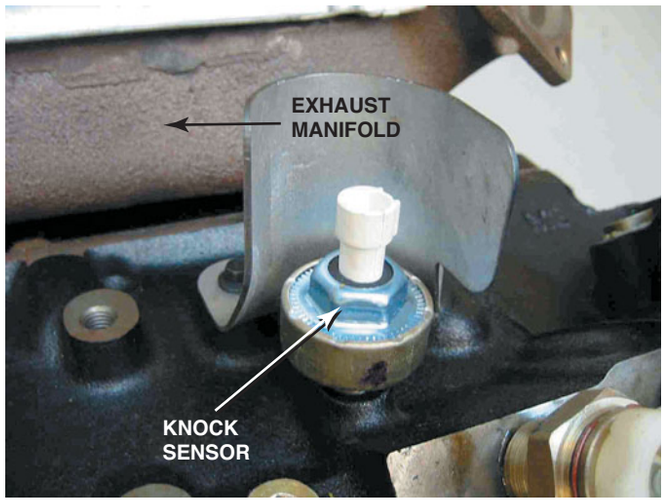


FIGURE 69–20 A typical knock sensor on the side of the block. Some are located in the "V" of a V-type engine and are not noticeable until the intake manifold has been removed.

Ion-sensing ignition systems still function the same as conventional coil-on-plug designs, but the engine does not need to be equipped with a camshaft position sensor for misfire detection or a knock sensor, because both of these faults are achieved using the electronics inside the ignition control circuits.

KNOCK SENSORS

PURPOSE AND FUNCTION

Knock sensors (KS) are used to detect abnormal combustion, often called **ping, spark knock,** or **detonation.** Whenever abnormal combustion occurs, a rapid pressure increase occurs in the cylinder, creating a vibration in the engine block. It is this vibration that is detected by the knock sensor. The signal from the knock sensor is used by the PCM to retard the ignition timing until the knock is eliminated, thereby reducing the damaging effects of the abnormal combustion on pistons and other engine parts.

Inside the knock sensor is a piezoelectric element which is a type of crystal that produces a voltage when pressure or a vibration is applied to the unit. The knock sensor is tuned to the engine knock frequency, in a range from 5 to 10 kHz depending on the engine design. The voltage signal from the knock sensor is sent to the PCM, which then retards the ignition timing until the knocking stops. ● **SEE FIGURE 69–20.**

DIAGNOSING THE KNOCK SENSOR

If a knock sensor diagnostic trouble code (DTC) is present, follow the specified testing procedure in the service information. A scan tool can be used to check the operation of the knock sensor, using the following procedure.

STEP 1 Start the engine and connect a scan tool to monitor ignition timing and/or knock sensor activity.

STEP 2 Create a simulated engine knocking sound by tapping on the engine block or cylinder head with a soft faced mallet or small ball peen hammer.

STEP 3 Observe the scan tool display. The vibration from the tapping should have been interpreted by the knock sensor as a knock, resulting in a knock sensor signal and a reduction in the spark advance.

A knock sensor also can be tested using a digital storage oscilloscope. ● **SEE FIGURE 69–21.**

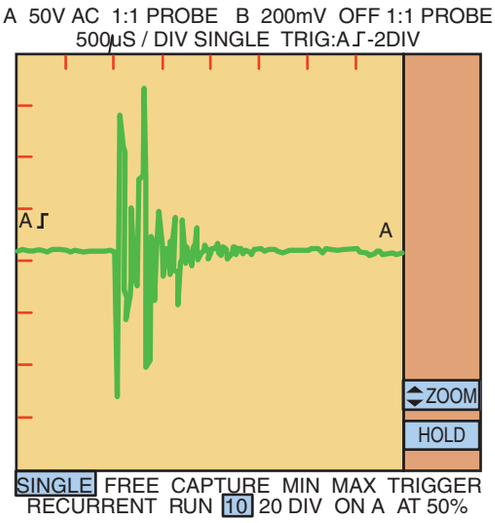


FIGURE 69–21 A typical waveform from a knock sensor during a spark knock event. This signal is sent to the computer which in turn retards the ignition timing. This timing retard is accomplished by an output command from the computer to either a spark advance control unit or directly to the ignition module.

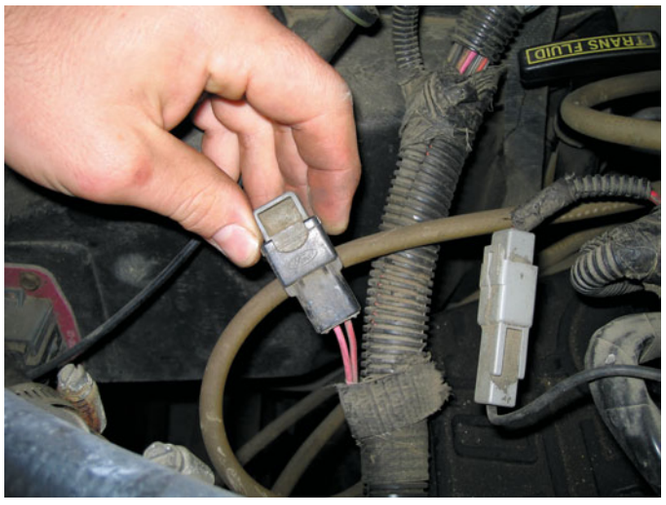


FIGURE 69–22 A SPOUT connector on a Ford that is equipped with a distributor ignition. This connector has to be disconnected to separate the PCM in order to set base ignition timing.

REAL WORLD FIX

The Low Power Toyota

A technician talked about the driver of a Toyota who complained about poor performance and low fuel economy. The technician checked everything, and even replaced all secondary ignition components. Then the technician connected a scan tool and noticed that the knock sensor was commanding the timing to be retarded. Careful visual inspection revealed a "chunk" missing from the serpentine belt, causing a "noise" similar to a spark knock. Apparently the knock sensor was "hearing" the accessory drive belt noise and kept retarding the ignition timing. After replacing the accessory drive belt, a test drive confirmed that normal engine power was restored.

Other items that can fool the knock sensor to retard the ignition timing include:

- Loose valve lifter adjustment
- Engine knocks
- Loose accessory brackets such as the air-conditioning compressor, power steering pumps, or alternator.

NOTE: Some engine computers are programmed to ignore knock sensor signals when the engine is at idle speed, to avoid having the noise from a loose accessory drive belt or other accessory interpreted as engine knock. Always follow the vehicle manufacturer's recommended testing procedure.

REPLACING A KNOCK SENSOR

If replacing a knock sensor, be sure to purchase the exact replacement needed, because they often look the same, but the frequency range can vary according to engine design and location on the engine. Many engines also use two knock sensors, so check service information for exact details and locations of the sensors for the engine being serviced. Always tighten the knock sensor using a torque wrench and tighten to the specified torque to avoid causing damage to the piezoelectric element inside the sensor.

TERMINOLOGY

Ignition control (IC) is the OBD-II terminology for the output signal from the PCM to the ignition system that controls engine timing. Previously, each manufacturer used a different term to describe this signal. For instance, Ford referred to this signal as **spark output (SPOUT)** and General Motors referred to this signal as **electronic spark timing (EST).** This signal is now referred to as the ignition control (IC) signal. The ignition control signal is usually a digital output that is sent to the ignition system as a timing signal. If the ignition system is equipped with an ignition module, then this signal is used by the ignition module to vary the timing as engine speed and load change. If the PCM directly controls the coils, such as most coil-on-plug ignition systems, then this IC signal directly controls the coil primary and there is a separate IC signal for each ignition coil. The IC signal controls the time that the coil fires and it can also either advance or retard the ignition timing. On many systems, this signal controls the duration of the primary current flow in the coil, referred to as the **dwell.** ● **SEE FIGURE 69–22.**

BYPASS IGNITION CONTROL SYSTEM

With **bypass ignition** control, the engine starts using the ignition module for timing control and then switches to the PCM for timing control after the engine starts. A bypass ignition is commonly used on General Motors engines equipped with distributor ignition (DI), as well as those equipped with waste-spark ignition.

The bypass circuit includes four wires.

- The *tach reference (purple/white)* wire comes from the ignition control (IC) module and is used by the PCM as engine speed information.
- The *ground (black/white)* wire is used to ensure that both the PCM and the ignition control module share the same ground.

- The *bypass (tan/black)* wire is used to conduct a 5 volt DC signal from the PCM to the ignition control module to switch the timing control from the module to the PCM.

  NOTE: It is this bypass wire that is disconnected before the ignition timing can be set on many General Motors engines equipped with a distributor ignition.

- The *EST (ignition control) (white)* wire is the ignition timing control signal from the PCM to the ignition control module.

UP-INTEGRATED IGNITION CONTROL Most coil-on-plug and many waste-spark-type ignition systems use the PCM for ignition timing control. This type of ignition control is called **up-integrated ignition** because all timing functions are interpreted in the PCM, rather than being split between the ignition control module and the PCM. The ignition module, if even used, contains only the power transistor for coil switching. The signal as to when the coil fires is determined and controlled from the PCM.

Unlike a bypass ignition control circuit, it is not possible to separate the PCM from the ignition coil control to help isolate a fault.

REVIEW QUESTIONS

1. How can 12 volts from a battery be changed to 40,000 volts for ignition?
2. How does a magnetic sensor work?
3. How does a Hall-effect sensor work?
4. How does a waste-spark ignition system work?

CHAPTER QUIZ

1. The primary (low-voltage) ignition system must be working correctly before any spark occurs from a coil. Which component is *not* in the primary ignition circuit?
   a. Spark plug wiring
   b. Ignition module (igniter)
   c. Pickup coil (pulse generator)
   d. Ignition switch
2. The ignition module has direct control over the firing of the coil(s) of an EI system. Which component(s) triggers (controls) the module?
   a. Pickup coil
   b. Computer
   c. Crankshaft sensor
   d. All of the above
3. Distributor ignition systems can be triggered by a _____.
   a. Hall-effect sensor
   b. Magnetic sensor
   c. Spark sensor
   d. Either a or b
4. A compression-sensing ignition system uses a _____-type ignition.
   a. Distributor
   b. Coil-on-plug
   c. Waste-spark
   d. All of the above
5. Coil polarity is determined by the _____.
   a. Direction of rotation of the coil windings
   b. Turns ratio
   c. Direction of laminations
   d. Saturation direction
6. How does a waste-spark ignition system fire the spark plugs?
   a. The polarity reverses at each firing (flip flops).
   b. The same plug always is fired straight or reverse polarity
   c. The waste spark is sent to the cylinder next to the cylinder being fired.
   d. Both a and c
7. The pulse generator _____.
   a. Fires the spark plug directly
   b. Signals the electronic control unit (module)
   c. Signals the computer that fires the spark plug directly
   d. Is used as a tachometer reference signal by the computer and has no other function
8. Two technicians are discussing distributor ignition. Technician A says that the pickup coil or optical sensor in the distributor is used to pulse the ignition module (igniter). Technician B says that some distributor ignition systems use an optical sensor. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. A waste-spark-type ignition system fires _____.
   a. Two spark plugs at the same time
   b. One spark plug with reverse polarity
   c. One spark plug with straight polarity
   d. All of the above
10. Technician A says that a two-wire COP system uses the PCM to trigger the coil. Technician B says that a three-wire COP system has an ICM built into the coil assembly. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

chapter 70

IGNITION SYSTEM DIAGNOSIS AND SERVICE

OBJECTIVES: **After studying Chapter 70, the reader will be able to:** • Prepare for ASE Engine Performance (A8) certification test content area "B" (Ignition System Diagnosis and Repair). • Describe the procedure used to check for spark. • Discuss what to inspect and look for during a visual inspection of the ignition system. • Explain how to test pickup coils, ignition coils, and spark plug wires. • Discuss how to current ramp ignition coils using a low ampere current clamp and a scope. • Describe how to test the ignition system using an oscilloscope.

KEY TERMS: Burn kV 809 • Charging rise time 796 • Firing line 807 • Firing order 805 • Ignition timing 804 • Iridium spark plugs 802 • Millisecond (ms) sweep 809 • Module current limits 796 • Platinum spark plugs 802 • Spark line 808 • Spark tester 794

CHECKING FOR SPARK

SPARK TESTER In the event of a no-start condition, the first step should be to check for secondary voltage out of the ignition coil or to the spark plugs. If the engine is equipped with a separate ignition coil, remove the coil wire from the center of the distributor cap, install a **spark tester,** and crank the engine. See the Tech Tip, "Always Use a Spark Tester." A good coil and ignition system should produce a blue spark at the spark tester. ● **SEE FIGURES 70–1 AND 70–2.**

If the ignition system being tested does not have a separate ignition coil, disconnect any spark plug wire from a spark plug and, while cranking the engine, test for spark available at the spark plug wire, again using a spark tester.

NOTE: An intermittent spark should be considered a no-spark condition.

Typical causes of a no-spark (intermittent spark) condition include the following:

1. Weak ignition coil
2. Low or no voltage to the primary (positive) side of the coil
3. High resistances or open coil wire, or spark plug wire
4. Negative side of the coil not being pulsed by the ignition module
5. Defective pickup coil or crankshaft position sensor
6. Defective ignition control module (ICM)
7. Defective main relay (can be labeled main, EFI, ASD [Chrysler products], or EEC [Ford vehicles] relay)

The triggering sensor has to work to create a spark from the ignition coil(s). If a no-spark condition occurs, then check for triggering by using a scan tool and check for engine RPM while cranking the engine.



FIGURE 70–1 A spark tester looks like a regular spark plug with an alligator clip attached to the shell. This tester has a specified gap that requires at least 25,000 volts (25 kV) to fire.



FIGURE 70–2 A close-up showing the recessed center electrode on a spark tester. It is recessed 3/8 in. into the shell and the spark must then jump another 3/8 in. to the shell for a total gap of 3/4 in.

- If the engine speed (RPM) shows zero or almost zero while cranking, the most likely cause is a defective triggering sensor or sensor circuit fault.
- If the engine speed (RPM) is shown on the scan tool while cranking the engine, then the triggering sensor is working (in most cases).

Check service information for the exact procedure to follow for testing triggering sensors.

IGNITION COIL TESTING

IGNITION COIL TESTING USING AN OHMMETER

If an ignition coil is suspected of being defective, a simple ohmmeter check can be performed to test the resistance of the primary and secondary winding inside the coil. For accurate resistance measurements, the wiring to the coil should be removed before testing. To test the primary coil winding resistance, take the following steps. ● **SEE FIGURE 70–3.**

STEP 1 Set the meter to read low ohms.

STEP 2 Measure the resistance between the positive terminal and the negative terminal of the ignition coil. Most coils will give a reading between 0.5 and 3 ohms. Check the manufacturer's specifications for the exact resistance values.

To test the secondary coil winding resistance, follow these steps.

STEP 1 Set the meter to read kilohms (kΩ).

STEP 2 Measure the resistance either between the primary terminal and the secondary coil tower or between the secondary towers. The normal resistance of most coils ranges between 6,000 and 30,000 ohms.

Check service information for the exact procedures and specifications.

CURRENT RAMPING IGNITION COILS

Testing an ignition coil for resistance does not always find a coil problem that occurs under actual heat and loads. However, by using a digital storage oscilloscope and a low-current probe, the ignition system can be checked for module current limits and the charging rise time.

Ignition coil operation begins with the ignition control module (ICM) completing the primary circuit through the ignition coil winding. The module allows primary current to ramp upward (primary charging time) to a preset limit. Once ramped to the preset limit, the coil remains on for a set period of time (primary saturation), known as the *dwell* period. Coil current is then turned off (open circuit) allowing the magnetic field built up through the dwell cycle to collapse inward, cutting across many turns of secondary coil windings, inducing a higher output voltage to fire the coil. The ignition systems used today must provide voltages of at least 25,000 volts and maintain spark duration of over 2 ms to assure good ignition over extended service intervals.

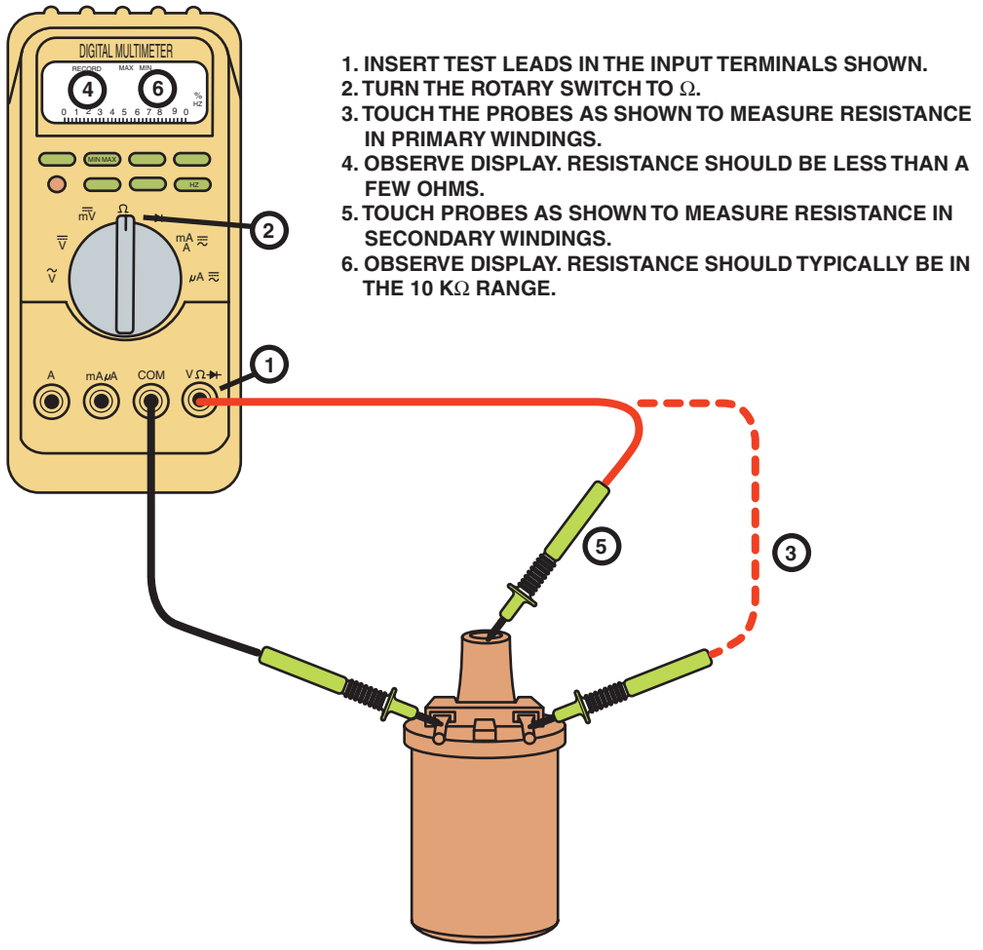


FIGURE 70–3 Checking an ignition coil using a multimeter set to read ohms.

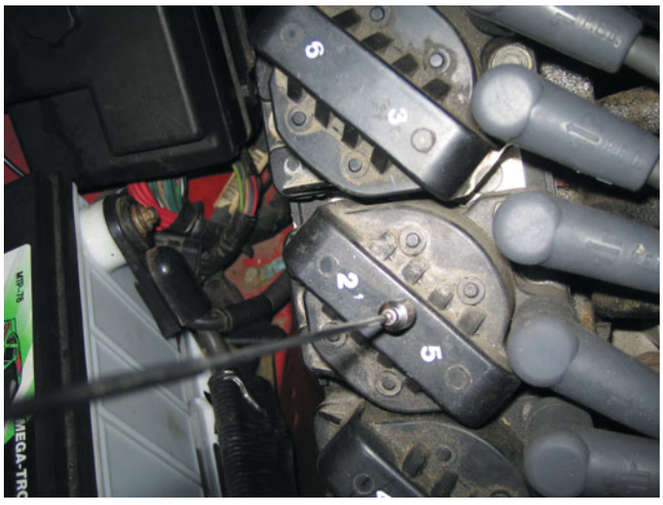


FIGURE 70–4 If the coil is working, the end of the magnetic pickup tool will move with the changes in the magnetic field around the coil with the engine running.

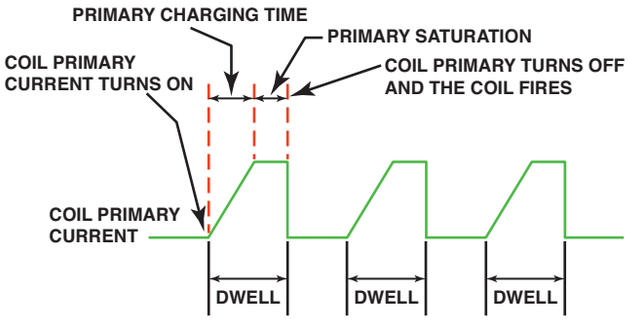


FIGURE 70–5 A waveform showing the primary current flow through the primary windings of an ignition coil.

TECH TIP

Always Use a Spark Tester

A spark tester looks like a spark plug except it has a recessed center electrode and no side electrode. The tester commonly has an alligator clip attached to the shell so that it can be clamped on a good ground connection on the engine. A good ignition system should be able to cause a spark to jump this wide gap at atmospheric pressure. Without a spark tester, a technician might assume that the ignition system is okay, because it can spark across a normal, grounded spark plug. The voltage required to fire a standard spark plug when it is out of the engine and not under pressure is about 3,000 volts or less. An electronic ignition spark tester requires a minimum of 25,000 volts to jump the 3/4 in. gap. Therefore, never assume that the ignition system is okay because it fires a spark plug—always use a spark tester. *Remember that an intermittent spark across a spark tester should be interpreted as a no-spark condition.*

TECH TIP

The Magnetic Pickup Tool Test

All ignition coils are pulsed on and off by the ignition control module or PCM. When the coil charges and discharges, the magnetic field around the coil changes. This pulsing of the coil can be observed by holding the magnetic end of a pickup tool near an operating ignition coil. The magnet at the end of the pickup tool will move as the magnetic field around the coil changes. ● **SEE FIGURE 70–4.**

Using the digital storage oscilloscope and a current probe, a quick check can be made of the overall primary condition of the two most important parameters of the ignition circuit, the **module current limits** and the **charging rise time** of the circuit. Actual circuit operation of the primary current control is a precise element in total ignition function and output. ● **SEE FIGURE 70–5.**

CURRENT RAMP TEST PROCEDURE

To perform a current ramp test of the ignition coil(s), take the following steps.

STEP 1 Every ignition system has a power feed circuit to the ignition coil(s). To perform current probe testing on the system, first locate the feed wire and make it current probe accessible. ● **SEE FIGURE 70–6.**

This will serve as a common point on all ignition systems and include both the DI and EI units.

STEP 2 Set up the scope to read approximately 100 mV per division and 2 ms per division. This may be adjusted to suit the waveform, but will give an initial reference point. ● **SEE CHART 70–1.**

A good current ramp waveform is shown in ● **FIGURE 70–7.**

Examples of some faults that a current waveform can detect are shown in ● **FIGURE 70–8.**

IGNITION SENSOR TESTING

MAGNETIC SENSOR TESTING

Magnetic sensors are found in pickup coils, located under the distributor cap on many distributor ignition (DI) equipped engines and in crankshaft position (CKP) sensors. If defective, they can cause a no-spark condition. Magnetic sensors must generate an AC voltage pulse to the ignition control module (ICM) so that the module can pulse the ignition coil.

A pickup coil or magnetic sensor contains a coil of wire, and the resistance of this coil should be within the range specified by the manufacturer.

Common tests for pickup coils and magnetic crankshaft position (CKP) sensors include:

- **Resistance.** The resistance is usually between 150 and 1,500 ohms (check service information for exact specifications). ● **SEE FIGURE 70–9.**
- **Short to ground.** Ensure that the coil windings are insulated from ground by checking for continuity using an ohmmeter. With one ohmmeter lead attached to ground, touch the other lead of the ohmmeter to either of the two pickup coil terminals. The ohmmeter should read OL (over limit or infinity) with the ohmmeter set on the highest ohms scale. If the ohmmeter shows a reading of any resistance or even zero, then the pickup coil is shorted to ground and should be

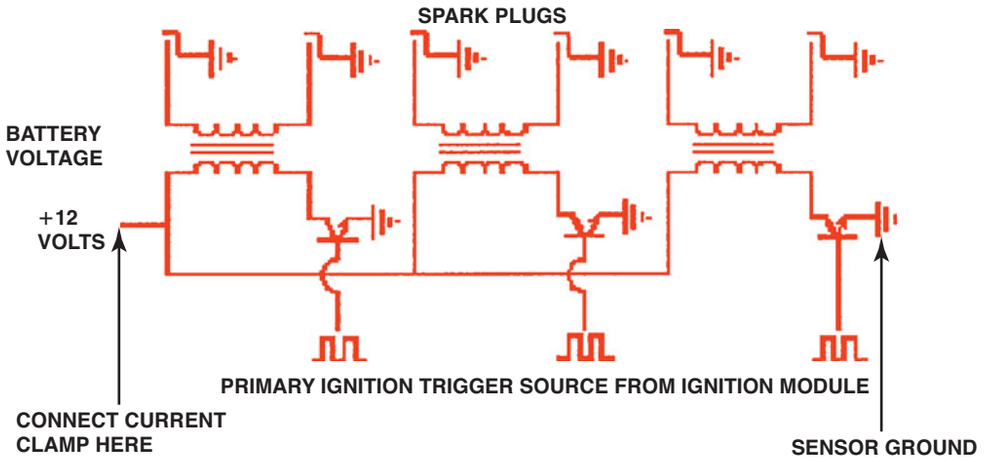
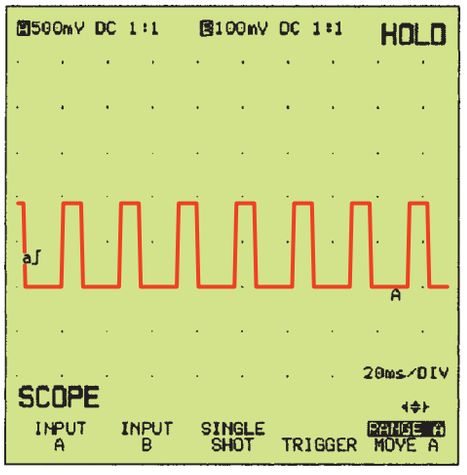


FIGURE 70–6 Schematic of a typical waste-spark ignition system showing the location for the power feed and grounds. (*Courtesy of Fluke Corporation*)

OBSERVED CURRENT RAMP TIMES	
GM electronic (DI) systems	3.6 ms
GM late 1996 and up (DI) systems	2.5 ms
GM electronic (EI) systems	2.6 ms
Ford electronic (DI) systems	3.6 ms
Ford electronic (EI) systems	2.6 ms
Chrysler electronic (DI) systems	3.8 ms
Chrysler electronic (EI) systems	2.6 ms

CHART 70–1

The ignition coil ramp times vary according to the type of ignition system.

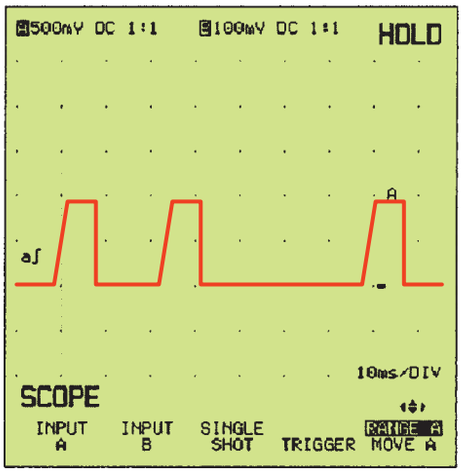


GOOD COIL PATTERN

FIGURE 70–7 An example of a good coil current flow waveform pattern. Note the regular shape of the rise time and slope. Duration of the waveform may change as the module adjusts the dwell. The dwell is usually increased as the engine speed is increased. (*Courtesy of Fluke Corporation*)

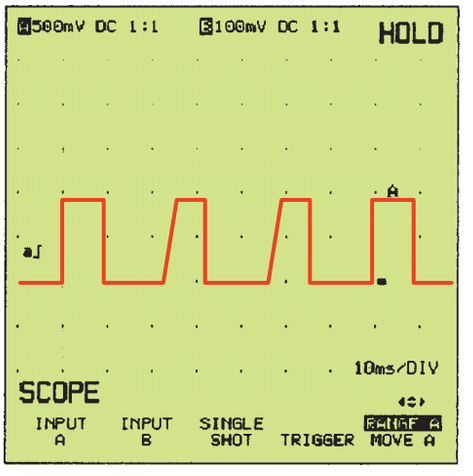
replaced. If the pickup coil resistance is not within the specified range or if it has continuity to ground, then replace the pickup coil assembly.

- **AC voltage output.** The pickup coil also can be tested for proper voltage output. During cranking, most pickup coils should produce a minimum of 0.25 volt AC.



AN OPEN COIL PRIMARY WINDING WILL BE IDENTIFIED BY A MISSING PULSE IN THE CURRENT PATTERN.

(a)



A SHORTENED COIL WILL HAVE A SQUARE SHAPED CURRENT RAMP (DUE TO REDUCED PRIMARY COIL RESISTANCE.)

(b)

FIGURE 70–8 (a) A waveform pattern showing an open in the coil primary. (b) A shorted coil pattern waveform. (*Courtesy of Fluke Corporation*)

- **Scope testing.** A pickup coil can also be checked on a scope. The waveform created is an analog (continuously variable) and is produced by the strengthening and weakening of the magnetic field as the points of the timer core rotate past the points of the pole pieces. ● **SEE FIGURE 70–10.**

The changing magnetic field is sent to the ICM where it turns off the current through the primary winding of the ignition coil. ● **SEE FIGURE 70–11.**



FIGURE 70–9 Measuring the resistance of an HEI pickup coil using a digital multimeter set to the ohms position. The reading on the face of the meter is 0.796 kΩ or 796 ohms in the middle of the 500 to 1,500 ohm specifications.

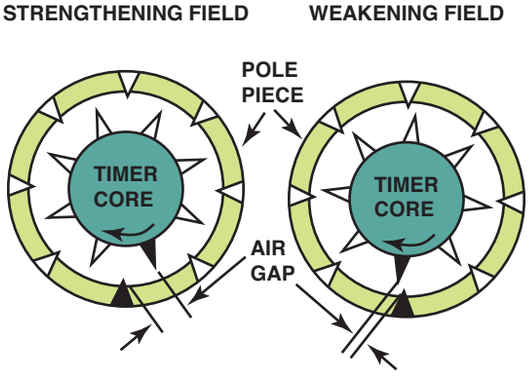


FIGURE 70–10 A typical pickup coil showing how the waveform is created as the timer core rotates inside the pole piece.

REAL WORLD FIX

The Weird Running Chevrolet Truck

An older Chevrolet pickup truck equipped with a V-8 engine was towed into a shop because it would not start. A quick check of the ignition system showed that the pickup coil had a broken wire below it and the ignition control module. The distributor was removed from the engine and the distributor shaft was removed, cleaned, and a replacement pickup coil was installed. The engine started but ran rough and hesitated when the accelerator pedal was depressed.

After an hour of troubleshooting, a careful inspection of the new pickup coil showed that the time core had six instead of eight points, meaning that the new pickup coil was meant for a V-6 instead of a V-8 engine. Replacing the pickup coil again solved the problem.

REAL WORLD FIX

The Hard-to-Start Chevrolet HHR

The owner of a 2008 Chevrolet HHR complained that the engine was hard to start and required a long period of cranking. Once the engine started, it ran great all day. A P0336 crankshaft position (CKP) sensor fault code was stored. ● **SEE FIGURE 70–12.**

The CKP sensor had been replaced several times before and the sensor output was scope tested yet everything appeared to be normal. Then one time when the engine started, the technician noticed that while it was running the engine speed (RPM) displayed on the Tech 2 scan tool was zero. ● **SEE FIGURE 70–13.**

After replacing the crankshaft position sensor again and checking the wiring, the technician looked at the reluctor wheel using a boroscope. Some blades of the reluctor wheel were bent. The cause was likely when the first sensor failed and possibly damaged the reluctor. As a result of the testing, the local Chevrolet dealer replaced the crankshaft under warranty. ● **SEE FIGURE 70–14.**

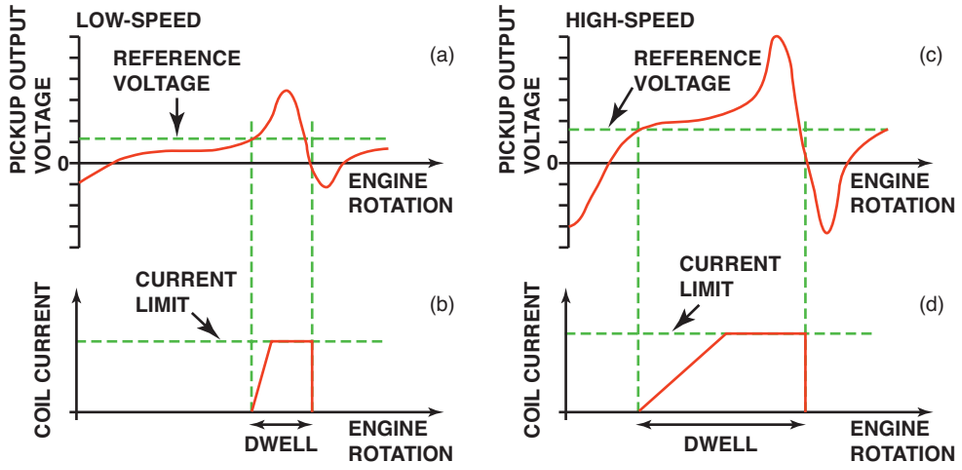


FIGURE 70–11 (a) A voltage waveform of a pickup coil at low engine speed. (b) A current waveform of the current through the primary windings of the ignition coil at low engine speed. (c) A voltage waveform of a pickup coil at high speed. (d) A current waveform through the primary winding of the ignition coil at high engine speed.

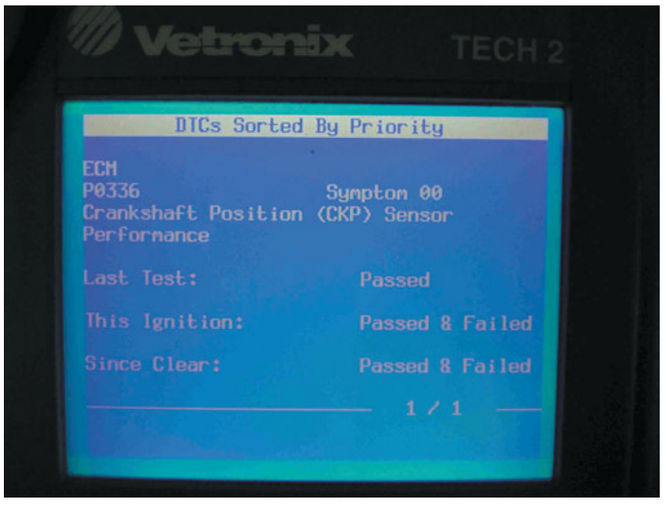


FIGURE 70–12 A diagnostic trouble code P0336 was displayed on a Tech 2 scan tool as the only code.

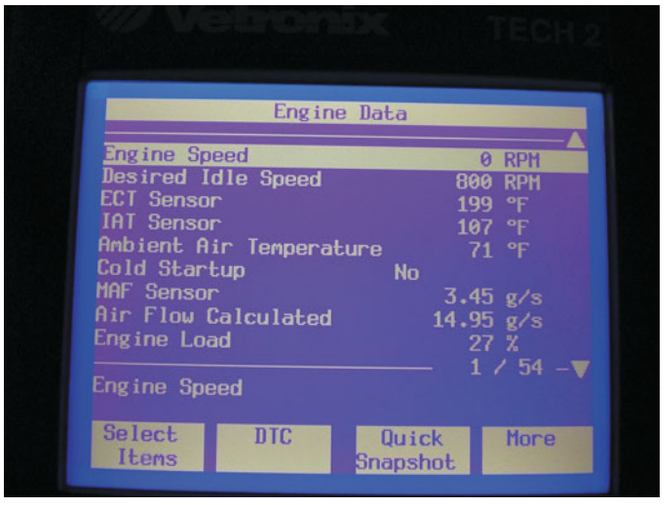


FIGURE 70–13 The engine started and was running, but the Tech 2 displayed zero RPM.

HALL-EFFECT SENSOR TESTING

A Hall effect sensor uses a semiconductor chip to produce an on and off signal when exposed to a magnetic field. Using a digital voltmeter, check for the following:

- Power and ground to the sensor
- Changing voltage (pulsed on and off or digital DC voltage) when the engine is being cranked (The usual voltage range is 0 to 5 volts, or 0 to 8 volts depending on the sensors and the application.)

Another test is to use an oscilloscope and observe the waveform. ● **SEE FIGURE 70–15.**

OPTICAL SENSOR TESTING

Optical sensors will not operate if dirty or covered in oil. Perform a thorough visual inspection and look for an oil leak that could cause dirty oil to get on the LED or phototransistor. Also be sure that the light shield is securely fastened and that the seal is lightproof. An optical sensor also can be checked using an oscilloscope. ● **SEE FIGURE 70–16.**

Because of the speed of the engine and the number of slits in the optical sensor disk, a scope is one of the only tools that can capture useful information. For example, a Nissan has 360 slits and if it is running at 2,000 RPM, a signal is generated 720,000 times per minute or 12,000 times per second.

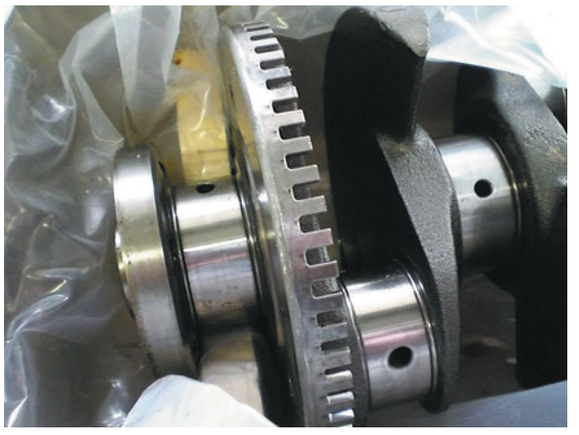


FIGURE 70–14 The old crankshaft showing the reluctor notches. The damage was not visible, but the engine started each time after the crankshaft was replaced.

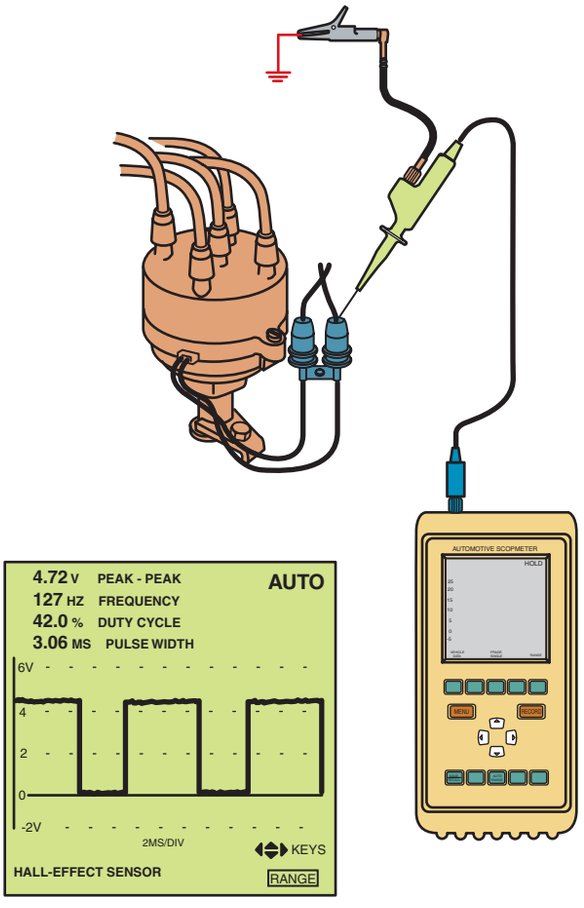
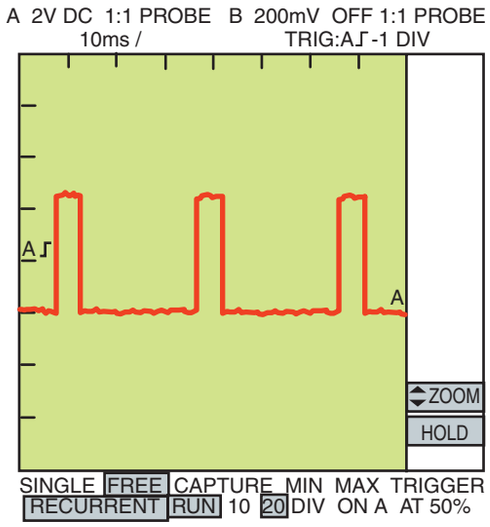


FIGURE 70–15 The connection required to test a Hall-effect sensor. A typical waveform from a Hall-effect sensor is a digital square wave. Check service information for the signal wire location.

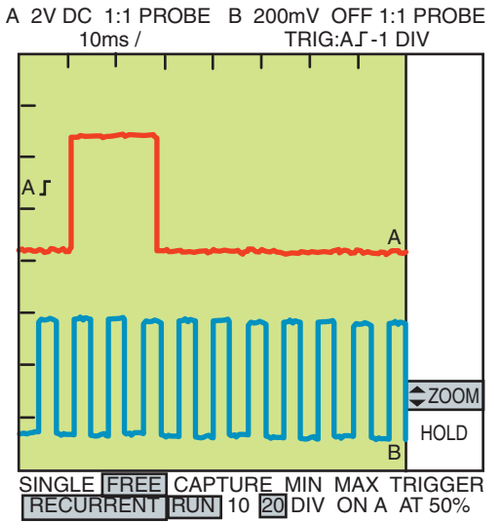
SPARK PLUG WIRE INSPECTION

VISUAL INSPECTION

Spark plug wires should be visually inspected for cuts or defective insulation. Faulty spark plug wire insulation can cause hard starting or no starting in rainy or damp weather conditions. When removing a spark plug wire, be sure to rotate the boot of the wire at the plug before pulling it off the spark plug. This



(a)



(b)

FIGURE 70–16 (a) The low-resolution signal has the same number of pulses as the engine has cylinders. (b) A dual trace pattern showing both the low-resolution and the high-resolution signals that usually represent 1 degree of rotation.

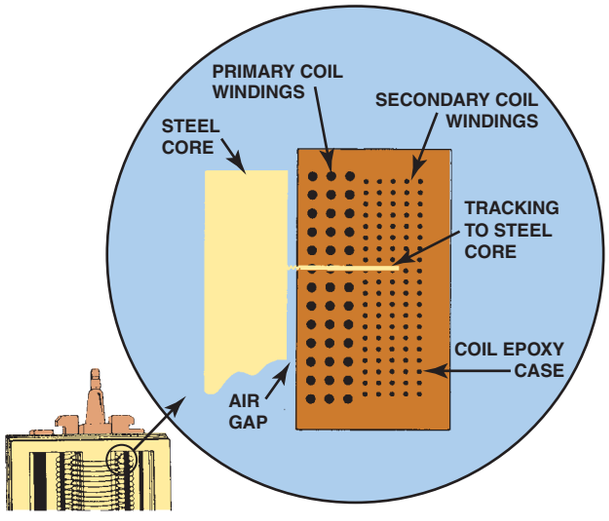


FIGURE 70–17 A track inside an ignition coil is not a short, but a low-resistance path or hole that has been burned through from the secondary wiring to the steel core.

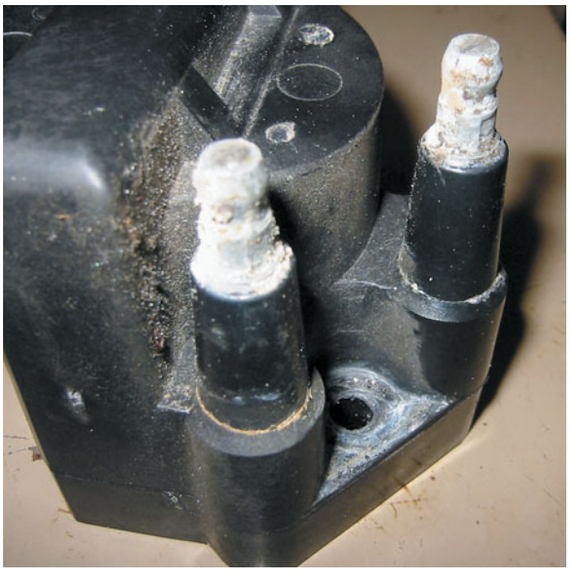


FIGURE 70–18 Corroded terminals on a waste-spark coil can cause misfire diagnostic trouble codes to be set.

TECH TIP

Bad Wire? Replace the Coil!

When performing engine testing (such as a compression test), always ground the coil wire or disable the primary ignition circuit by removing the ignition fuse. If the spark cannot spark to ground, the coil energy can (and usually does) arc inside the coil itself, creating a low-resistance path to the primary windings or the steel laminations of the coil. ● **SEE FIGURE 70–17.**

This low-resistance path is called a *track* and could cause an engine miss under load even though all of the remaining component parts of the ignition system are functioning correctly. Often these tracks do not show up on any coil test, including most scopes. Because the track is a lower resistance path to ground than normal, it requires that the ignition system be put under a load for it to be detected; and even then, the problem such as an engine misfire may be intermittent.

TECH TIP

Spark Plug Wire Pliers Are a Good Investment

Spark plug wires are often difficult to remove. Using good-quality spark plug wire pliers, as shown in ● **FIGURE 70–18,** saves time and reduces the chance of harming the wire during removal.

will help prevent damaging the wire as many wires are stuck to the spark plug and are often difficult to remove.

Make a thorough visual inspection of the following items.

- Check all spark plug wires for proper routing. All plug wires should be in the factory wiring separators and be clear of any metallic object that could damage the insulation and cause a short-to-ground fault.
- Check that all spark plug wires are securely attached to the spark plugs and to the distributor cap or ignition coil(s).



FIGURE 70–19 This spark plug boot on an overhead camshaft engine has been arcing to the valve cover causing a misfire to occur.



FIGURE 70–20 Measuring the resistance of a spark plug wire with a multimeter set to the ohms position. The reading of 16.03 kΩ (16.03 ohms) is okay because the wire is about 2 ft long. Maximum allowable resistance for a spark plug wire this long would be 20 kΩ (20,000 ohms).



FIGURE 70–21 Spark plug wire boot pliers are a handy addition to any tool box.

- Check that all spark plug wires are clean and free from excessive dirt or oil. Check that all protective covers normally covering the coil and/or distributor cap are in place and not damaged.
- Carefully check the cap and distributor rotor for faults or coil secondary terminal on waste spark coils. ● **SEE FIGURE 70–19.**

Visually check the wires and boots for damage. ● **SEE FIGURE 70–20.**

OHMMETER TESTING Check all spark plug wires with an ohmmeter for proper resistance. Good spark plug wires should measure less than 10,000 ohms per foot of length. ● **SEE FIGURE 70–21.**



FIGURE 70–22 A water spray bottle is an excellent diagnostic tool to help find an intermittent engine misfire caused by a break in a secondary ignition circuit component.

TECH TIP

Use a Water Spray Bottle to Check for Bad Spark Plug Wires

For intermittent problems, use a spray bottle to apply a water mist to the spark plugs, distributor cap, and spark plug wires. ● **SEE FIGURE 70–22.** With the engine running, the water may cause an arc through any weak insulating materials and cause the engine to miss or stall.

NOTE: Adding a little salt or liquid soap to the water makes the water more conductive and also makes it easier to find those hard-to-diagnose intermittent ignition faults.

SPARK PLUGS

SPARK PLUG CONSTRUCTION Spark plugs are manufactured from ceramic insulators inside a steel shell. The threads of the shell are rolled and a seat is formed to create a gas-tight seal with the cylinder head. ● **SEE FIGURE 70–23.**

Physical differences in spark plugs include the following:

- **Reach.** The reach is the length of the threaded part of the plug.
- **Heat range.** The heat range of the spark plug refers to how rapidly the heat created at the tip is transferred to the cylinder head. A plug with a long ceramic insulator path will run hotter at the tip than a spark plug that has a shorter path because the heat must travel farther. ● **SEE FIGURE 70–24.**
- **Type of seat.** Some spark plugs use a gasket and others rely on a tapered seat to seal.

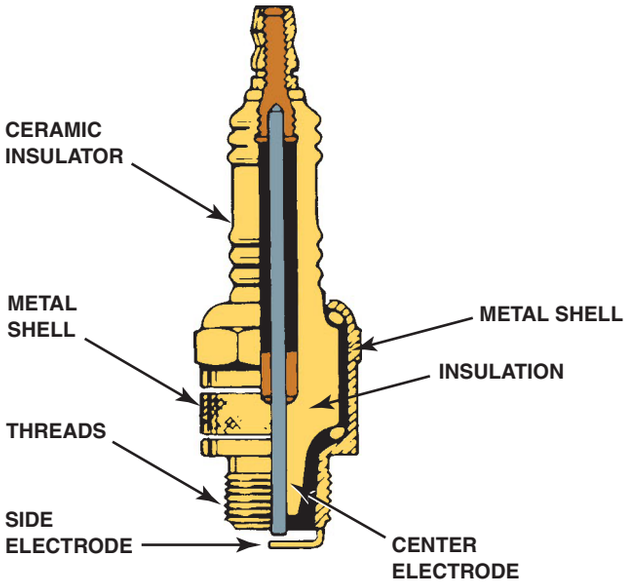


FIGURE 70–23 Parts of a spark plug.

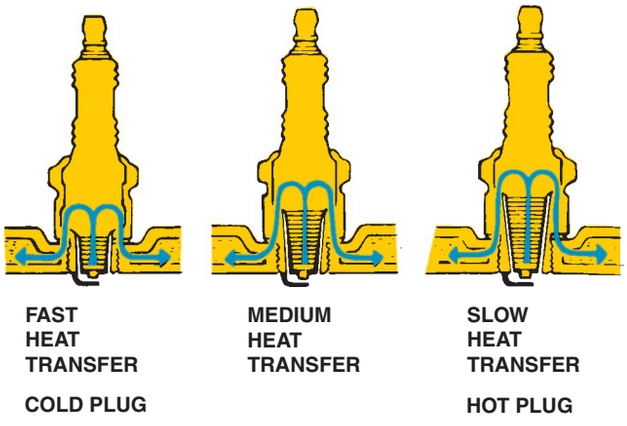


FIGURE 70–24 The heat range of a spark plug is determined by the distance the heat flows from the tip to the cylinder head.

RESISTOR SPARK PLUGS

Most spark plugs include a resistor in the center electrode, to reduce electromagnetic noise or radiation from the ignition system. The closer the resistor is to the actual spark or arc, the more effective it becomes. The value of the resistor is usually between 2,500 and 7,500 ohms.

PLATINUM SPARK PLUGS

Platinum spark plugs have a small amount of the precious metal platinum included onto the end of the center electrode, as well as on the ground or side electrode. Platinum is a gray-white metal that does not react with oxygen and, therefore, will not erode away as can occur with conventional nickel alloy spark plug electrodes. Platinum is also used as a catalyst in catalytic converters where it is able to start a chemical reaction without itself being consumed.

IRIDIUM SPARK PLUGS

Iridium is a white precious metal and is the most corrosion-resistant metal known. Most **iridium spark plugs** use a small amount of iridium welded onto the tip of a small center electrode 0.0015 to 0.002 in. (0.4 to 0.6 mm) in diameter. The small diameter reduces the voltage required to jump the gap between the center and the side electrode, thereby reducing possible misfires. The ground or side electrode is usually tipped with platinum to help reduce electrode gap wear.

Spark plugs should be inspected when an engine performance problem occurs and should be replaced at specified intervals to ensure proper ignition system performance.



FIGURE 70–25 When removing spark plugs, it is wise to arrange them so that they can be compared and any problem can be identified with a particular cylinder.



FIGURE 70–26 A spark plug thread chaser is a low-cost tool that hopefully will not be used often, but is necessary in order to clean the threads before installing new spark plugs.

- Nonplatinum spark plugs have a service life of over 20,000 miles (32,000 km).
- Platinum-tipped original equipment spark plugs have a typical service life of 60,000 to 100,000 miles (100,000 to 160,000 km) or longer.

Used *Platinum-tipped spark plugs should not be regapped!* Using a gapping tool can break the platinum after it has been used in an engine. Check service information regarding the recommended type of spark plugs and the specified service procedures.

SPARK PLUG SERVICE

When replacing spark plugs, perform the following steps.

STEP 1 **Check service information.** Check for the exact spark plug to use and the specified instructions and/or technical service bulletins that affect the part number of plug to be used or a revised replacement procedure.

STEP 2 **Allow the engine to cool before removing spark plugs.** This step is especially critical on engines with aluminum cylinder heads.

STEP 3 **Use compressed air or a brush to remove dirt from around the spark plug before removal.** This step helps prevent dirt from getting into the cylinder of an engine while removing a spark plug.

STEP 4 **Check the spark plug gap and correct as needed.** Be careful not to damage the tip on the center electrode if adjusting a platinum or iridium type of spark plug.

STEP 5 **Install the spark plugs.** Be sure the threads are clean by using a thread chaser. Then install the spark plug by hand, then using the proper spark plug socket and a torque wrench, tighten the plugs to factory specifications.

● **SEE FIGURES 70–25 AND 70–26.**



FIGURE 70–27 A normally worn spark plug that uses a tapered platinum-tipped center electrode.



FIGURE 70–28 Spark plug removed from an engine after a 500-mile race. Note the clipped side (ground) electrode. The electrode design and narrow (0.025 in.) gap are used to ensure that a spark occurs during extremely high engine speed operation.

Spark plugs are the windows to the inside of the combustion chamber. A thorough visual inspection of the spark plugs often can lead to the root cause of an engine performance problem. Two indications on spark plugs and their possible root causes in engine performance include the following:

1. **Carbon fouling.** If the spark plug(s) has *dry black carbon* (soot), the usual causes include:
   - Excessive idling
   - Defective thermostat
   - Overly rich air-fuel mixture due to a fuel system fault
   - Weak ignition system output
2. **Oil fouling.** If the spark plug has *wet, oily* deposits with little electrode wear, oil may be getting into the combustion chamber from the following:



FIGURE 70–29 Typical worn spark plug. Notice the rounded center electrode. The deposits indicate a possible coolant usage problem.



FIGURE 70–30 New spark plug that was fouled by an overly rich air-fuel mixture. The engine from which this spark plug came had a defective (stuck partially open) injector on this one cylinder only.

   - Worn or broken piston rings
   - Worn valve guides
   - Defective or missing valve stem seals

When removing spark plugs, place them in order so that they can be inspected to check for engine problems that might affect one or more cylinders. All spark plugs should be in the same condition, and the color of the center insulator should be light tan or gray. If all the spark plugs are black or dark, the engine should be checked for conditions that could cause an overly rich air-fuel mixture or possible oil burning. If only one or a few spark plugs are black, check those cylinders for proper firing (possible defective spark plug wire) or an engine condition affecting only those particular cylinders. ● **SEE FIGURES 70–27 THROUGH 70–30.**

If all spark plugs are white, check for possible overadvanced ignition timing or a vacuum leak causing a lean air-fuel mixture. If only one or a few spark plugs are white, check for a vacuum leak or injector fault affecting the air-fuel mixture only to those particular cylinders.

SPARK PLUG TYPE	TORQUE WITH TORQUE WRENCH (LB-FT) CAST-IRON HEAD	ALUMINUM HEAD	TORQUE WITHOUT TORQUE WRENCH (TURNS AFTER SEATED) CAST-IRON HEAD	ALUMINUM HEAD
Gasket				
14 mm	26–30	18–22	1/4	1/4
18 mm	32–38	28–34	1/4	1/4
Tapered seat				
14 mm	7–15	7–15	1/16 (snug)	1/16 (snug)
18 mm	15–20	15–20	1/16 (snug)	1/16 (snug)

CHART 70–2

Typical spark plug installation torque.

TECH TIP

Two-Finger Trick

To help prevent overtightening a spark plug when a torque wrench is not available, simply use two fingers on the ratchet handle. Even the strongest service technician cannot overtighten a spark plug by using two fingers.

NOTE: The PCM "senses" rich or lean air-fuel ratios by means of input from the oxygen sensor(s). If one cylinder is lean, the PCM may make all other cylinders richer to compensate.

Inspect all spark plugs for wear by first checking the condition of the center electrode. As a spark plug wears, the center electrode becomes rounded. If the center electrode is rounded, higher ignition system voltage is required to fire the spark plug.

When installing spark plugs, always use the correct tightening torque to ensure proper heat transfer from the spark plug shell to the cylinder head. ● **SEE CHART 70–2.**

NOTE: General Motors does not recommend the use of antiseize compound on the threads of spark plugs being installed in an aluminum cylinder head, because the spark plug will be overtightened. This excessive tightening torque places the threaded portion of the spark plug too far into the combustion chamber where carbon can accumulate and result in the spark plugs being difficult to remove. If antiseize compound is used on spark plug threads, reduce the tightening torque by 40%. Always follow the vehicle manufacturer's recommendations.

IGNITION TIMING

PURPOSE **Ignition timing** refers to when the spark plug fires in relation to piston position. The time when the spark occurs depends on engine speed, and therefore, it must be advanced (spark plugs fire sooner) as the engine rotates faster. The ignition process in the cylinder takes a certain amount of time, usually 30 ms (30/1,000 of a second) and remains constant regardless of engine speed. Therefore, to maintain the most efficient combustion, the ignition sequence has to occur sooner as the engine speed increases. For maximum efficiency from the expanding gases inside the combustion chamber, the burning of the air-fuel mixture should end by about 10 degrees after top dead center (ATDC). If the burning of the mixture is still occurring after that point, the expanding gases do not exert much force on the piston because the gases are "chasing" the piston as it moves downward.

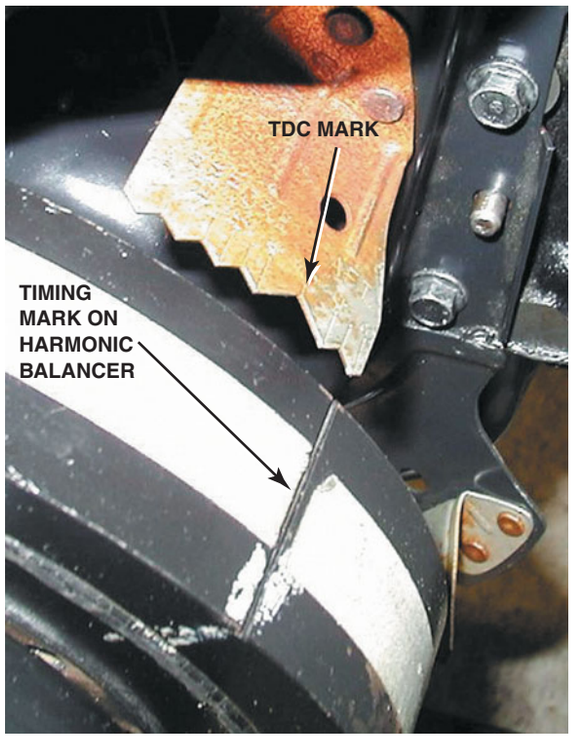


FIGURE 70–31 Ignition timing marks are found on the harmonic balancers on engines equipped with distributors that can be adjusted for timing.

Therefore, to achieve the goal of having the air-fuel mixture be completely burned by the time the piston reaches 10° after top dead center (ATDC), the spark must be advanced (occur sooner) as the engine speed increases. This timing advance is determined and controlled by the PCM on most vehicles. ● **SEE FIGURE 70–31.**

If the engine is equipped with a distributor, it *may* or *may not* be possible to adjust the base or the initial timing. Check service information for details regarding the vehicle being serviced.

The initial timing is usually set to fire the spark plug between zero degrees (top dead center, or TDC) or slightly before TDC (BTDC). Initial (base) ignition timing changes as mechanical wear occurs on the following:

- Timing chain
- Distributor gear
- Camshaft drive gear

● **SEE FIGURE 70–32.**

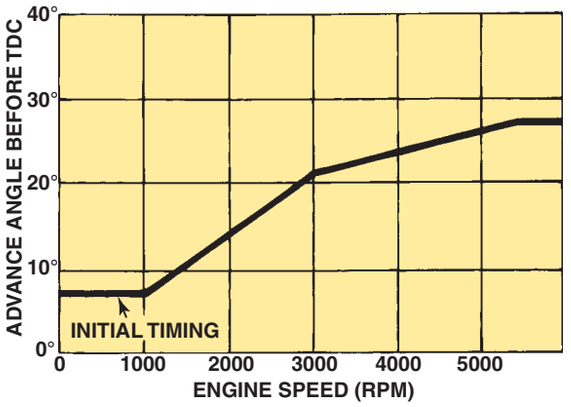


FIGURE 70–32 The initial (base) timing is where the spark plug fires at idle speed. The PCM then advances the timing based primarily on engine speed.

TECH TIP

Two Marks Are the Key to Success

When a distributor is removed from an engine, always mark where the rotor is pointing to ensure that the distributor is reinstalled in the correct position. Because of the helical cut on the distributor drive gear, the rotor rotates as the distributor is being removed from the engine. To help reinstall a distributor without problems, simply make another mark where the rotor is pointing just as the distributor is lifted out of the engine. Then to reinstall, line up the rotor to the second mark and lower the distributor into the engine. The rotor should then line up with the original mark as a double check.

CHECKING IGNITION TIMING To be assured of the proper ignition timing, follow the exact timing procedure indicated on the underhood vehicle emission control information (VECI) decal. If the decal is missing, check with service information for the timing procedure.

NOTE: The ignition timing for waste-spark and coil-on-plug ignition systems cannot be adjusted.

FIRING ORDER

Firing order is the order that the spark is distributed to the correct spark plug at the right time. The firing order of an engine is determined by crankshaft and camshaft design. The ignition firing order is determined by the location of the spark plug wires in the distributor cap of an engine equipped with a distributor and how the spark plug wires are installed on the waste-spark coils. The firing order is often cast into the intake manifold for easy reference. ● **SEE FIGURE 70–33.**

NOTE: Most service manuals also show the firing order and the direction of the distributor rotor rotation, how the cylinders are numbered, and the location of the spark plug wires on the distributor cap.

Firing order is also important for waste-spark-type ignition systems. The spark plug wire can often be installed on the wrong coil pack, creating a no-start condition or poor engine operation.



FIGURE 70–33 The firing order is cast or stamped on the intake manifold of most engines that have a distributor ignition.



FIGURE 70–34 Always take the time to install spark plug wires back into the original holding brackets (wiring combs).

TECH TIP

Route the Wires Right!

High voltage is present through spark plug wires when the engine is running. Surrounding the spark plugs is a magnetic field that can affect other circuits or components of the vehicle. For example, if a spark plug wire is routed too closely to the signal wire from a mass airflow (MAF) sensor, the induced signal from the ignition wire could create a false MAF signal to the PCM. The PCM, not knowing the signal was false, would act on the MAF signal and command the appropriate amount of fuel based on the false MAF signal.

To prevent any problems associated with high-voltage spark plug wires, be sure to route them the same as the original plug wires, using all factory holding brackets and wiring combs. ● **SEE FIGURE 70–34.**

Most factory service manuals show the correct routing if the factory method is unknown.

DISTRIBUTOR INDEXING

A few engines using a distributor also use it to house a camshaft position (CMP) sensor. One purpose of this sensor is to properly initiate the fuel-injection sequence. Some of these engines use a positive distributor position notch or clamp that allows the distributor to be placed in only one position, while others use a method of indexing to verify the distributor position. ● **SEE FIGURE 70–35.**

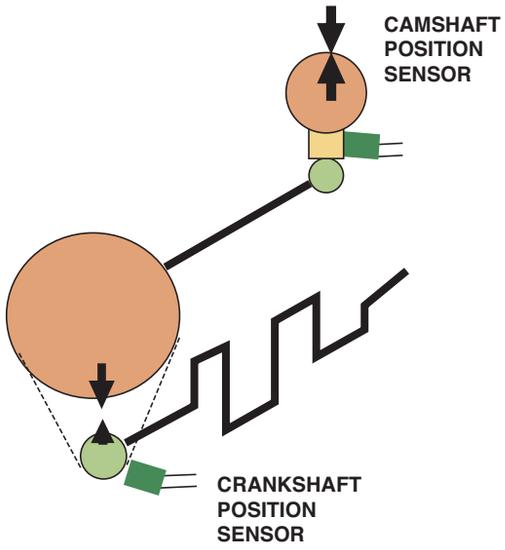


FIGURE 70–35 The relationship between the crankshaft position (CKP) sensor and the camshaft position (CMP) sensor is affected by wear in the timing gear and/or chain.

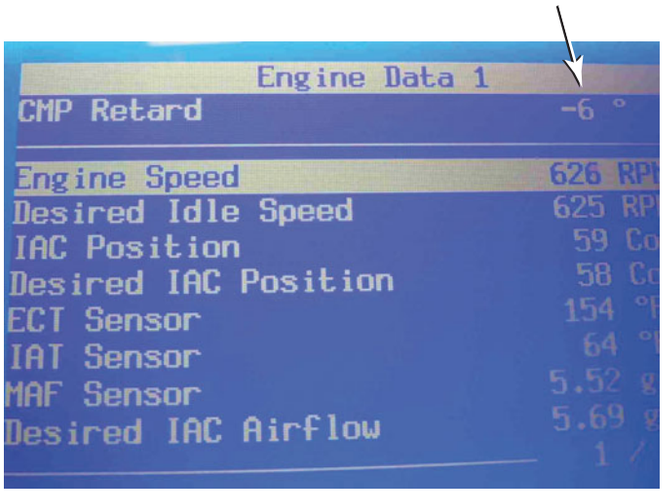


FIGURE 70–36 A scan tool displays excessive cam retard on a Chevrolet pickup truck V-6. The cam retard value should be ± 2 degrees.

If a distributor is not indexed correctly, the following symptoms may occur.

- Surging (especially at idle speed)
- Light bucking
- Intermittent engine misfiring

This will most likely occur when the vehicle is at operating temperature, and under a light load at approximately 2,000 RPM. A misindexed distributor may cause these conditions.

NOTE: This is not the same as setting the ignition timing. Indexing the distributor does not affect the ignition timing.

Always use the factory procedure as stated in service information. Some of the methods may require a scan tool, while others require the use of a voltmeter to verify position. Jeep, late model Chrysler V-6 and V-8 engines, and some GM trucks require indexing. ● **SEE FIGURES 70–36 AND 70–37.**



FIGURE 70–37 A worn distributor drive gear can be the cause of an out-of-specification camshaft position (CMP) signal.

NO-START DIAGNOSIS

A no-start condition (with normal engine cranking speed) can be the result of either no spark or no fuel delivery.

The PCM uses the ignition primary pulses as a signal to inject fuel in a fuel-injection system. If there is no pulse, then there is no squirt of fuel. To determine exactly what is wrong, follow these steps.

STEP 1 Test the output signal from the crankshaft sensor. Most engines with waste-spark or COP ignitions use a crankshaft position (CKP) sensor. These sensors are either the Hall-effect or the magnetic type. The sensors must be able to produce a variable (either analog or digital) signal. A voltmeter set to read DC volts for a Hall-effect sensor or set to read AC volts for a magnetic sensor should read a voltage across the sensor leads when the engine is being cranked. If there is no changing voltage output, replace the sensor.

STEP 2 If the sensor tests okay in step 1, check for a changing voltage signal at the ignition module.

NOTE: Step 2 checks the wiring between the crankshaft position (CKP) sensor and the ignition control module.

STEP 3 If the ignition control module is receiving a changing signal from the crankshaft position sensor, it must be capable of switching the power to the ignition coils on and off. Remove a coil or coil package, and with the ignition switched to on (run), check for voltage at the positive terminal of the coil(s).

NOTE: Several manufacturers program the current to the coils to be turned off within several seconds of the ignition being switched to on if no pulse is received by the PCM. This circuit design helps prevent ignition coil damage in the event of a failure in the control circuit or driver error, by keeping the ignition switch on (run) without operating the starter (start position). Some Chrysler brand engines do not supply power to the positive (+) side of the coil through the automatic shutdown (ASD) relay until a crank pulse is received by the PCM.

CAUTION: Most ignition systems can produce 40,000 volts or more, with energy levels high enough to cause personal injury. Do not disconnect a spark plug wire while the engine is running, because it may damage the ignition system or create a shock hazard.

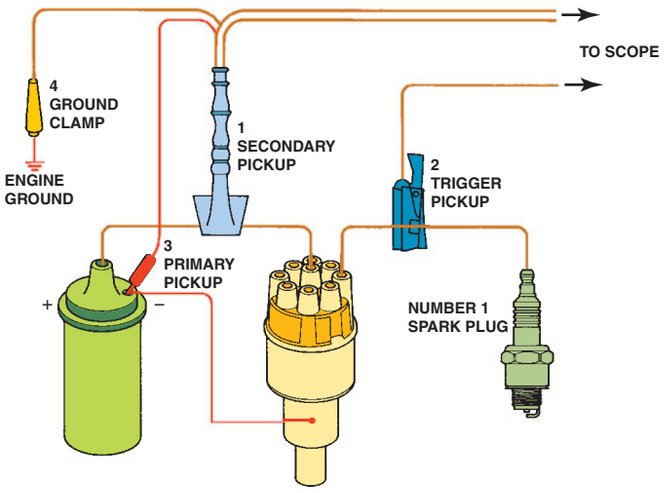


FIGURE 70–38 Typical engine analyzer hookup that includes a scope display. (1) Coil wire on top of the distributor cap if integral type of coil; (2) number 1 spark plug connection; (3) negative side of the ignition coil; (4) ground (negative) connection of the battery.

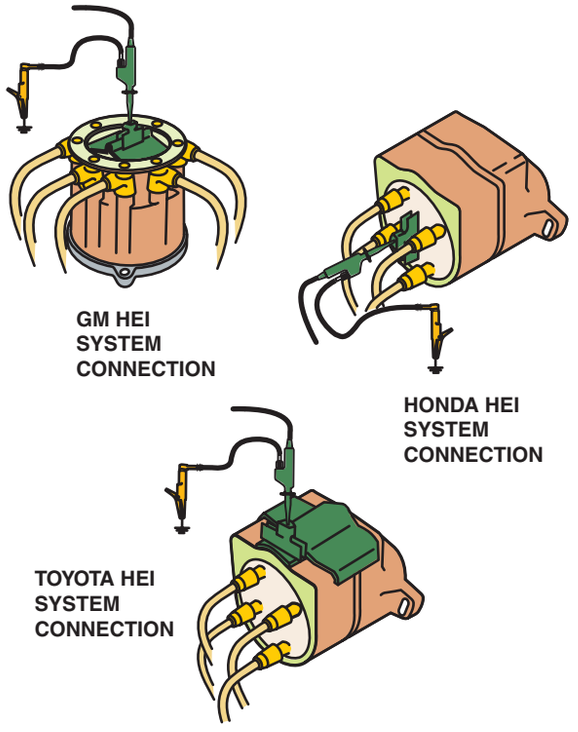


FIGURE 70–39 Clip-on adapters are used with an ignition system that uses an integral ignition coil.

IGNITION SCOPE TESTING

TERMINOLOGY All ignition systems must charge and discharge an ignition coil. With the engine off, ignition scopes will display a horizontal line. With the engine running, this horizontal (zero) line is changed to a pattern that will have sections both above and below the zero line. Sections of this pattern that are above the zero line indicate that the ignition coil is discharging. Sections of the scope pattern below the zero line indicate charging of the ignition coil. The height of the scope pattern indicates voltage. The length (from left to right) of the scope pattern indicates time. ● **SEE FIGURES 70–38 AND 70–39** for typical scope hookups.

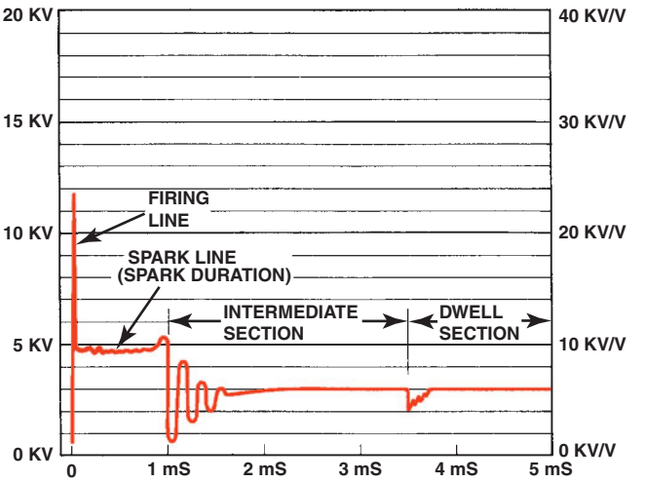


FIGURE 70–40 Typical secondary ignition oscilloscope pattern.

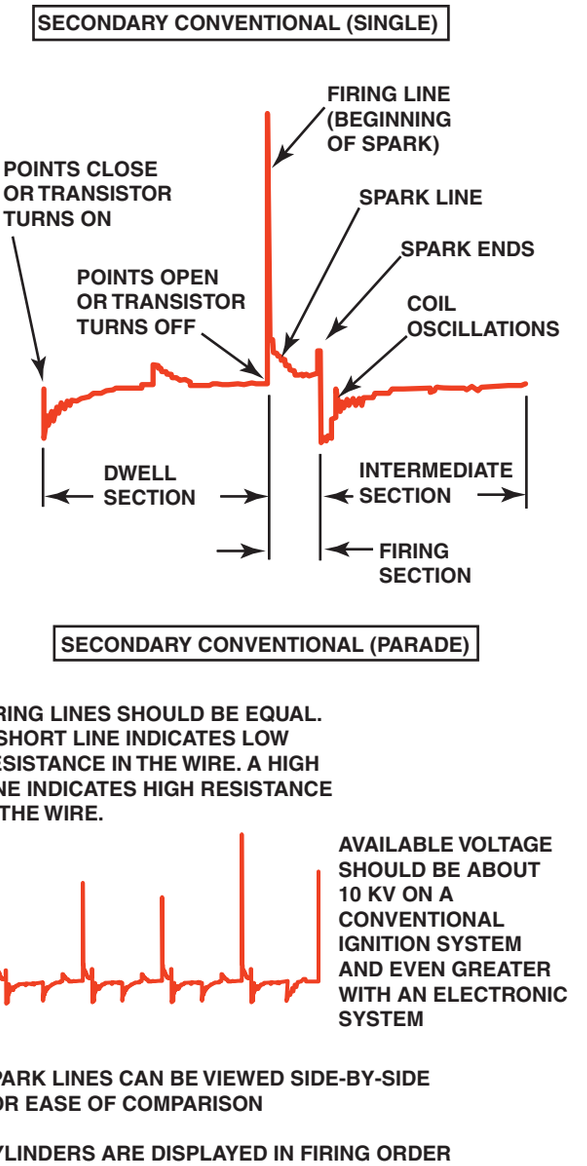


FIGURE 70–41 A single cylinder is shown at the top and a 4-cylinder engine at the bottom.

FIRING LINE The leftmost vertical (upward) line is called the **firing line.** The height of the firing line should be between 5,000 and 15,000 volts (5 and 15 kV) with not more than a 3 kV difference between the highest and the lowest cylinder's firing line. ● **SEE FIGURES 70–40 AND 70–41.**

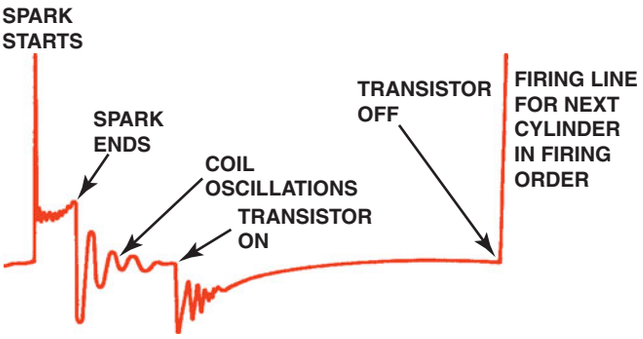


FIGURE 70–42 Drawing shows what is occurring electrically at each part of the scope pattern.

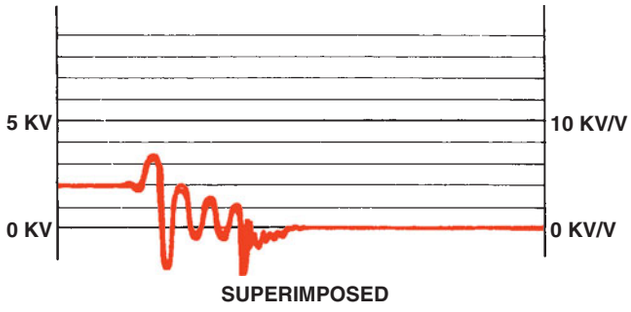


FIGURE 70–43 Typical secondary ignition pattern. Note the lack of firing lines on the superimposed pattern.

The height of the firing line indicates the *voltage* required to fire the spark plug. It requires a high voltage to make the air inside the cylinder electrically conductive (to ionize the air). One or more of the following conditions may cause higher-than-normal height firing lines.

1. Spark plug gapped too wide
2. Lean fuel mixture
3. Defective spark plug wire (excessive resistance or electrically open)

If the firing lines are higher than normal for *all* cylinders, then possible causes include one or more of the following:

1. Worn distributor cap and/or rotor (if the vehicle is so equipped)
2. Excessive wearing of all spark plugs
3. Defective coil wire (the high voltage could still jump across the open section of the wire to fire the spark plugs)

SPARK LINE

The **spark line** is a short horizontal line connected to the firing line. The height of the spark line represents the voltage required to maintain the spark across the spark plug after the spark has started. The height of the spark line should be one-fourth of the height of the firing line (between 1.5 and 2.5 kV). The length (from left to right) of the line represents the length of time for which the spark lasts (duration). The spark duration should be between 0.8 and 2.2 milliseconds (usually between 1.0 and 2.0 ms). The spark stops at the end (right side) of the spark line, as shown in ● **FIGURE 70–42.**

INTERMEDIATE OSCILLATIONS

After the spark has stopped, some energy remains in the coil. This remaining energy dissipates in the coil windings and the entire secondary circuit. The oscillations are also called the "ringing" of the coil as it is pulsed.

The secondary pattern amplifies any voltage variation occurring in the primary circuit because of the turns ratio between the primary and secondary windings of the ignition coil. A correctly operating ignition system should display five or more "bumps" (oscillations) (three or more for a GM HEI system).

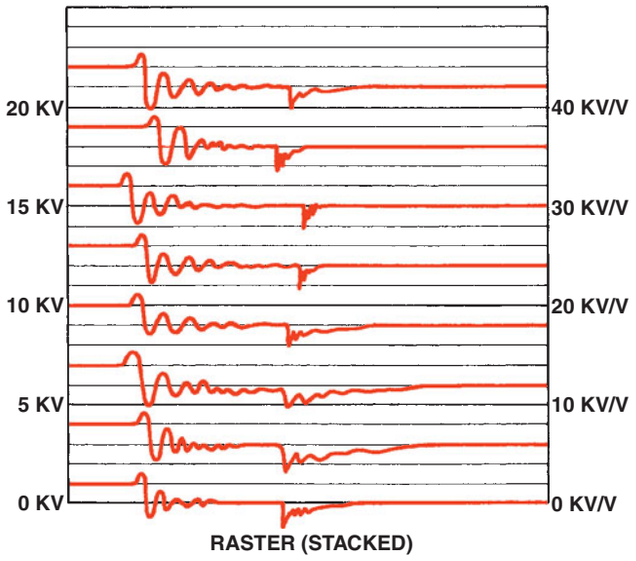


FIGURE 70–44 Raster is the best scope position to view the spark lines of all the cylinders to check for differences. Most scopes display cylinder 1 at the bottom. The other cylinders are positioned by firing order above cylinder 1.

TRANSISTOR-ON POINT

After the intermediate oscillations, the coil is empty (not charged), as indicated by the scope pattern being on the zero line for a short period. When the transistor turns on in an electronic ignition system, the coil is being charged. Note that the charging of the coil occurs slowly (coil-charging oscillations) because of the inductive reactance of the coil.

DWELL SECTION

Dwell is the amount of time that the current is charging the coil from the transistor-on point to the transistor-off point. The end of the dwell section marks the beginning of the next firing line. This point is called "transistor off," and indicates that the primary current of the coil is stopped, resulting in a high-voltage spark out of the coil.

PATTERN SELECTION

The entire pattern is not seen on a scope. Ignition oscilloscopes use three positions to view certain sections of the basic pattern more closely. These three positions are as follows:

1. **Superimposed.** This superimposed position is used to look at differences in patterns between cylinders in all areas except the firing line. There are no firing lines illustrated in superimposed positions. ● **SEE FIGURE 70–43.**
2. **Raster (*stacked*).** Cylinder 1 appears at the bottom of the screen and all other cylinder patterns are displayed upward in the engine's firing order. Use the raster (stacked) position to look at the spark line length and transistor-on point. The raster pattern shows all areas of the scope pattern except the firing lines. ● **SEE FIGURE 70–44.**
3. **Display *(parade).*** Display (parade) is the only position in which firing lines are visible and the cylinders are displayed on the screen from left to right in the engine's firing order. This selection is used to compare the height of firing lines among all cylinders. ● **SEE FIGURE 70–45.**

READING THE SCOPE ON DISPLAY (PARADE)

Start the engine and operate at approximately 1,000 RPM to ensure a smooth and accurate scope pattern. Firing lines are visible only on the display (parade) position. The firing lines should all be 5 to 15 kV in height and be within 3 kV of each other. If one or more cylinders have high firing lines, this could indicate a defective (open) spark

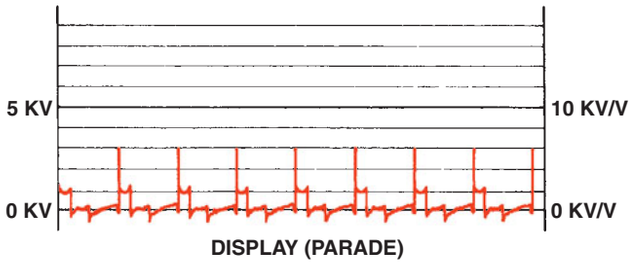


FIGURE 70–45 Display is the only position to view the firing lines of all cylinders. Cylinder 1 is displayed on the left (except for its firing line, which is shown on the right). The cylinders are displayed from left to right by firing order.

REAL WORLD FIX

A Technician's Toughie

A vehicle ran poorly, yet its scope patterns were "perfect." Remembering that the scope indicates only that a spark has occurred (not necessarily inside the engine), the technician grounded one spark plug wire at a time using a vacuum hose and a test light. Every time a plug wire was grounded, the engine ran worse, until the last cylinder was checked. When the last spark plug wire was grounded, the engine ran the same. The technician checked the spark plug wire with an ohmmeter; it tested within specifications (less than 10,000 ohms per foot of length). The technician also removed and inspected the spark plug. The spark plug looked normal. The spark plug was reinstalled and the engine tested again. The test had the same results as before—the engine seemed to be running on seven cylinders, yet the scope pattern was perfect.

The technician then replaced the spark plug for the affected cylinder. The engine ran correctly. Very close examination of the spark plug showed a thin crack between the wire terminal and the shell of the plug. Why didn't the cracked plug show on the scope? The scope simply indicated that a spark had occurred. The scope cannot distinguish between a spark inside and outside the engine. In this case, the voltage required to travel through the spark plug crack to ground was about the same voltage required to jump the spark plug electrodes inside the engine. The spark that occurred across the cracked spark plug, however, may have been visible at night with the engine running.

plug wire, a spark plug gapped too far, or a lean fuel mixture affecting only those cylinders.

A lean mixture (not enough fuel) requires a higher voltage to ignite because there are fewer droplets of fuel in the cylinder for the spark to use as "stepping stones" for the voltage to jump across. Therefore, a lean mixture is less conductive than a rich mixture.

READING THE SPARK LINES

Spark lines can easily be seen on either superimposed or raster (stacked) position. On the raster position, each individual spark line can be viewed.

The spark lines should be level and one-fourth as high as the firing lines (1.5 to 2.5 kV, but usually less than 2 kV). The spark line voltage is called the **burn kV.** The *length* of the spark line is the critical factor for determining proper operation of the engine because it represents the spark duration time. There is only a limited amount of energy in an ignition coil. If most of the energy is used to ionize the air

NORMAL SPARK LINE LENGTH (AT 700 TO 1200 RPM)

NUMBER OF CYLINDERS	MILLISECONDS	PERCENTAGE (%) OF DWELL SCALE	DEGREES
4	1–2	3–6	3–5
6	1–2	4–9	2–5
8	1–2	6–13	3–6

CHART 70–3

Converting between units is sometimes needed depending on the type of scope used.

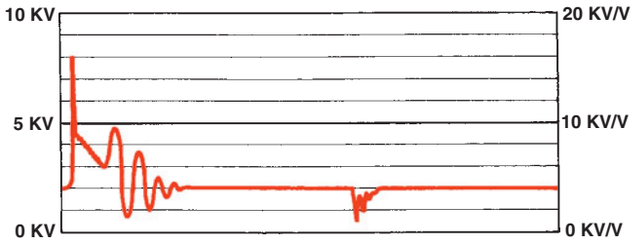


FIGURE 70–46 A downward-sloping spark line usually indicates high secondary ignition system resistance or an excessively rich air-fuel mixture.

gaps of the rotor and the spark plug, there may not be enough energy remaining to create a spark duration long enough to completely burn the air-fuel mixture. Many scopes are equipped with a **millisecond (ms) sweep.** This means that the scope will sweep only that portion of the pattern that can be shown during a 5 ms or 25 ms setting.

Following are guidelines for spark line length.

- 0.8 ms: too short
- 1.5 ms: average
- 2.2 ms: too long

If the spark line is too short, possible causes include the following:

1. Spark plug(s) gapped too widely
2. Rotor tip to distributor cap insert distance gapped too widely (worn cap or rotor)
3. High-resistance spark plug wire
4. Air-fuel mixture too lean (vacuum leak, broken valve spring, etc.)

If the spark line is too long, possible causes include the following:

1. Fouled spark plug(s)
2. Spark plug(s) gapped too closely
3. Shorted spark plug or spark plug wire

Many scopes do not have a millisecond scale. Some scopes are labeled in degrees and/or percentage (%) of dwell. ● **CHART 70–3** can be used to determine acceptable spark line length.

SPARK LINE SLOPE

Downward-sloping spark lines indicate that the voltage required to maintain the spark duration is decreasing during the firing of the spark plug. Although it is normal for the spark line to angle downward slightly, a steep slope indicates that the spark energy is finding ground through spark plug deposits (the plug is fouled) or other ignition problems. ● **SEE FIGURE 70–46.**

An upward-sloping spark line usually indicates a mechanical engine problem. A defective piston ring or valve would tend to seal better in the increasing pressures of combustion. As the spark plug fires, the effective increase in pressures increases the voltage required to maintain the spark, and the height of the spark line rises during the duration of the spark. ● **SEE FIGURE 70–47.**

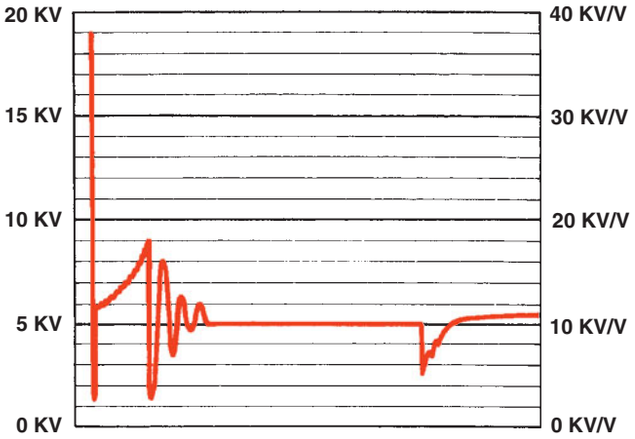


FIGURE 70–47 An upward-sloping spark line usually indicates a mechanical engine problem or a lean air-fuel mixture.

An upward-sloping spark line can also indicate a lean air-fuel mixture. Typical causes include:

1. Clogged injector(s)
2. Vacuum leak
3. Sticking intake valve

● **SEE FIGURE 70–48** for an example showing the relationship between the firing line and the spark line.

READING THE INTERMEDIATE SECTION

The intermediate section should have three or more oscillations (bumps) for a correctly operating ignition system. Because approximately 250 volts are in the primary ignition circuit when the spark stops flowing across the spark plugs, this voltage is reduced by about 75 volts per oscillation. Additional resistances in the primary circuit would decrease the number of oscillations. If there are fewer than three oscillations, possible problems include the following:

1. Shorted ignition coil
2. Loose or high-resistance primary connections on the ignition coil or primary ignition wiring

DWELL AND CURRENT-LIMITING HUMP

Ignition systems use a dwell period to charge the coil. Dwell is the time that current is charging the coil, and changes with increasing RPM in many electronic ignition systems. This change in dwell with RPM should be considered normal.

Many EI systems also produce a "hump" in the dwell section, which reflects a current-limiting circuit in the control module. These current-limiting humps may have slightly different shapes depending on the exact module used. For example, the humps produced by various GM HEI modules differ slightly.

DWELL VARIATION (DISTRIBUTOR IGNITION)

A worn distributor gear, worn camshaft gear, or other distributor problem may cause engine performance problems, because the signal created in the distributor will be affected by the inaccurate distributor operation. However, many electronic ignitions vary the length of the dwell period electronically in the module to maintain acceptable current flow levels through the ignition coil and ignition control module (ICM).

Different EI systems use one of three different designs. The dwell length characteristic and the types of EI systems that use each design are as follows:

1. Dwell time remains *constant* as the engine speed is increased.
2. Dwell time *decreases* as the engine speed is increased.
3. Dwell time *increases* as the engine speed is increased.

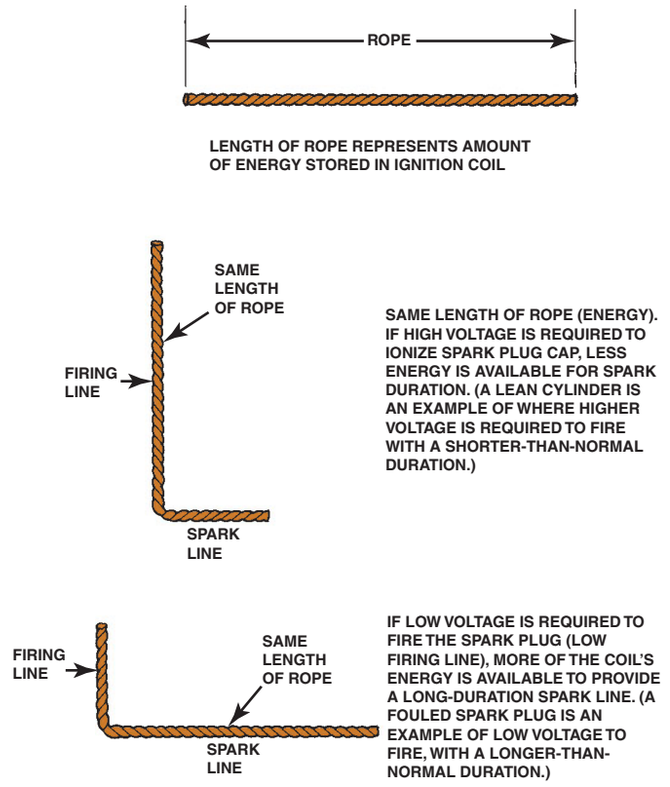


FIGURE 70–48 The relationship between the height of the firing line and length of the spark line can be illustrated using a rope. Because energy cannot be destroyed, the stored energy in an ignition coil must dissipate totally, regardless of engine operating conditions.

NOTE: Waste-spark and coil-on-plug ignition systems also vary dwell time electronically within the PCM or ignition module.

ACCELERATION CHECK

With the scope selector set on the display (parade) position, rapidly accelerate the engine (gear selector in park or neutral with the parking brake on). The results should be interpreted as follows:

1. All firing lines should rise evenly (not to exceed 75% of maximum coil output) for properly operating spark plugs.
2. If the firing lines on one or more cylinders fail to rise, this indicates fouled spark plugs.

ROTOR GAP VOLTAGE (DI SYSTEMS)

The rotor gap voltage test measures the voltage required to jump the gap (0.03 to 0.05 in., or 0.8 to 1.3 mm) between the rotor and the inserts (segments) of the distributor cap. Select the display (parade) scope pattern and remove a spark plug wire (at the spark plug end), then using a jumper connected to a good ground, insert the jumper into the spark plug boot making sure it contacts the plug wire terminal. Start the engine and observe the height of the firing line for the cylinder being tested. Because the spark plug wire is connected directly to ground, the firing line height on the scope will indicate the voltage required to jump the air gap between the rotor and the distributor cap insert. The normal rotor gap voltage is 3 to 7 kV, and the voltage should not exceed 8 kV. If the rotor gap voltage indicated is near or above 8 kV, inspect and replace the distributor cap and/or rotor as required.

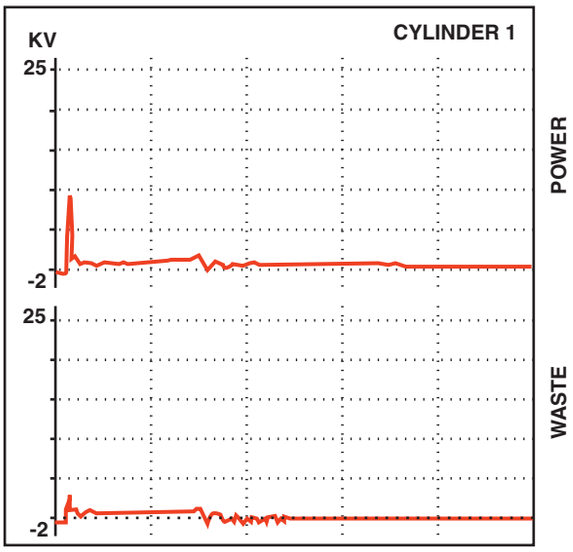


FIGURE 70–49 A dual trace scope pattern showing both the power and the waste spark from the same coil (cylinders 1 and 6). Note that the firing line is higher on the cylinder that is under compression (power); otherwise, both patterns are almost identical.

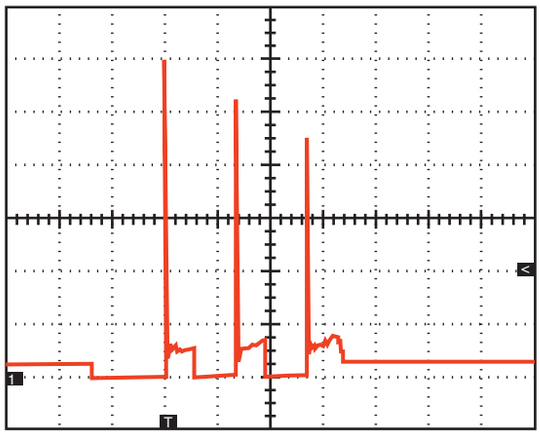


FIGURE 70–50 A secondary waveform of a Ford 4.6 liter V-8, showing three sparks occurring at idle speed.

The spark plugs are fired three times when the engine is at idle speed to improve idle quality and to reduce exhaust emissions. Above certain engine speeds, the ignition system switches to a single-fire event. ● **SEE FIGURE 70–50.**

SCOPE-TESTING A WASTE-SPARK SYSTEM

A handheld digital storage oscilloscope can be used to check the pattern of individual cylinders. Some larger scopes can be connected to all spark plug wires and therefore are able to display both power and waste-spark waveforms. ● **SEE FIGURE 70–49.**

Because the waste spark does not require as high a voltage level as the cylinder on the power stroke, the waste-spark firing line will be normally lower. The high and low firing lines will alternately change from high to low as the "paired" cylinders change from the compression to the exhaust strokes.

SCOPE-TESTING A COP SYSTEM

On a coil-on-plug (COP) type of ignition system, the individual coils can be shown on a scope and using the proper cables and adapters, the waveform for all of the cylinders can be viewed at the same time. Always follow the scope equipment manufacturer's instructions. Many Ford COP systems use a triple-strike secondary spark event.

IGNITION SYSTEM SYMPTOM GUIDE

The following list will assist technicians in troubleshooting ignition system problems.

Problem	Possible Causes and/or Solutions
No spark out of the coil	1. Open in the ignition switch circuit 2. Defective ignition module (if electronic ignition coil) 3. Defective trigger sensor 4. Open ignition fuse or power feed circuit
Weak spark out of the coil	1. High-resistance coil wire or spark plug wire 2. Poor ground between the distributor or module and the engine block
Engine misfiring	1. Defective (open) spark plug wire 2. Worn, cracked, or fouled spark plugs 3. Defective pickup coil 4. Defective module 5. Poor electrical connections at the pickup coil and/or module

REVIEW QUESTIONS

1. Why should a spark tester be used to check for spark rather than a standard spark plug?
2. How do you test a pickup coil for resistance and AC voltage output?
3. What harm can occur if the engine is cranked or run with an open (defective) spark plug wire?
4. What are the sections of a secondary ignition scope pattern?
5. What can the slope of the spark line indicate about the engine?

CHAPTER QUIZ

1. Technician A says that a pickup coil (pulse generator) can be tested with an ohmmeter. Technician B says that ignition coils can be tested with an ohmmeter. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
2. Technician A says that a defective spark plug wire can cause an engine misfire. Technician B says that a defective spark plug can cause an engine misfire. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. A spark tester should be used to check for spark because _____.
   a. A spark tester requires at least 25,000 volts to fire
   b. It is connected to the CKP sensor to check its output
   c. It can detect a cracked spark plug
   d. It can detect the gap of the spark plugs
4. Typical primary coil resistance specifications usually range from _____ ohms.
   a. 100 to 450 **c.** 0.5 to 3
   b. 500 to 1,500 **d.** 6,000 to 30,000
5. Typical secondary coil resistance specifications usually range from _____ ohms.
   a. 100 to 450 **c.** 1 to 3
   b. 500 to 1,500 **d.** 6,000 to 30,000
6. A coil is being tested using current ramping. The waveform should _____.
   a. Slope downward
   b. Slope upward
   c. Remain flat
   d. Start off flat then slope upward
7. Camshaft variation as displayed on a scan tool on an engine with a distributor-mounted CMP sensor should be ± _____ degrees.
   a. 10 **c.** 2
   b. 5 **d.** None of the above
8. The spark plug threads in the cylinder head should be cleaned using a(n) _____ before installing new plugs.
   a. Wire brush **c.** Old toothbrush
   b. Tap **d.** Thread chaser
9. Two technicians are discussing a no-start condition. During cranking, a magnet held over the coil moves and the engine backfires at times. Technician A says that a bad pickup coil or CKP sensor is the most likely cause. Technician B says that an open coil primary is the most likely cause. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
10. Which sensor produces a digital signal?
    a. Magnetic sensor **c.** Pickup coil
    b. Hall-effect sensor **d.** Both b and c

chapter 71

COMPUTER FUNDAMENTALS

OBJECTIVES: **After studying Chapter 71, the reader will be able to:** • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "A" (General Electrical/Electronic Systems Diagnosis). • Explain the purpose and function of onboard computers. • List the various parts of an automotive computer. • List input sensors. • List output devices (actuators) controlled by the computer.

KEY TERMS: Actuator 814 • Analog-to-digital (AD) converter 813 • Baud rate 815 • Binary system 816 • Clock generator 815 • Controller 812 • CPU 814 • Digital computer 814 • Duty cycle 817 • E^2PROM 813 • ECA 812 • ECM 812 • ECU 812 • EEPROM 813 • Engine mapping 814 • Input 813 • Input conditioning 813 • KAM 814 • Nonvolatile RAM 814 • Output drivers 816 • Powertrain control module (PCM) 812 • PROM 813 • PWM 817 • RAM 814 • ROM 813 • SAE 812

COMPUTER FUNDAMENTALS

PURPOSE AND FUNCTION Modern automotive control systems consist of a network of electronic sensors, actuators, and computer modules designed to regulate the powertrain and vehicle support systems. The onboard automotive computer has many names. It may be called an **electronic control unit (ECU), electronic control module (ECM), electronic control assembly (ECA),** or a **controller,** depending on the manufacturer and the computer application. The **Society of Automotive Engineers (SAE)** bulletin J1930 standardizes the name as a **powertrain control module (PCM).** The PCM coordinates engine and transmission operation, processes data, maintains

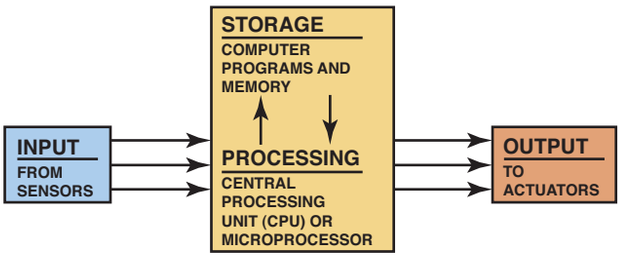


FIGURE 71–1 All computer systems perform four basic functions: input, processing, storage, and output.

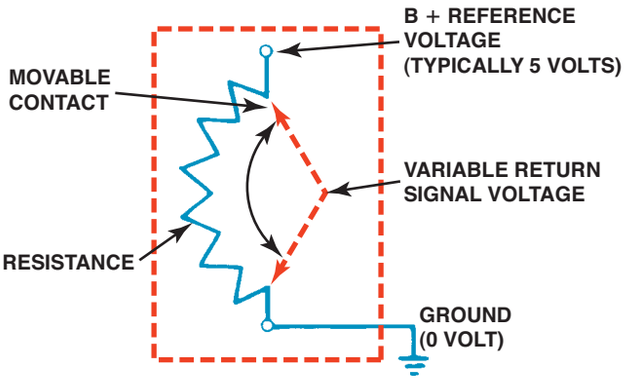


FIGURE 71–2 A potentiometer uses a movable contact to vary resistance and send an analog voltage right to the PCM.

communications, and makes the control decisions needed to keep the vehicle operating. Not only is it capable of operating the engine and transmission, but it is also able to perform the following:

- Undergo self-tests (40% of the computing power is devoted to diagnosis)
- Set and store diagnostic trouble codes (DTCs)
- Communicate with the technician using a scan tool

VOLTAGE SIGNALS Automotive computers use voltage to send and receive information. Voltage is electrical pressure and does not flow through circuits, but voltage can be used as a signal. A computer converts input information or data into voltage signal combinations that represent number combinations. A computer processes the input voltage signals it receives by computing what they represent, and then delivering the data in computed or processed form.

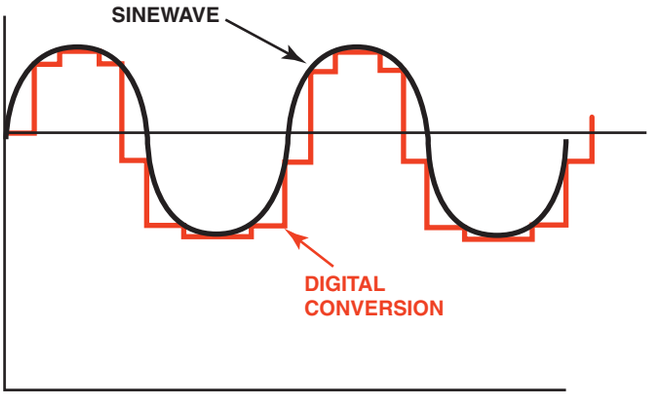


FIGURE 71–3 An AD converter changes analog (variable) voltage signals into digital signals that the PCM can process.

COMPUTER FUNCTIONS

BASIC FUNCTIONS The operation of every computer can be divided into four basic functions. ● **SEE FIGURE 71–1.**

- **Input.** Receives voltage signals from sensors
- **Processing.** Performs mathematical calculations
- **Storage.** Includes short-term and long-term memory
- **Output.** Controls an output device by either turning it on or off

INPUT FUNCTIONS First, the computer receives a voltage signal (input) from an input device. **Input** is a signal from a device that can be as simple as a button or a switch on an instrument panel, or a sensor on an automotive engine. ● **SEE FIGURE 71–2** for a typical type of automotive sensor.

Vehicles use various mechanical, electrical, and magnetic sensors to measure factors such as vehicle speed, throttle position, engine RPM, air pressure, oxygen content of exhaust gas, airflow, engine coolant temperature, and status of electrical circuits (on-off). Each sensor transmits its information in the form of voltage signals. The computer receives these voltage signals, but before it can use them, the signals must undergo a process called **input conditioning.** This process includes amplifying voltage signals that are too small for the computer circuitry to handle. Input conditioners generally are located inside the computer, but a few sensors have their own input conditioning circuitry.

A digital computer changes the analog input signals (voltage) to digital bits (*bi*nary digit*s*) of information through an **analog-to-digital (AD) converter** circuit. The binary digital number is used by the computer in its calculations or logic networks. ● **SEE FIGURE 71–3.**

PROCESSING The term *processing* is used to describe how input voltage signals received by a computer are handled through a series of electronic logic circuits maintained in its programmed instructions. These logic circuits change the input voltage signals, or data, into output voltage signals or commands.

STORAGE Storage is the place where the program instructions for a computer are stored in electronic memory. Some programs may require that certain input data be stored for later reference or future processing. In others, output commands may be delayed or stored before they are transmitted to devices elsewhere in the system.

Computers have two types of memory.

1. Permanent memory is called **read-only memory (ROM)** because the computer can only read the contents; it cannot change the data stored in it. This data is retained even when power to the computer is shut off. Part of the ROM is built into the computer, and the rest is located in an integrated circuit (IC) chip called a **programmable read-only memory (PROM)** or calibration assembly. Many chips are erasable, meaning that the program can be changed. These chips are called erasable programmable read-only memory, or EPROM. Since the early 1990s, most programmable memory has been electronically erasable, meaning that the program in the chip can be reprogrammed by using a scan tool and the proper software. This computer reprogramming is usually called *reflashing*. These chips are electrically erasable programmable read-only memory, abbreviated **EEPROM** or **E²PROM.**

   All vehicles equipped with onboard diagnosis second generation, called OBD-II, are equipped with EEPROMs.

2. Temporary memory is called **random-access memory (RAM),** because the computer can write or store new data into it as directed by the computer program, as well as read the data already in it. Automotive computers use two types of RAM memory.
   - Volatile RAM memory is lost whenever the ignition is turned off. However, a type of volatile RAM called **keep-alive memory (KAM)** can be wired directly to battery power. This prevents its data from being erased when the ignition is turned off. One example of RAM and KAM is the loss of station settings in a programmable radio when the battery is disconnected. Because all the settings are stored in RAM, they have to be reset when the battery is reconnected. System trouble codes are commonly stored in RAM and can be erased by disconnecting the battery.
   - **Nonvolatile RAM** memory can retain its information even when the battery is disconnected. One use for this type of RAM is the storage of odometer information in an electronic speedometer. The memory chip retains the mileage accumulated by the vehicle. When speedometer replacement is necessary, the odometer chip is removed and installed in the new speedometer unit. KAM is used primarily in conjunction with adaptive strategies.

OUTPUT FUNCTIONS

After the computer has processed the input signals, it sends voltage signals or commands to other devices in the system, such as system actuators. An **actuator** is an electrical or mechanical output device that converts electrical energy into a mechanical action, such as:

- Adjusting engine idle speed
- Operating fuel injectors
- Ignition timing control
- Altering suspension height

COMPUTER COMMUNICATION

A typical vehicle can have many computers, also called modules or controllers. Computers also can communicate with, and control, each other through their output and input functions. This means that the output signal from one computer system can be the input signal for another computer system through a data network. See Chapter 14 for details on network communications.

DIGITAL COMPUTERS

PARTS OF A COMPUTER

The software consists of the programs and logic functions stored in the computer's circuitry. The hardware is the mechanical and electronic parts of a computer.

- **Central processing unit.** The microprocessor is the **central processing unit (CPU)** of a computer. Because it performs the essential mathematical operations and logic decisions that make up its processing function, the CPU can be considered the brain of a computer. Some computers use more than one microprocessor, called a coprocessor. The digital computer can process thousands of digital signals per second because its circuits are able to switch voltage signals on and off in billionths of a second. It is called a **digital computer** because it processes zeros and ones (digits) and needs to have any variable input signals, called analog inputs, converted to digital form before it can function. ● **SEE FIGURE 71–4.**

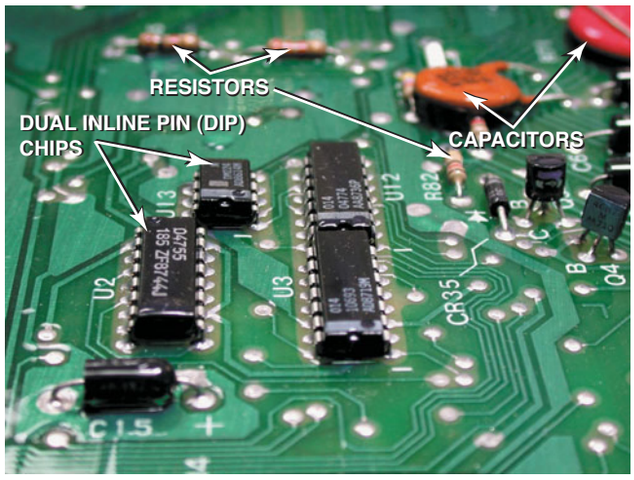


FIGURE 71–4 Many electronic components are used to construct a typical vehicle computer including chips, resistors, and capacitors.

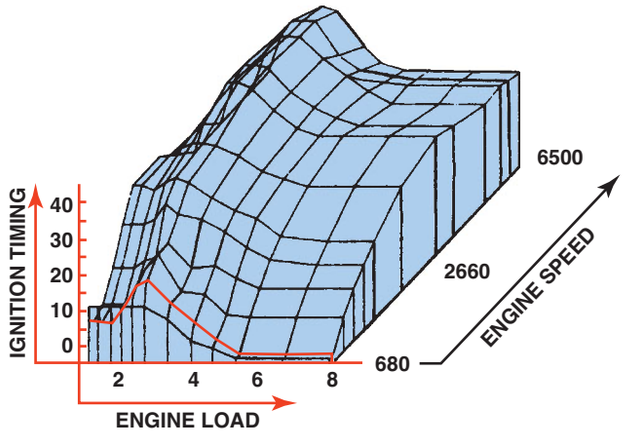


FIGURE 71–5 Typical engine map developed from testing and used by the vehicle computer to provide the optimum ignition timing for all engine speeds and load combinations.

- **Computer memory.** Other integrated circuit (IC) devices store the computer operating program, system sensor input data, and system actuator output data—information that is necessary for CPU operation.
- **Computer programs.** By operating a vehicle on a dynamometer and manually adjusting the variable factors such as speed, load, and spark timing, it is possible to determine the optimum output settings for the best driveability, economy, and emission control. This is called engine mapping. ● **SEE FIGURE 71–5.**

Engine mapping creates a three-dimensional performance graph that applies to a given vehicle and powertrain combination. Each combination is mapped in this manner to produce a PROM or EEPROM calibration. This allows an automaker to use one basic computer for all models.

Many older-vehicle computers used a single PROM that plugged into the computer.

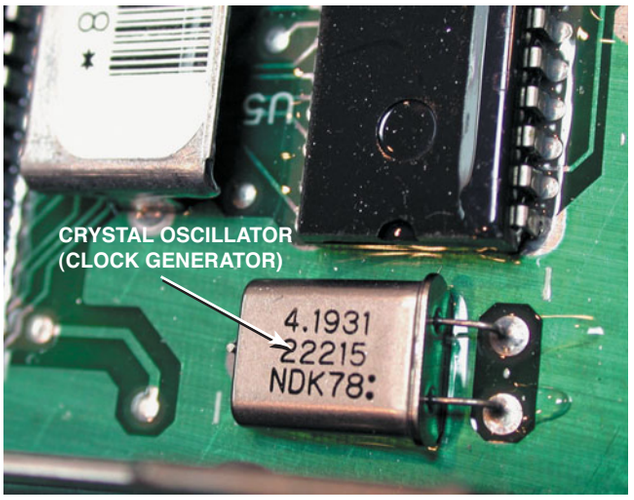


FIGURE 71–6 The clock generator produces a series of pulses that are used by the microprocessor and other components to stay in step with each other at a steady rate.

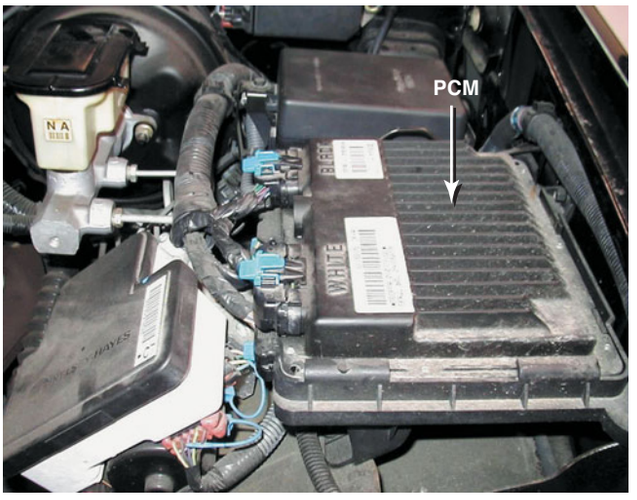


FIGURE 71–7 This powertrain control module (PCM) is located under the hood on this Chevrolet pickup truck.

NOTE: If the computer needs to be replaced, the PROM or calibration module must be removed from the defective unit and installed in the replacement computer. Since the mid-1990s, PCMs do not have removable calibration PROMs, and must be programmed or *flashed* using a scan tool before being put into service.

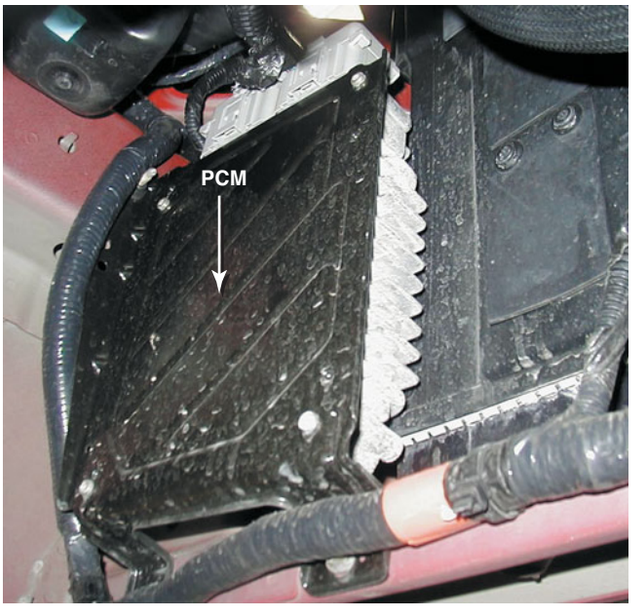


FIGURE 71–8 This PCM on a Chrysler vehicle can only be seen by hoisting the vehicle, because it is located next to the radiator and in the airflow to help keep it cool.

CLOCK RATES AND TIMING

The microprocessor receives sensor input voltage signals, processes them by using information from other memory units, and then sends voltage signals to the appropriate actuators. The microprocessor communicates by transmitting long strings of 0s and 1s in a language called binary code; but the microprocessor must have some way of knowing when one signal ends and another begins. That is the job of a crystal oscillator called a **clock generator.** ● **SEE FIGURE 71–6.**

The computer's crystal oscillator generates a steady stream of one-bit-long voltage pulses. Both the microprocessor and the memories monitor the clock pulses while they are communicating. Because they know how long each voltage pulse should be, they can distinguish between a 01 and a 0011. To complete the process, the input and output circuits also watch the clock pulses.

COMPUTER SPEEDS

Not all computers operate at the same speed; some are faster than others. The speed at which a computer operates is specified by the cycle time, or clock speed, required to perform certain measurements. Cycle time or clock speed is measured in megahertz (4.7 MHz, 8 MHz, 15 MHz, 18 MHz, and 32 Hz, which is the clock speed of most vehicle computers today).

BAUD RATE

The computer transmits bits of a serial datastream at precise intervals. The computer's speed is called the **baud rate,** or bits per second. The term *baud* was named after J. M. Emile Baudot (1845–1903), a French telegraph operator who developed a five-bit-per-character code of telegraph. Just as mph helps in estimating the length of time required to travel a certain distance, the baud rate is useful in estimating how long a given computer will need to transmit a specified amount of data to another computer.

Automotive computers have evolved from a baud rate of 160 used in the early 1980s to a baud rate as high as 500,000 for some networks. The speed of data transmission is an important factor both in system operation and in system troubleshooting.

CONTROL MODULE LOCATIONS

The computer hardware is all mounted on one or more circuit boards and installed in a metal case to help shield it from electromagnetic interference (EMI). The wiring harnesses that link the computer to sensors and actuators connect to multipin connectors or edge connectors on the circuit boards.

Onboard computers range from single-function units that control a single operation to multifunction units that manage all of the separate (but linked) electronic systems in the vehicle. They vary in size from a small module to a notebook-size box. Most other engine computers are installed in the passenger compartment either under the instrument panel or in a side kick panel where they can be shielded from physical damage caused by temperature extremes, dirt, and vibration, or interference by the high currents and voltages of various underhood systems. ● **SEE FIGURES 71–7 AND 71–8.**

FREQUENTLY ASKED QUESTION

What Is a Binary System?

In a digital computer the signals are simple high-low, yes-no, on-off signals. The digital signal voltage is limited to two voltage levels: high voltage and low voltage. Since there is no stepped range of voltage or current in between, a digital binary signal is a "square wave." The signal is called "digital" because the on and off signals are processed by the computer as the digits or numbers 0 and 1. The number system containing only these two digits is called the **binary system.** Any number or letter from any number system or language alphabet can be translated into a combination of binary 0s and 1s for the digital computer. A digital computer changes the analog input signals (voltage) to digital bits (*bi*nary digi*ts*) of information through an analog-to-digital (AD) converter circuit. The binary digital number is used by the computer in its calculations or logic networks. Output signals usually are digital signals that turn system actuators on and off.

COMPUTER INPUT SENSORS

The vehicle computer uses signals (voltage levels) from the following sensors.

- **Engine speed (revolutions per minute, or RPM) sensor.** This signal comes from the primary ignition signal in the ignition control module (ICM) or directly from the crankshaft position (CKP) sensor.
- **Switches or buttons for accessory operation.** Many accessories use control buttons that signal the body computer to turn on or off an accessory such as the windshield wiper or heated seats.
- **Manifold absolute pressure (MAP) sensor.** This sensor detects engine load by using a signal from a sensor that measures the vacuum in the intake manifold.
- **Mass airflow (MAF) sensor.** This sensor measures the mass (weight and density) of the air flowing through the sensor and entering the engine.
- **Engine coolant temperature (ECT) sensor.** This sensor measures the temperature of the engine coolant. This is a sensor used for engine controls and for automatic air-conditioning control operation.
- **Oxygen sensor (O2S).** This sensor measures the oxygen in the exhaust stream. There are as many as four oxygen sensors in some vehicles.
- **Throttle position (TP) sensor.** This sensor measures the throttle opening and is used by the computer for engine control and the shift points of the automotive transmission/transaxle.
- **Vehicle speed (VS) sensor.** This sensor measures the vehicle speed using a sensor located at the output of the transmission/transaxle or by monitoring sensors at the wheel speed sensors. This sensor is used by the speedometer, cruise control, and airbag systems.

COMPUTER OUTPUTS

OUTPUT CONTROLS After the computer has processed the input signals, it sends voltage signals or commands to other devices in the system, as follows:

- **Operate actuators.** An actuator is an electrical or mechanical device that converts electrical energy into heat, light, or motion to control engine idle speed, suspension height, ignition timing, and other output devices.
- **Network communication.** Computers also can communicate with another computer system through a network.

A vehicle computer can do only two things.

1. Turn a device on.
2. Turn a device off.

Typical output devices include the following:

- **Fuel injectors.** The computer can vary the amount of time in milliseconds the injectors are held open, thereby controlling the amount of fuel supplied to the engine.
- **Blower motor control.** Many blower motors are controlled by the body computer by pulsing the current on and off to maintain the desired speed.
- **Transmission shifting.** The computer provides a ground to the shift solenoids and torque converter clutch (TCC) solenoid. The operation of the automatic transmission/transaxle is optimized based on vehicle sensor information.
- **Idle speed control.** The computer can control the idle air control (IAC) or electronic throttle control (ETC) to maintain engine idle speed and to provide an increased idle speed as needed.
- **Evaporative emission control solenoids.** The computer can control the flow of gasoline fumes from the charcoal canister to the engine and seal off the system to perform a fuel system leak detection test as part of the OBD-II system requirements.

Most outputs work electrically in one of three ways:

1. Digital
2. Pulse-width modulated
3. Switched

Digital control is mostly used for computer communications and involves voltage signals that are transmitted and received in packets.

Pulse-width control allows a device, such as a blower motor, to be operated at variable speed by changing the amount of time electrical power is supplied to the device.

A switched output is an output that is either on or off. In many circuits, the PCM uses a relay to switch a device on or off, because the relay is a low-current device that can switch to a higher current device. Most computer circuits cannot handle high amounts of current. By using a relay circuit, the PCM provides the output control to the relay, which in turn provides the output control to the device.

The relay coil, which the PCM controls, typically draws less than 0.5 ampere. The device that the relay controls may draw 30 amperes or more. The PCM switches are actually transistors, and are often called **output drivers.** ● **SEE FIGURE 71–9.**

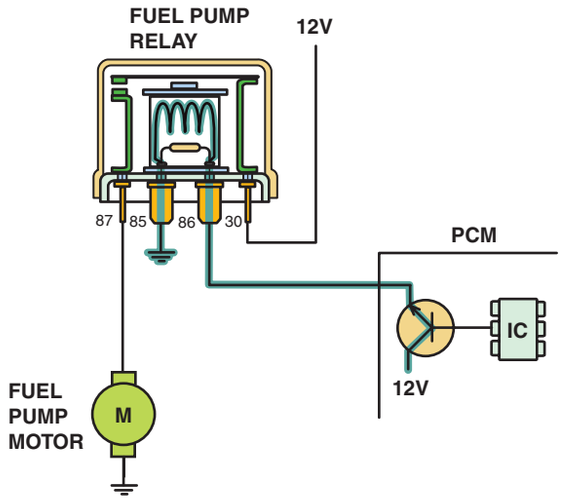


FIGURE 71–9 A typical output driver. In this case, the PCM applies voltage to the fuel pump relay coil to energize the fuel pump.

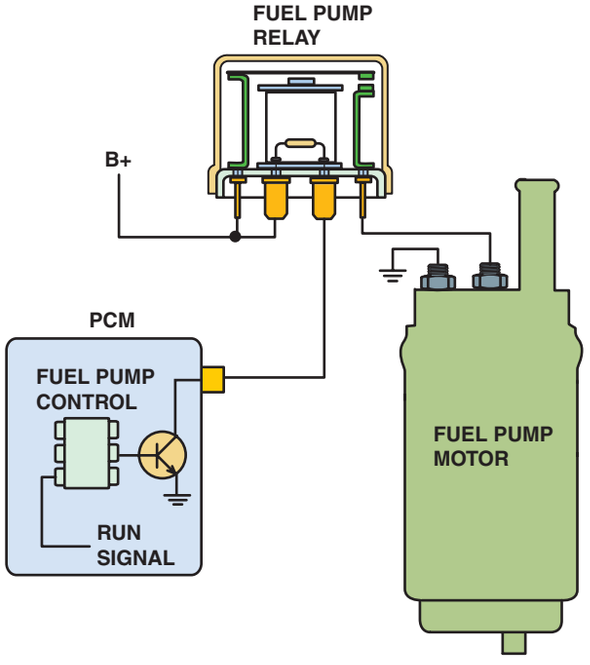


FIGURE 71–10 A typical low-side driver (LSD) which uses a control module to control the ground side of the relay coil.

OUTPUT DRIVERS

There are two basic types of output drivers.

1. **Low-side drivers.** The low-side drivers (LSDs) are transistors inside the computer that complete the ground path of relay coil. Ignition (key-on) voltage and battery voltage are supplied to the relay. The ground side of the relay coil is connected to the transistor inside the computer. In the example of a fuel pump relay, when the transistor turns "on," it will complete the ground for the relay coil, and the relay will then complete the power circuit between the battery power and the fuel pump. A relatively low current flows through the relay coil and transistor that is inside the computer. This causes the relay to switch and provides the fuel pump with battery voltage. The majority of switched outputs have typically been low-side drivers. ● **SEE FIGURE 71–10.**

   Low-side drivers can often perform a diagnostic circuit check by monitoring the voltage from the relay to check that the control circuit for the relay is complete. A low-side driver, however, cannot detect a short-to-ground.

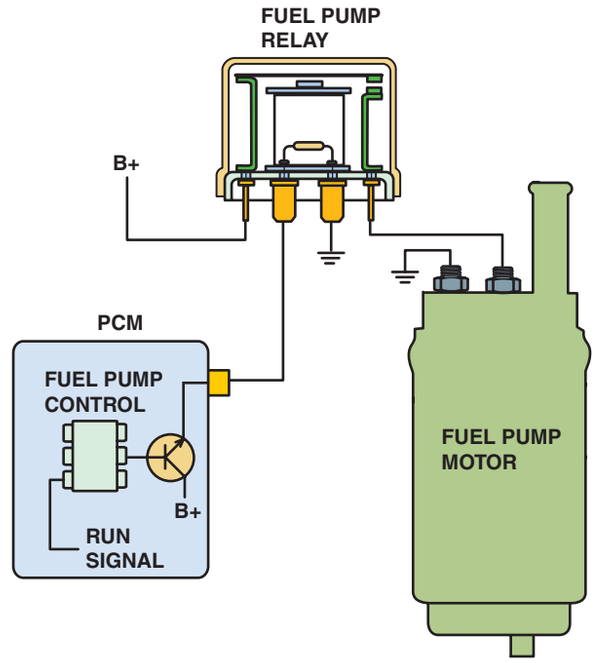


FIGURE 71–11 A typical module-controlled high-side driver (HSD) where the module itself supplies the electrical power to the device. The logic circuit inside the module can detect circuit faults including continuity of the circuit and if there is a short-to-ground in the circuit being controlled.

2. **High-side drivers.** The high-side drivers (HSDs) control the power side of the circuit. In these applications when the transistor is switched on, voltage is applied to the device. A ground has been provided to the device so when the high-side driver switches, the device will be energized. In some applications, high-side drivers are used instead of low-side drivers to provide better circuit protection. General Motors vehicles have used a high-side driver to control the fuel pump relay instead of a low-side driver. In the event of an accident, should the circuit to the fuel pump relay become grounded, a high-side driver would cause a short circuit, which would cause the fuel pump relay to de-energize. High-side drivers inside modules can detect electrical faults such as a lack of continuity when the circuit is not energized. ● **SEE FIGURE 71–11.**

PULSE-WIDTH MODULATION

Pulse-width modulation (PWM) is a method of controlling an output using a digital signal. Instead of just turning devices on or off, the computer can control the amount of on-time. For example, a solenoid could be a PWM device. If, for example, a vacuum solenoid is controlled by a switched driver, switching either on or off would mean that either full vacuum would flow through the solenoid or no vacuum would flow through the solenoid. However, to control the amount of vacuum that flows through the solenoid, pulse-width modulation could be used. A PWM signal is a digital signal, usually 0 volt and 12 volts, which is cycling at a fixed frequency. Varying the length of time that the signal is on provides a signal that can vary the on- and off-time of an output. The ratio of on-time relative to the period of the cycle is referred to as **duty cycle.** ● **SEE FIGURE 71–12.**

Depending on the frequency of the signal, which is usually fixed, this signal would turn the device on and off a fixed number of times per second. When, for example, the voltage is high (12 volts) 90% of the time and low (0 volt) the other 10% of the time, the signal has a 90% duty cycle. In other words, if this signal were applied to

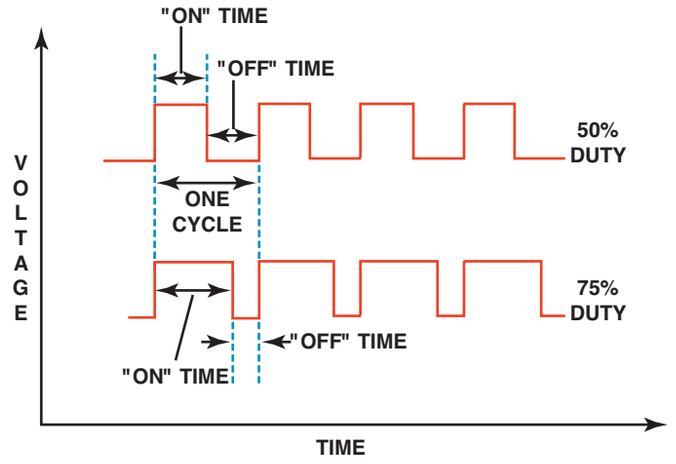


FIGURE 71–12 Both the top and bottom pattern have the same frequency. However, the amount of on-time varies. Duty cycle is the percentage of the time during a cycle that the signal is turned on.

the vacuum solenoid, the solenoid would be on 90% of the time. This would allow more vacuum to flow through the solenoid. The computer has the ability to vary this on- and off-time or pulse-width modulation at any rate between 0% and 100%. A good example of pulse-width modulation is the cooling fan speed control. The speed of the cooling fan is controlled by varying the amount of on-time that the battery voltage is applied to the cooling fan motor.

- 100% duty cycle: fan runs at full speed
- 75% duty cycle: fan runs at 3/4 speed
- 50% duty cycle: fan runs at 1/2 speed
- 25% duty cycle: fan runs at 1/4 speed

The use of PWM, therefore, results in precise control of an output device to achieve the amount of cooling needed and conserve electrical energy compared to simply timing the cooling fan on high when needed. PWM may be used to control vacuum through a solenoid, the amount of purge of the evaporative purge solenoid, the speed of a fuel pump motor, control of a linear motor, or even the intensity of a light bulb.

REVIEW QUESTIONS

1. What part of the vehicle computer is considered to be the brain?
2. What is the difference between volatile and nonvolatile RAM?
3. What are the four input sensors?
4. What are the four output devices?

CHAPTER QUIZ

1. What unit of electricity is used as a signal for a computer?
   a. Volt
   b. Ohm
   c. Ampere
   d. Watt
2. The four basic computer functions include _____.
   a. Writing, processing, printing, and remembering
   b. Input, processing, storage, and output
   c. Data gathering, processing, output, and evaluation
   d. Sensing, calculating, actuating, and processing
3. All OBD-II vehicles use what type of read-only memory?
   a. ROM
   b. PROM
   c. EPROM
   d. EEPROM
4. The “brain” of the computer is the_____.
   a. PROM
   b. RAM
   c. CPU
   d. AD converter
5. Computer speed is measured in _____.
   a. Baud rate
   b. Clock speed (Hz)
   c. Voltage
   d. Bytes
6. Which item is a computer input sensor?
   a. RPM
   b. Throttle position
   c. Engine coolant temperature
   d. All of the above
7. Which item is a computer output device?
   a. Fuel injector
   b. Transmission shift solenoid
   c. Evaporative emission control solenoid
   d. All of the above
8. The SAE term for the vehicle computer is _____.
   a. PCM
   b. ECM
   c. ECA
   d. Controller
9. What two things can a vehicle computer actually perform (output)?
   a. Store and process information
   b. Turn something on or turn something off
   c. Calculate and vary temperature
   d. Control fuel and timing only
10. Analog signals from sensors are changed to digital signals for processing by the computer through which type of circuit?
    a. Digital
    b. Analog
    c. Analog-to-digital converter
    d. PROM

chapter 72

TEMPERATURE SENSORS

OBJECTIVES: **After studying Chapter 72, the reader will be able to:** • Prepare for ASE Engine Performance (A8) certification test content area "E" (Computerized Engine Controls Diagnosis and Repair). • Explain the purpose and function of the ECT and IAT temperature sensors. • Describe how to test temperature sensors. • Discuss how automatic transmission fluid temperature sensor values can affect transmission operation.

KEY TERMS: Cylinder head temperature (CHT) 826 • Engine coolant temperature (ECT) 819 • Engine fuel temperature (EFT) 826 • Negative temperature coefficient (NTC) 819 • Throttle-body temperature (TBT) 824 • Transmission fluid temperature (TFT) 825

ENGINE COOLANT TEMPERATURE SENSORS

PURPOSE AND FUNCTION Computer-equipped vehicles use an **engine coolant temperature (ECT)** sensor. When the engine is cold, the fuel mixture must be richer to prevent stalling and engine stumble. When the engine is warm, the fuel mixture can be leaner to provide maximum fuel economy with the lowest possible exhaust emissions. Because the computer controls spark timing and fuel mixture, it will need to know the engine temperature. An engine coolant temperature (ECT) sensor installed into the engine coolant passage will provide the computer with this information. ● **SEE FIGURE 72–1.** This will be the most important (high-authority) sensor while the engine is cold. The ignition timing can also be tailored to engine (coolant) temperature. A hot engine cannot have the spark timing as far advanced as can a cold engine. The ECT sensor is also used as an important input for the following:

- Idle air control (IAC) position
- Oxygen sensor closed-loop status
- Canister purge on/off times
- Idle speed

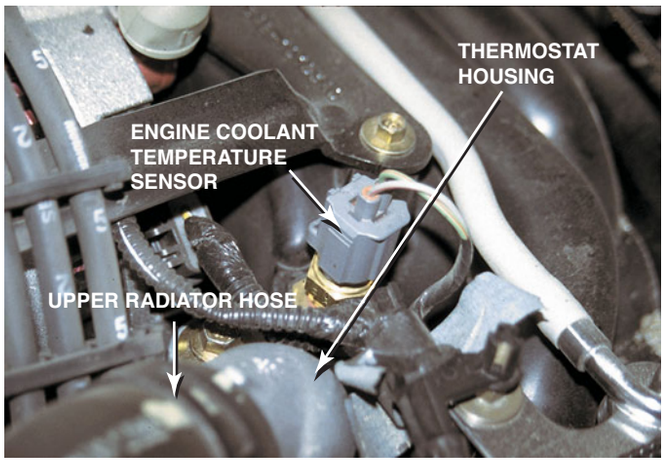


FIGURE 72–1 A typical engine coolant temperature (ECT) sensor. ECT sensors are located near the thermostat housing on most engines.

ECT SENSOR CONSTRUCTION Engine coolant temperature sensors are constructed of a semiconductor material that decreases in resistance as the temperature of the sensor increases. Coolant sensors have very high resistance when the coolant is cold and low resistance when the coolant is hot. This is referred to as having a **negative temperature coefficient (NTC),** which is opposite to the situation with most other electrical components. ● **SEE FIGURE 72–2.** Therefore, if the coolant sensor has a poor connection (high resistance) at the wiring connector, the computer will supply a richer-than-normal fuel mixture based on the resistance of the coolant sensor. Poor fuel economy and a possible-rich code can be caused by a defective sensor or high resistance in the sensor wiring. If the sensor was shorted or defective and had too low a resistance, a leaner-than-normal fuel mixture would be supplied to the engine. A too-lean fuel mixture can cause driveability problems and a possible-lean computer code.

STEPPED ECT CIRCUITS Some vehicle manufacturers use a step-up resistor to effectively broaden the range of the ECT sensor. Chrysler and General Motors vehicles use the same sensor as a non-stepped ECT circuit, but instead apply the sensor voltage through two different resistors.

- When the temperature is cold, usually below 120°F (50°C), the ECT sensor voltage is applied through a high-value resistor inside the PCM.
- When the temperature is warm, usually above 120°F (50°C), the ECT sensor voltage is applied through a much lower resistance value inside the PCM. ● **SEE FIGURE 72–3.**

The purpose of this extra circuit is to give the PCM a more accurate reading of the engine coolant temperature compared to the same sensor with only one circuit. ● **SEE FIGURE 72–4.**

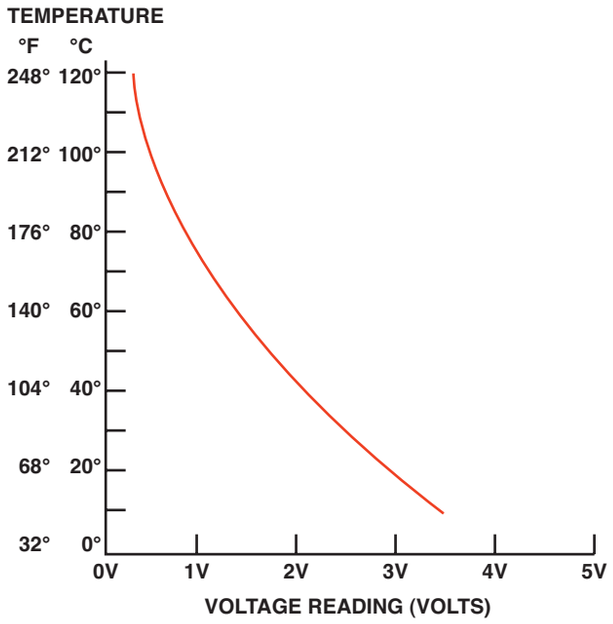


FIGURE 72–2 A typical ECT sensor temperature versus voltage curve.

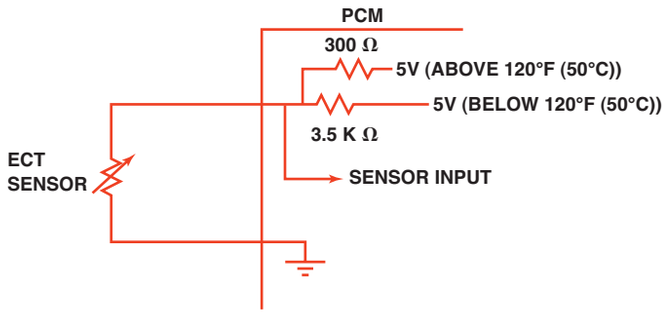


FIGURE 72–3 A typical two-step ECT circuit showing that when the coolant temperature is low, the PCM applies a 5-volt reference voltage to the ECT sensor through a higher resistance compared to when the temperature is higher.

TESTING THE ENGINE COOLANT TEMPERATURE SENSOR

TESTING THE ENGINE COOLANT TEMPERATURE BY VISUAL INSPECTION

The correct functioning of the engine coolant temperature (ECT) sensor depends on the following items that should be checked or inspected:

- **Properly filled cooling system.** Check that the radiator reservoir bottle is full and that the radiator itself is filled to the top.

  CAUTION: Be sure that the radiator is cool before removing the radiator cap to avoid being scalded by hot coolant.

  The ECT sensor must be submerged in coolant to be able to indicate the proper coolant temperature.
- **Proper pressure maintained by the radiator cap.** If the radiator cap is defective and cannot allow the cooling system to become pressurized, air pockets could develop. These air pockets could cause the engine to operate at a hotter-than-normal temperature and prevent proper temperature measurement, especially if the air pockets occur around the sensor.
- **Proper antifreeze–water mixture.** Most vehicle manufacturers recommend a 50/50 mixture of antifreeze and water as the best compromise between freezing protection and heat transfer ability.
- **Proper operation of the cooling fan.** If the cooling fan does not operate correctly, the engine may overheat.

TESTING THE ECT USING A MULTIMETER

Both the resistance (in ohms) and the voltage drop across the sensor can be measured and compared with specifications. ● **SEE FIGURE 72–5.** See the following charts showing examples of typical engine coolant temperature sensor specifications. Some vehicles use the PCM to attach another resistor in the ECT circuit to provide a more accurate measure of the engine temperature. ● **SEE FIGURE 72–6.**

If resistance values match the approximate coolant temperature and there is still a coolant sensor trouble code, the problem is generally in the wiring between the sensor and the computer. Always consult the manufacturers' recommended procedures for checking this wiring. If the resistance values do not match, the sensor may need to be replaced.

General Motors ECT Sensor with Pull-up Resistor

°F	°C	Ohms	Voltage Drop Across Sensor
−40	−40	100,000 +	4.95
18	−8	14,628	4.68
32	0	9,420	4.52
50	10	5,670	4.25
68	20	3,520	3.89
86	30	2,238	3.46
104	40	1,459	2.97
122	50	973	2.47
140	60	667	2.00
158	70	467	1.59
176	80	332	1.25
194	90	241	0.97
212	100	177	0.75

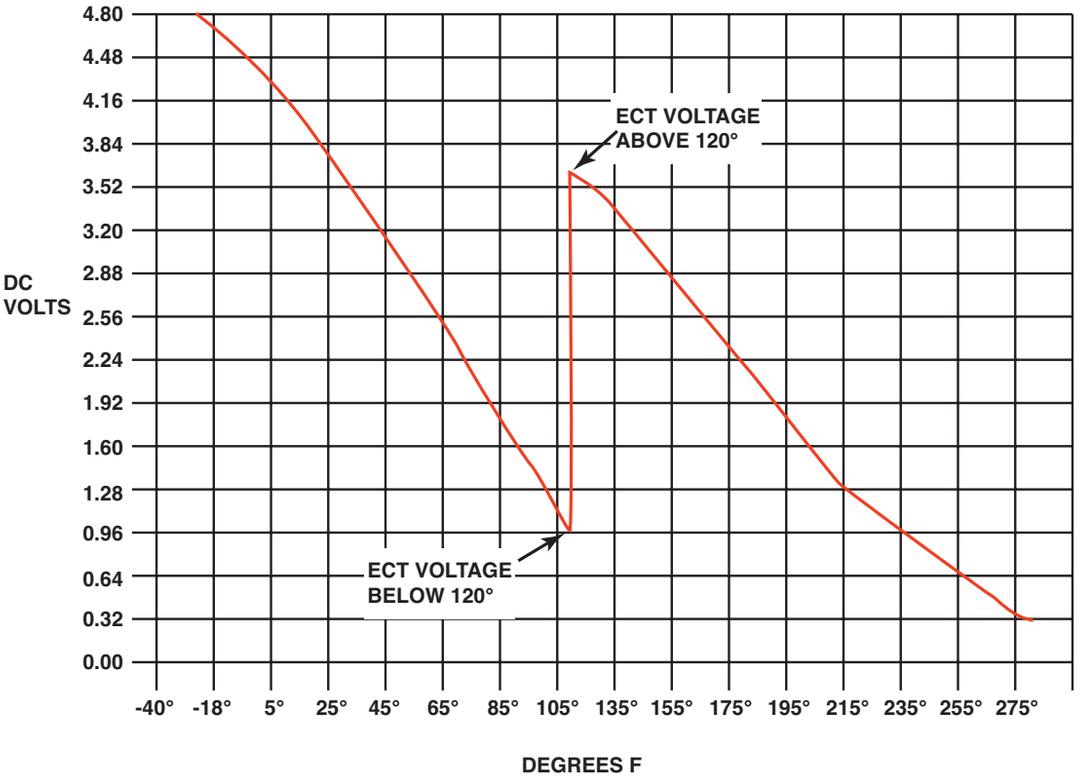


FIGURE 72–4 The transition between steps usually occurs at a temperature that would not interfere with cold engine starts or the cooling fan operation. In this example, the transition occurs when the sensor voltage is about 1 volt and rises to about 3.6 volts.

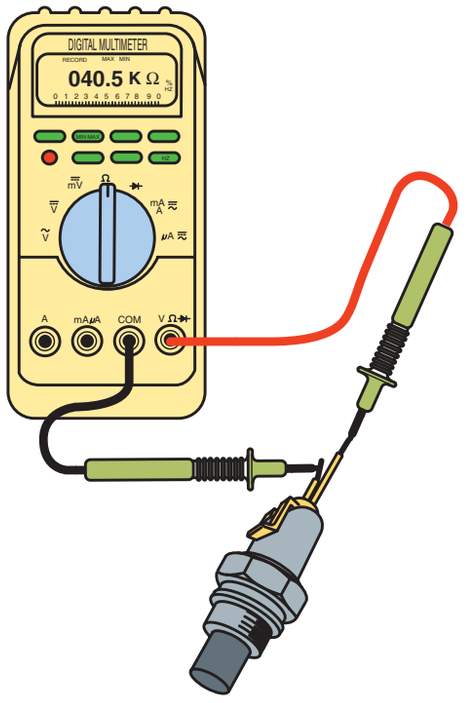


FIGURE 72–5 Measuring the resistance of the ECT sensor. The resistance measurement can then be compared with specifications. (*Courtesy of Fluke Corporation*)

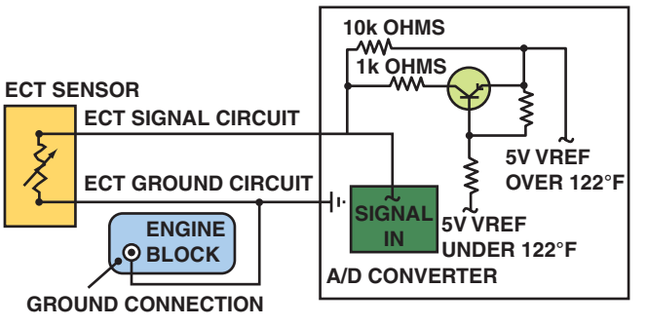


FIGURE 72–6 When the voltage drop reaches approximately 1.20 volts, the PCM turns on a transistor. The transistor connects a 1-kΩ resistor in parallel with the 10-kΩ resistor. Total circuit resistance now drops to around 909 ohms. This function allows the PCM to have full binary control at cold temperatures up to approximately 122°F, and a second full binary control at temperatures greater than 122°F.

General Motors ECT Sensor without Pull-up Resistor

°F	°C	Ohms	Voltage Drop Across Sensor
−40	−40	100,000	5
−22	−30	53,000	4.78
−4	−20	29,000	4.34
14	−10	16,000	3.89
32	0	9,400	3.45
50	10	5,700	3.01
68	20	3,500	2.56
86	30	2,200	1.80
104	40	1,500	1.10
122	50	970	3.25
140	60	670	2.88
158	70	470	2.56
176	80	330	2.24
194	90	240	1.70
212	100	177	1.42
230	110	132	1.15
248	120	100	.87

Ford ECT Sensor

°F	°C	Resistance (Ω)	Voltage (V)
50	10	58,750	3.52
68	20	37,300	3.06
86	30	24,270	2.26
104	40	16,150	2.16
122	50	10,970	1.72
140	60	7,600	1.35
158	70	5,370	1.04
176	80	3,840	0.80
194	90	2,800	0.61
212	100	2,070	0.47
230	110	1,550	0.36
248	120	1,180	0.28

Chrysler ECT Sensor without Pull-up Resistor

°F	°C	Voltage (V)
130	54	3.77
140	60	3.60
150	66	3.40
160	71	3.20
170	77	3.02
180	82	2.80
190	88	2.60
200	93	2.40
210	99	2.20
220	104	2.00
230	110	1.80
240	116	1.62
250	121	1.45

Chrysler ECT Sensor with Pull-up Resistor

°F	°C	Volts
−20	−29	4.70
−10	−23	4.57
0	−18	4.45
10	−12	4.30
20	−7	4.10
30	−1	3.90
40	4	3.60
50	10	3.30
60	16	3.00
70	21	2.75
80	27	2.44
90	32	2.15
100	38	1.83
		Pull-up Resistor Switched by PCM
110	43	4.20
120	49	4.10
130	54	4.00
140	60	3.60
150	66	3.40
160	71	3.20
170	77	3.02
180	82	2.80
190	88	2.60
200	93	2.40
210	99	2.20
220	104	2.00
230	110	1.80
240	116	1.62
250	121	1.45

Nissan ECT Sensor

°F	°C	Resistance (Ω)
14	−10	7,000–11,400
68	20	2,100–2,900
122	50	680–1,000
176	80	260–390
212	100	180–200

Mercedes ECT

°F	°C	Voltage (DCV)
60	20	3.5
86	30	3.1
104	40	2.7
122	50	2.3
140	60	1.9
158	70	1.5
176	80	1.2
194	90	1.0
212	100	0.8

European Bosch ECT Sensor

°F	°C	Resistance (Ω)
32	0	6,500
50	10	4,000
68	20	3,000
86	30	2,000
104	40	1,500
122	50	900
140	60	650
158	70	500
176	80	375
194	90	295
212	100	230

Honda ECT Sensor (Resistance Chart)

°F	°C	Resistance (Ω)
0	−18	15,000
32	0	5,000
68	20	3,000
104	40	1,000
140	60	500
176	80	400
212	100	250

Honda ECT Sensor (Voltage Chart)

°F	°C	Voltage (V)
0	−18	4.70
10	−12	4.50
20	−7	4.29
30	−1	4.10
40	4	3.86
50	10	3.61
60	16	3.35
70	21	3.08
80	27	2.81
90	32	2.50
100	38	2.26
110	43	2.00
120	49	1.74
130	54	1.52
140	60	1.33
150	66	1.15
160	71	1.00
170	77	0.88
180	82	0.74
190	88	0.64
200	93	0.55
210	99	0.47

Normal operating temperature varies with vehicle make and model. Some vehicles are equipped with a thermostat with an opening temperature of 180°F (82°C), whereas other vehicles use a thermostat that is 195°F (90°C) or higher. Before replacing the ECT sensor, be sure that the engine is operating at the temperature specified by the manufacturer. Most manufacturers recommend checking the ECT sensor after the cooling fan has cycled twice, indicating a fully warmed engine. To test for voltage at the ECT sensor, select DC volts on a digital meter and carefully back probe the sensor wire and read the voltage. ● **SEE FIGURE 72–7.**

TESTING THE ECT SENSOR USING A SCAN TOOL

Follow the scan tool manufacturer's instructions and connect a scan tool to the data link connector (DLC) of the vehicle. Comparing the temperature of the engine coolant as displayed on a scan tool with the actual temperature of the engine is an excellent method to test an engine coolant temperature sensor.

1. Record the scan tool temperature of the coolant (ECT).
2. Measure the actual temperature of the coolant using an infrared pyrometer or contact-type temperature probe.

NOTE: Often the coolant temperature gauge in the dash of the vehicle can be used to compare with the scan tool temperature. Although not necessarily accurate, it may help to diagnose a faulty sensor, especially if the temperature shown on the scan tool varies greatly from the temperature indicated on the dash gauge.

The maximum difference between the two readings should be 10°F (5°C). If the actual temperature varies by more than 10°F from the temperature indicated on the scan tool, check the ECT sensor wiring and connector for damage or corrosion. If the connector and wiring are okay, check the sensor with a DVOM for resistance and compare to the actual engine temperature chart. If that checks out okay, check the computer.

NOTE: Some manufacturers use two coolant sensors, one for the dash gauge and another one for the computer.

INTAKE AIR TEMPERATURE SENSOR

PURPOSE AND FUNCTION

The intake air temperature (IAT) sensor is a negative temperature coefficient (NTC) thermistor that decreases in resistance as the temperature of the sensor increases. The IAT sensor can be located in one of the following locations:

- In the air cleaner housing
- In the air duct between the air filter and the throttle body, as shown in ● **FIGURE 72–8**
- Built into the mass air flow (MAF) or airflow sensor
- Screwed into the intake manifold where it senses the temperature of the air entering the cylinders

NOTE: An IAT installed in the intake manifold is the most likely to suffer damage due to an engine backfire, which can often destroy the sensor.

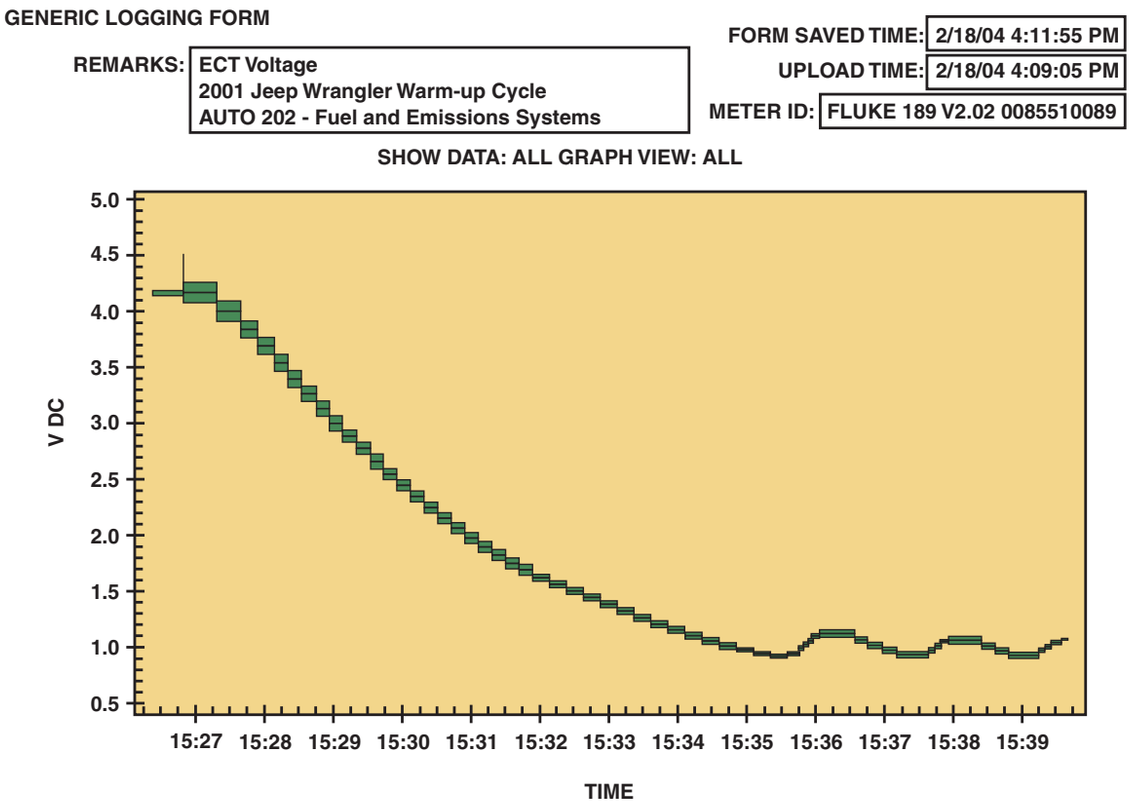


FIGURE 72–7 An ECT sensor being tested using a digital meter set to DC volts and record mode to capture the data shown. A chart showing the voltage decrease of the ECT sensor as the temperature increases from a cold start. The bumps at the bottom of the waveform represent temperature decreases when the thermostat opens and is controlling coolant temperature.

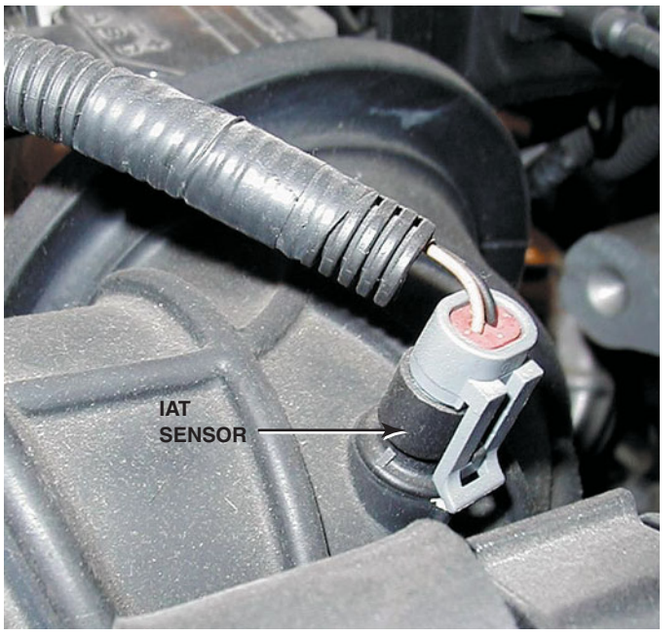


FIGURE 72–8 The IAT sensor on this General Motors 3800 V-6 engine is in the air passage duct between the air cleaner housing and the throttle body.

The purpose and function of the intake air temperature sensor is to provide the engine computer (PCM) the temperature of the air entering the engine. The IAT sensor information is used for fuel control (adding or subtracting fuel) and spark timing, depending on the temperature of incoming air.

- If the air temperature is cold, the PCM will modify the amount of fuel delivery and add fuel.
- If the air temperature is hot, the PCM will subtract the calculated amount of fuel.
- Spark timing is also changed, depending on the temperature of the air entering the engine. The timing is advanced if the temperature is cold and retarded from the base-programmed timing if the temperature is hot.
- Cold air is more dense, contains more oxygen, and therefore requires a richer mixture to achieve the proper air–fuel mixture. Air at 32°F (0°C) is 14% denser than air at 100°F (38°C).
- Hot air is less dense, contains less oxygen, and therefore requires less fuel to achieve the proper air–fuel mixture.

The IAT sensor is a low-authority sensor and is used by the computer to modify the amount of fuel and ignition timing as determined by the engine coolant temperature sensor.

The IAT sensor is used by the PCM as a backup in the event that the ECT sensor is determined to be inoperative.

NOTE: Some engines use a throttle-body temperature (TBT) sensor to sense the temperature of the air entering the engine, instead of an intake air temperature sensor.

Engine temperature is most accurately determined by looking at the engine coolant temperature (ECT) sensor. In certain conditions, the IAT has an effect on performance and driveability. One such condition is a warm engine being stopped in very cold weather. In this case, when the engine is restarted, the ECT may be near normal operating temperature such as 200°F (93°C) yet the air temperature could be −20°F (−30°C). In this case, the engine requires a richer mixture due to the cold air than the ECT would seem to indicate.

TECH TIP

Quick and Easy ECT Test

To check that the wiring and the computer are functioning, regarding the ECT sensor, connect a scan tool and look at the ECT temperature display.

STEP 1 Unplug the connector from the ECT sensor. The temperature displayed on the scan tool should read about −40.

NOTE: −40° Celsius is also −40° Fahrenheit. This is the point where both temperature scales meet.

STEP 2 With the connector still removed from the ECT sensor, use a fused jumper lead and connect the two terminals of the connector together. The scan tool should display about 285°F (140°C).

This same test procedure will work for the IAT and most other temperature sensors.

TECH TIP

Poor Fuel Economy? Black Exhaust Smoke? Look at the IAT

If the intake air temperature sensor is defective, it may be signaling the computer that the intake air temperature is extremely cold when in fact it is warm. In such a case the computer will supply a mixture that is much richer than normal.

If a sensor is physically damaged or electrically open, the computer will often set a diagnostic trouble code (DTC). This DTC is based on the fact that the sensor temperature did not change for a certain amount of time, usually about 8 minutes. If, however, the wiring or the sensor itself has excessive resistance, a DTC will not be set and the result will be lower-than-normal fuel economy, and in serious cases, black exhaust smoke from the tailpipe during acceleration.

TESTING THE INTAKE AIR TEMPERATURE SENSOR

If the intake air temperature sensor circuit is damaged or faulty, a diagnostic trouble code (DTC) is set and the malfunction indicator lamp (MIL) may or may not turn on depending on the condition and the type and model of the vehicle. To diagnose the IAT sensor follow these steps:

STEP 1 After the vehicle has been allowed to cool for several hours, use a scan tool, observe the IAT temperature, and compare it to the engine coolant temperature (ECT). The two temperatures should be within 5°F of each other.

STEP 2 Perform a thorough visual inspection of the sensor and the wiring. If the IAT is screwed into the intake manifold, remove the sensor and check for damage.

STEP 3 Check the voltage and compare to the following chart.

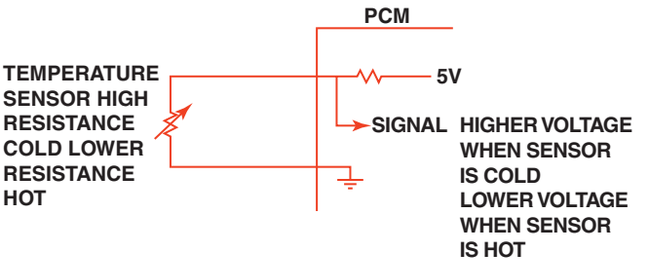


FIGURE 72–9 A typical temperature sensor circuit.

FREQUENTLY ASKED QUESTION

What Exactly Is an NTC Sensor?

A negative temperature coefficient (NTC) thermistor is a semiconductor whose resistance decreases as the temperature increases. In other words, the sensor becomes more electrically conductive as the temperature increases. Therefore, when a voltage is applied, typically 5 volts, the signal voltage is high when the sensor is cold because the sensor has a high resistance and little current flows through to ground. ● **SEE FIGURE 72–9.**

However, when the temperature increases, the sensor becomes more electrically conductive and takes more of the 5 volts to ground, resulting in a lower signal voltage as the sensor warms.

Intake Air Temperature Sensor Temperature vs. Resistance and Voltage Drop (Approximate)

°F	°C	Ohms	Voltage Drop Across the Sensor
−40	−40	100,000	4.95
+18	−8	15,000	4.68
32	0	9,400	4.52
50	10	5,700	4.25
68	20	3,500	3.89
86	30	2,200	3.46
104	40	1,500	2.97
122	50	1,000	2.47
140	60	700	2.00
158	70	500	1.59
176	80	300	1.25
194	90	250	0.97
212	100	200	0.75

TRANSMISSION FLUID TEMPERATURE SENSOR

The **transmission fluid temperature (TFT),** also called *transmission oil temperature (TOT),* sensor is an important sensor for the proper operation of the automatic transmission. A TFT sensor is a negative temperature coefficient (NTC) thermistor that decreases in resistance as the temperature of the sensor increases.

General Motors

Transaxle Sensor–Temperature to Resistance (approximate)

°F	°C	Resistance Ohms
32	0	7,987–10,859
50	10	4,934–6,407
68	20	3,106–3,923
86	30	1,991–2,483
104	40	1,307–1,611
122	50	878–1,067
140	60	605–728
158	70	425–507
176	80	304–359
194	90	221–259
212	100	163–190

Chrysler

Sensor Resistance (Ohms)–Transmission Temperature Sensor

°F	°C	Resistance Ohms
−40	−40	291,490–381,710
−4	−20	85,850–108,390
14	−10	49,250–61,430
32	0	29,330–35,990
50	10	17,990–21,810
68	20	11,370–13,610
77	25	9,120–10,880
86	30	7,370–8,750
104	40	4,900–5,750
122	50	3,330–3,880
140	60	2,310–2,670
158	70	1,630–1,870
176	80	1,170–1,340
194	90	860–970
212	100	640–720
230	110	480–540
248	120	370–410

Ford

Transmission Fluid Temperature

°F	°C	Resistance Ohms
−40 to −4	−40 to −20	967K–284K
−3 to 31	−19 to −1	284K–100K
32 to 68	0 to 20	100K–37K
69 to 104	21 to 40	37K–16K
105 to 158	41 to 70	16K–5K
159 to 194	71 to 90	5K–2.7K
195 to 230	91 to 110	2.7K–1.5K
231 to 266	111 to 130	1.5K–0.8K
267 to 302	131 to 150	0.8K–0.54K

The transmission fluid temperature signal is used by the Powertrain Control Module (PCM) to perform certain strategies based on the temperature of the automatic transmission fluid. For example:

- If the temperature of the automatic transmission fluid is low (typically below 32°F [0°C]), the shift points may be delayed and overdrive disabled. The torque converter clutch also may not be applied to assist in the heating of the fluid.
- If the temperature of the automatic transmission fluid is high (typically above 260°F [130°C]), the overdrive is disabled and the torque converter clutch is applied to help reduce the temperature of the fluid.

NOTE: Check service information for the exact shift strategy based on high and low transmission fluid temperatures for the vehicle being serviced.

CYLINDER HEAD TEMPERATURE SENSOR

Some vehicles are equipped with **cylinder head temperature (CHT)** sensors.

VW Golf

14°F (−10°C) = 11,600 Ω

68°F (20°C) = 2,900 Ω

176°F (80°C) = 390 Ω

ENGINE FUEL TEMPERATURE (EFT) SENSOR

Some vehicles, such as many Ford vehicles that are equipped with an electronic returnless type of fuel injection, use an **engine fuel temperature (EFT)** sensor to give the PCM information regarding the temperature and, therefore, the density of the fuel.

EXHAUST GAS RECIRCULATION (EGR) TEMPERATURE SENSOR

Some engines, such as Toyota, are equipped with exhaust gas recirculation (EGR) temperature sensors. EGR is a well-established method for reduction of NO_x emissions in internal combustion engines. The exhaust gas contains unburned hydrocarbons, which are recirculated in the combustion process. Recirculation is controlled by valves, which operate as a function of exhaust gas speed, load, and temperature. The gas reaches a temperature of about 850°F (450°C) for which a special heavy-duty glass-encapsulated NTC sensor is available.

The PCM monitors the temperature in the exhaust passage between the EGR valve and the intake manifold. If the temperature increases when the EGR is commanded on, the PCM can determine that the valve or related components are functioning.

ENGINE OIL TEMPERATURE SENSOR

Engine oil temperature sensors are used on many General Motors vehicles and are used as an input to the oil life monitoring system. The computer program inside the PCM calculates engine oil life based on run time, engine RPM, and oil temperature.

TEMPERATURE SENSOR DIAGNOSTIC TROUBLE CODES

The OBD-II diagnostic trouble codes that relate to temperature sensors include both high- and low-voltage codes, as well as intermittent codes.

Diagnostic Trouble Code	Description	Possible Causes
P0112	IAT sensor low voltage	• IAT sensor internally shorted-to-ground • IAT sensor wiring shorted-to-ground • IAT sensor damaged by backfire (usually associated with IAT sensors that are mounted in the intake manifold) • Possible defective PCM
P0113	IAT sensor high voltage	• IAT sensor internally (electrically) open • IAT sensor signal, circuit, or ground circuit open • Possible defective PCM
P0117	ECT sensor low voltage	• ECT sensor internally shorted-to-ground • The ECT sensor circuit wiring shorted-to-ground • Possible defective PCM
P0118	ECT sensor high voltage	• ECT sensor internally (electrically) open • ECT sensor signal, circuit, or ground circuit open • Engine operating in an overheated condition • Possible defective PCM

REVIEW QUESTIONS

1. How does a typical NTC temperature sensor work?
2. What is the difference between a stepped and a non-stepped ECT circuit?
3. What temperature should be displayed on a scan tool if the ECT sensor is unplugged with the key on, engine off?
4. What are the three ways that temperature sensors can be tested?
5. If the transmission fluid temperature (TFT) sensor were to fail open (as if it were unplugged), what would the PCM do to the transmission shifting points?

CHAPTER QUIZ

1. The sensor that most determines fuel delivery when a fuel-injected engine is first started is the _____.
   a. O2S
   b. ECT sensor
   c. Engine MAP sensor
   d. IAT sensor
2. What happens to the voltage measured at the ECT sensor when the thermostat opens?
   a. Increases slightly
   b. Increases about 1 volt
   c. Decreases slightly
   d. Decreases about 1 volt
3. Two technicians are discussing a stepped ECT circuit. Technician A says that the sensor used for a stepped circuit is different than one used in a non-stepped circuit. Technician B says that a stepped ECT circuit uses different internal resistance inside the PCM. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. When testing an ECT sensor on a vehicle, a digital multimeter can be used and the signal wires back probed. What setting should the technician use to test the sensor?
   a. AC volts
   b. DC volts
   c. Ohms
   d. Hz (hertz)
5. When testing the ECT sensor with the connector disconnected, the technician should select what position on the DMM?
   a. AC volts
   b. DC volts
   c. Ohms
   d. Hz (hertz)
6. When checking the ECT sensor with a scan tool, about what temperature should be displayed if the connector is removed from the sensor with the key on, engine off?
   a. 284°F (140°C)
   b. 230°F (110°C)
   c. 120°F (50°C)
   d. −40°F (−40°C)

7. Two technicians are discussing the IAT sensor. Technician A says that the IAT sensor is more important to the operation of the engine (higher authority) than the ECT sensor. Technician B says that the PCM will add fuel if the IAT indicates that the incoming air temperature is cold. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

8. A typical IAT or ECT sensor reads about 3,000 ohms when tested using a DMM. This resistance represents a temperature of about _____.
   a. −40°F (−40°C)
   b. 70°F (20°C)
   c. 120°F (50°C)
   d. 284°F (140°C)

9. If the transmission fluid temperature (TFT) sensor indicates cold automatic transmission fluid temperature, what would the PCM do to the shifts?
   a. Normal shifts and normal operation of the torque converter clutch
   b. Disable torque converter clutch; normal shift points
   c. Delayed shift points and torque converter clutch disabled
   d. Normal shifts but overdrive will be disabled

10. A P0118 DTC is being discussed. Technician A says that the ECT sensor could be shorted internally. Technician B says that the signal wire could be open. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

chapter 73

THROTTLE POSITION (TP) SENSORS

OBJECTIVES: **After studying Chapter 73, the reader will be able to:** • Prepare for ASE Engine Performance (A8) certification test content area "E" (Computerized Engine Controls Diagnosis and Repair). • Discuss how throttle position sensors work. • List the methods that can be used to test TP sensors. • Describe the symptoms of a failed TP sensor. • List how the operation of the TP sensor affects vehicle operation. • Discuss TP sensor rationality tests.

KEY TERMS: Potentiometer 828 • Skewed 830 • Throttle position (TP) sensor 828

THROTTLE POSITION SENSOR CONSTRUCTION

Most computer-equipped engines use a **throttle position (TP) sensor** to signal to the computer the position of the throttle. ● **SEE FIGURE 73–1.** The TP sensor consists of a **potentiometer,** a type of variable resistor.

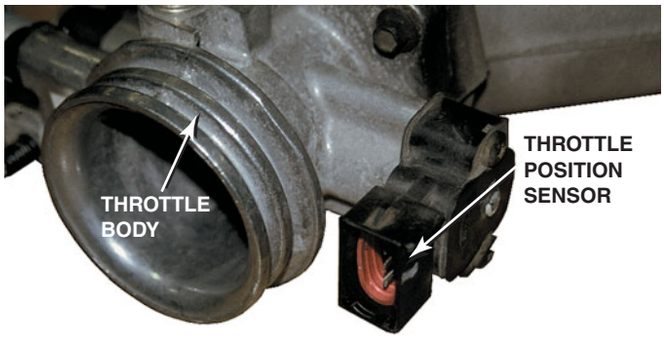


FIGURE 73–1 A typical TP sensor mounted on the throttle plate of this port-injected engine.

POTENTIOMETERS A potentiometer is a variable-resistance sensor with three terminals. One end of the resistor receives reference voltage, while the other end is grounded. The third terminal is attached to a movable contact that slides across the resistor to vary its resistance. Depending on whether the contact is near the supply end or the ground end of the resistor, return voltage is high or low. ● **SEE FIGURE 73–2.**

Throttle position (TP) sensors are among the most common potentiometer-type sensors. The computer uses their input to determine the amount of throttle opening and the rate of change.

A typical sensor has three wires:

- A 5-volt reference feed wire from the computer
- Signal return (A ground wire back to the computer)
- A voltage signal wire back to the computer; as the throttle is opened, the voltage to the computer changes

Normal throttle position voltage on most vehicles is about 0.5 volt at idle (closed throttle) and 4.5 volts at wide-open throttle (WOT).

NOTE: The TP sensor voltage at idle is usually about 10% of the TP sensor voltage when the throttle is wide open, but can vary from as low as 0.3 volt to 1.2 volts, depending on the make and model of vehicle.

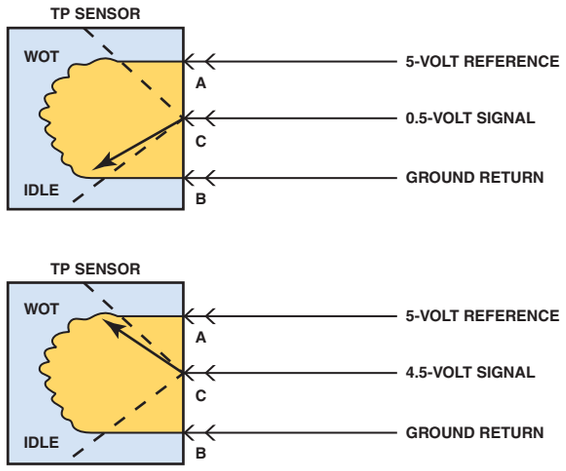


FIGURE 73–2 The signal voltage from a throttle position increases as the throttle is opened because the wiper arm is closer to the 5-volt reference. At idle, the resistance of the sensor winding effectively reduces the signal voltage output to the computer.

TP SENSOR COMPUTER INPUT FUNCTIONS

- The computer senses any change in throttle position and changes the fuel mixture and ignition timing. The actual change in fuel mixture and ignition timing is also partly determined by the other sensors, such as the manifold pressure (engine vacuum), engine RPM, the coolant temperature, and oxygen sensor(s). Some throttle position sensors are adjustable and should be set according to the exact engine manufacturer's specifications.
- The throttle position (TP) sensor used on fuel-injected vehicles acts as an "electronic accelerator pump." This means that the computer will pulse additional fuel from the injectors when the throttle is depressed. Because the air can quickly flow into the engine when the throttle is opened, additional fuel must be supplied to prevent the air–fuel mixture from going lean, causing the engine to hesitate when the throttle is depressed. If the TP sensor is unplugged or defective, the engine may still operate satisfactorily, but hesitate upon acceleration.
- The PCM supplies the TP sensor with a regulated voltage that ranges from 4.8 to 5.1 volts. This reference voltage is usually referred to as a 5-volt reference or "Vref." The TP output signal is an input to the PCM, and the TP sensor ground also flows through the PCM.

See the Ford throttle position (TP) sensor chart for an example of how sensor voltage changes with throttle angle.

Ford Throttle Position (TP) Sensor Chart

Throttle Angle (Degrees)	Voltage (V)
0	0.50
10	0.97
20	1.44
30	1.90
40	2.37
50	2.84
60	3.31
70	3.78
80	4.24

NOTE: Generally, any reading higher than 80% represents wide-open throttle to the computer.

PCM USES FOR THE TP SENSOR

The TP sensor is used by the Powertrain Control Module (PCM) for the following reasons.

CLEAR FLOOD MODE

If the throttle is depressed to the floor during engine cranking, the PCM will either greatly reduce or entirely eliminate any fuel-injector pulses to aid in cleaning a flooded engine. If the throttle is depressed to the floor and the engine is not flooded with excessive fuel, the engine may not start.

TORQUE CONVERTER CLUTCH ENGAGEMENT AND RELEASE

The torque converter clutch will be released if the PCM detects rapid acceleration to help the transmission deliver maximum torque to the drive wheels. The torque converter clutch is applied when the vehicle is lightly accelerating and during cruise conditions to help improve fuel economy.

RATIONALITY TESTING FOR MAP AND MAF SENSORS

As part of the rationality tests for the MAP and/or MAF sensor, the TP sensor signal is compared to the reading from other sensors to determine if they match. For example, if the throttle position sensor is showing wide-open throttle (WOT), the MAP and/or MAF reading should also indicate that this engine is under a heavy load. If not, a diagnostic trouble code could be set for the TP, as well as the MAP and/or MAF sensors.

AUTOMATIC TRANSMISSION SHIFT POINTS

The shift points are delayed if the throttle is opened wide to allow the engine speed to increase, thereby producing more power and aiding in the acceleration of the vehicle. If the throttle is barely open, the shift point occurs at the minimum speed designed for the vehicle.

TARGET IDLE SPEED (IDLE CONTROL STRATEGY)

When the TP sensor voltage is at idle, the PCM then controls idle speed using the idle air control (IAC) and/or spark timing variation to maintain the commanded idle speed. If the TP sensor indicates that the throttle has moved off idle, fuel delivery and spark timing are programmed for acceleration. Therefore, if the throttle linkage is stuck or binding, the idle speed may not be correct.

AIR-CONDITIONING COMPRESSOR OPERATION

The TP sensor is also used as an input sensor for air-conditioning compressor operation. If the PCM detects that the throttle is at or close to wide open, the air-conditioning compressor is disengaged.

BACKS UP OTHER SENSORS

The TP sensor is used as a backup to the MAP sensor and/or MAF in the event the PCM detects that one or both are not functioning correctly. The PCM then calculates fuel needs and spark timing based on the engine speed (RPM) and throttle position.



FIGURE 73–3 A meter lead connected to a T-pin that was gently pushed along the signal wire of the TP sensor until the point of the pin touched the metal terminal inside the plastic connector.

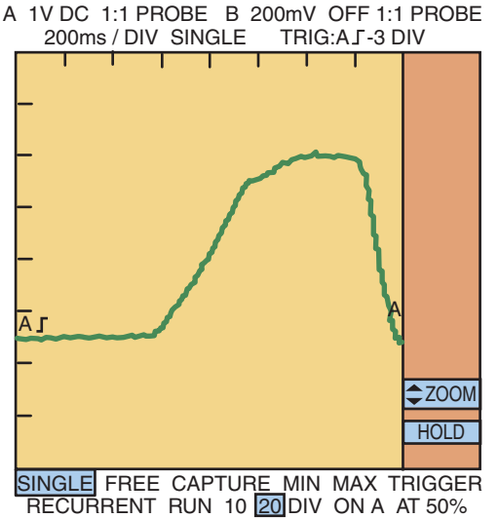


FIGURE 73–4 A typical waveform of a TP sensor signal as recorded on a DSO when the accelerator pedal was depressed with the ignition switch on (engine off). Clean transitions and the lack of any glitches in this waveform indicate a good sensor. (*Courtesy of Fluke Corporation*)

TESTING THE THROTTLE POSITION SENSOR

TOOLS NEEDED A TP sensor can be tested using one or more of the following tools:

- A digital voltmeter with three test leads connected in series between the sensor and the wiring harness connector or back probing using T-pins or other recommended tool that will not cause harm to the connector or wiring.
- A scan tool or a specific tool recommended by the vehicle manufacturer.
- A breakout box that is connected in series between the computer and the wiring harness connector(s). A typical breakout box includes test points at which TP voltages can be measured with a digital voltmeter.
- An oscilloscope.

Use jumper wires, T-pins to back-probe the wires, or a breakout box to gain electrical access to the wiring to the TP sensor. ● **SEE FIGURE 73–3.**

NOTE: The procedure that follows is the usual method used by many manufacturers. Always refer to service information for the exact recommended procedure and specifications for the vehicle being tested.

TESTING PROCEDURE The procedure for testing the sensor using a digital multimeter is as follows:

1. Turn the ignition switch on (engine off).
2. Set the digital meter to read to DC volts and measure the voltage between the signal wire and ground (reference low) wire. The voltage should be about 0.5 volt.

   NOTE: Consult the service information for exact wire colors or locations.

3. With the engine still not running (but with the ignition still on), slowly increase the throttle opening. The voltage signal from the TP sensor should also increase. Look for any "dead spots" or open circuit readings as the throttle is increased to the wide-open position. ● **SEE FIGURE 73–4** for an example of how a good TP sensor would look when tested with a digital storage oscilloscope (DSO).

   NOTE: Use the accelerator pedal to depress the throttle because this applies the same forces on the TP sensor as the driver does during normal driving. Moving the throttle by hand under the hood may not accurately test the TP sensor.

4. With the voltmeter still connected, slowly return the throttle down to the idle position. The voltage from the TP sensor should also decrease evenly on the return to idle.

The TP sensor voltage at idle should be within the acceptable range as specified by the manufacturer. Some TP sensors can be adjusted by loosening their retaining screws and moving the sensor in relation to the throttle opening. This movement changes the output voltage of the sensor.

TECH TIP

Check Power and Ground Before Condemning a Bad Sensor

Most engine sensors use a 5-volt reference and a ground. If the 5 volts to the sensor is too high (shorted to voltage) or too low (high resistance), then the sensor output will be **skewed** or out of range. Before replacing the sensor that did not read correctly, measure both the 5-volt reference and ground. To measure the ground, simply turn the ignition on (engine off) and touch one test lead of a DMM set to read DC volts to the sensor ground and the other to the negative terminal of the battery. Any reading higher than 0.2 volt (200 mV) represents a poor ground. ● **SEE FIGURES 73–5 AND 73–6.**



FIGURE 73–5 Checking the 5-volt reference from the computer being applied to the TP sensor with the ignition switch on (engine off). The reading for this vehicle (5.02 volts DC) is within the normal range for the 5-volt reference voltage of 4.9 to 5.1 volts.



FIGURE 73–6 Checking the voltage drop between the TP sensor ground and a good engine ground with the ignition on (engine off). A reading of greater than 0.2 volt (200 mV) represents a bad computer ground.

All TP sensors should also provide a smooth transition voltage reading from idle to WOT and back to idle. Replace the TP sensor if erratic voltage readings are obtained or if the correct setting at idle cannot be obtained.

MIN/MAX TESTING Many digital multimeters are capable of recording voltage readings over time and then displaying the minimum, maximum, and average readings. To perform a MIN/MAX test of the TP sensor, manually set the meter to read higher than 4 volts.

STEP 1 Connect the red meter lead to the signal wire and the black meter lead to a good ground or the ground return wire at the TP sensor.

STEP 2 With the ignition on, engine off, slowly depress and release the accelerator pedal from inside the vehicle.

STEP 3 Check the minimum and maximum voltage reading on the meter display. Any 0- or 5-volt reading would indicate a fault or short in the TP sensor.

SCAN TOOL TESTING A scan tool can be used to check for proper operation of the throttle position sensor using the following steps.

STEP 1 With the key on, engine off, the TP sensor voltage display should be about 0.5 volt, but can vary from as low as 0.3 volt to as high as 1.2 volts.

STEP 2 Check the scan tool display for the percentage of throttle opening. The reading should be zero and gradually increase in percentage as the throttle is depressed.

STEP 3 The idle air control (IAC) counts should increase as the throttle is opened and decrease as the throttle is closed. Start the engine and observe the IAC counts as the throttle is depressed.

STEP 4 Start the engine and observe the TP sensor reading. Use a wedge at the throttle stop to increase the throttle opening slightly. The throttle percentage reading should increase. Shut off and restart the engine. If the percentage of throttle opening returns to 0%, the PCM determines that the increased throttle opening is now the new minimum and resets the idle position of the TP sensor. Remove the wedge and cycle the ignition key. The throttle position sensor should again read zero percentage.

NOTE: Some engine computers are not capable of resetting the throttle position sensor.

TP SENSOR DIAGNOSTIC TROUBLE CODES

The diagnostic trouble codes (DTCs) associated with the throttle position sensor include the following.

Diagnostic Trouble Code	Description	Possible Causes
P0122	TP sensor low voltage	• TP sensor internally shorted-to-ground • TP sensor wiring shorted-to-ground • TP sensor or wiring open
P0123	TP sensor high voltage	• TP sensor internally shorted to 5-volt reference • TP sensor ground open • TP sensor wiring shorted-to-voltage
P0121	TP sensor signal does not agree with MAP	• Defective TP sensor • Incorrect vehicle-speed (VS) sensor signal • MAP sensor out-of-calibration or defective

REVIEW QUESTIONS

1. What is the purpose of each of the three wires on a typical TP sensor?
2. What all does the PCM do with the TP sensor signal voltage?
3. What is the procedure to follow when checking the 5-volt reference and TP sensor ground?
4. How can a TP sensor be diagnosed using a scan tool?

CHAPTER QUIZ

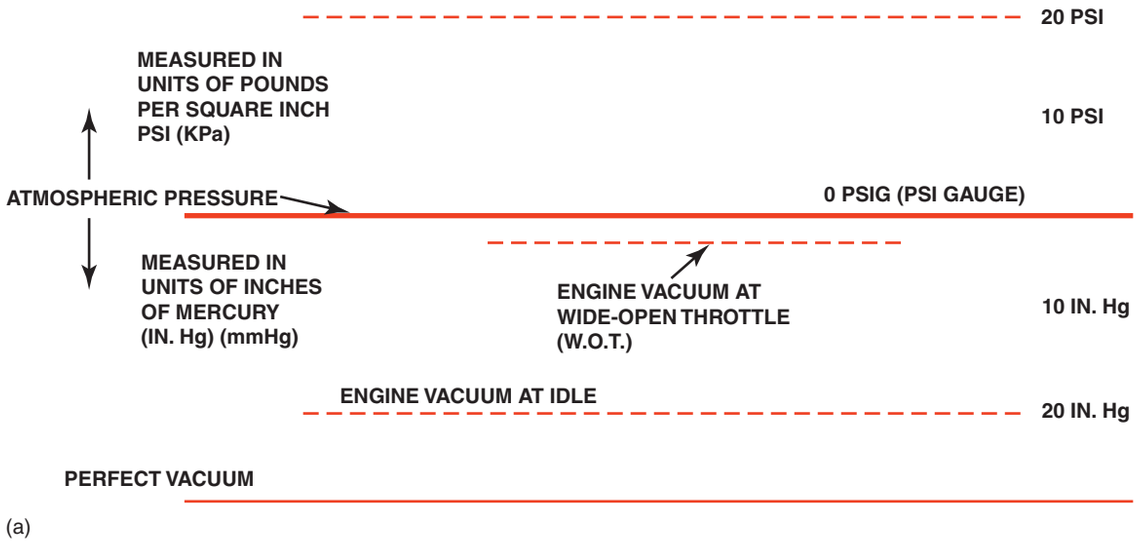
1. Which sensor is generally considered to be the electronic accelerator pump of a fuel-injected engine?
   a. O2S
   b. ECT sensor
   c. Engine MAP sensor
   d. TP sensor
2. Typical TP sensor voltage at idle is about _____.
   a. 2.50 to 2.80 volts
   b. 0.5 volt or 10% of WOT TP sensor voltage
   c. 1.5 to 2.8 volts
   d. 13.5 to 15.0 volts
3. A TP sensor is what type of sensor?
   a. Rheostat
   b. Voltage generating
   c. Potentiometer
   d. Piezoelectric
4. Most TP sensors have how many wires?
   a. 1 **c.** 3
   b. 2 **d.** 4
5. Which sensor does the TP sensor back up if the PCM determines that a failure has occurred?
   a. Oxygen sensor **c.** MAP sensor
   b. MAF sensor **d.** Either b or c
6. Which wire on a TP sensor should be back-probed to check the voltage signal to the PCM?
   a. 5-volt reference (Vref)
   b. Signal
   c. Ground
   d. Meter should be connected between the 5-volt reference and the ground
7. After a TP sensor has been tested using the MIN/MAX function on a DMM, a reading of zero volts is displayed. What does this reading indicate?
   a. The TP sensor is open at one point during the test.
   b. The TP sensor is shorted.
   c. The TP sensor signal is shorted to 5-volt reference.
   d. Both b and c are possible.
8. After a TP sensor has been tested using the MIN/MAX function on a DMM, a reading of 5 volts is displayed. What does this reading indicate?
   a. The TP sensor is open at one point during the test.
   b. The TP sensor is shorted.
   c. The TP sensor signal is shorted to 5-volt reference.
   d. Both b and c are possible.
9. A technician attaches one lead of a digital voltmeter to the ground terminal of the TP sensor and the other meter lead to the negative terminal of the battery. The ignition is switched to on, engine off and the meter displays 37.3 mV. Technician A says that this is the signal voltage and is a little low. Technician B says that the TP sensor ground circuit has excessive resistance. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. A P0122 DTC is retrieved using a scan tool. This DTC means _____.
    a. The TP sensor voltage is low
    b. The TP sensor could be shorted-to-ground
    c. The TP sensor signal circuit could be shorted-to-ground
    d. All of the above are correct.

chapter 74

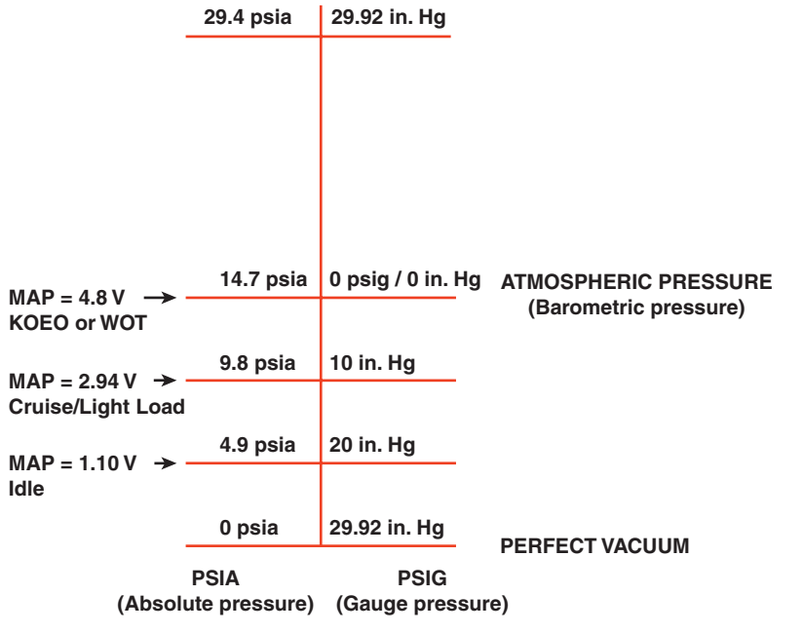
MAP/BARO SENSORS

OBJECTIVES: **After studying Chapter 74, the reader will be able to:** • Prepare for ASE Engine Performance (A8) certification test content area "E" (Computerized Engine Controls Diagnosis and Repair). • Discuss how MAP sensors work. • List the methods that can be used to test MAP sensors. • Describe the symptoms of a failed MAP sensor. • List how the operation of the MAP sensor affects vehicle operation. • Discuss MAP sensor rationality tests. • Describe how the BARO sensor is used to determine altitude.

KEY TERMS: Barometric manifold absolute pressure (BMAP) sensor 837 • Barometric pressure (BARO) sensor 837 • Manifold absolute pressure (MAP) sensor 834 • Piezoresistivity 834 • Pressure differential 833 • Speed density 835 • Vacuum 833



(a)



(b)

FIGURE 74–1 (a) As an engine is accelerated under a load, the engine vacuum drops. This drop in vacuum is actually an increase in absolute pressure in the intake manifold. A MAP sensor senses all pressures greater than that of a perfect vacuum. (b) The relationship between absolute pressure, vacuum, and gauge pressure.

AIR PRESSURE—HIGH AND LOW

Think of an internal combustion engine as a big air pump. As the pistons move up and down in the cylinders, they pump in air and fuel for combustion and pump out exhaust gases. They do this by creating a difference in air pressure. The air outside an engine has weight and exerts pressure, as does the air inside an engine.

As a piston moves down on an intake stroke with the intake valve open, it creates a larger area inside the cylinder for the air to fill. This lowers the air pressure within the engine. Because the pressure inside the engine is lower than the pressure outside, air flows into the engine to fill the low-pressure area and equalize the pressure.

The low pressure within the engine is called **vacuum.** Vacuum causes the higher-pressure air on the outside to flow into the low-pressure area inside the cylinder. The difference in pressure between the two areas is called a **pressure differential.** ● **SEE FIGURE 74–1.**

PRINCIPLES OF PRESSURE SENSORS

Intake manifold pressure changes with changing throttle positions. At wide-open throttle, manifold pressure is almost the same as atmospheric pressure. On deceleration or at idle, manifold pressure is below atmospheric pressure, thus creating a vacuum. In cases where turbo- or supercharging is used, under part- or full-load condition, intake manifold pressure rises above atmospheric pressure. Also, oxygen content and barometric pressure change with differences in altitude, and the computer must be able to compensate by

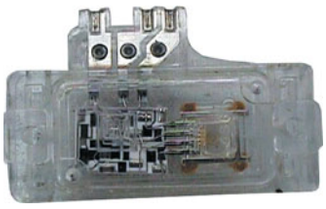


FIGURE 74–2 A clear plastic MAP sensor used for training purposes showing the electronic circuit board and electrical connections.

making changes in the flow of fuel entering the engine. To provide the computer with changing airflow information, a fuel-injection system may use the following:

- Manifold absolute pressure (MAP) sensor
- Manifold absolute pressure (MAP) sensor plus barometric absolute pressure (BARO) sensor
- Barometric and manifold absolute pressure sensors combined (BMAP)

The **manifold absolute pressure (MAP) sensor** may be a ceramic capacitor diaphragm, an aneroid bellows, or a piezoresistive crystal. It has a sealed vacuum reference input on one side; the other side is connected (vented) to the intake manifold. This sensor housing also contains signal conditioning circuitry. ● **SEE FIGURE 74–2.** Pressure changes in the manifold cause the sensor to deflect, varying its analog or digital return signal to the computer. As the air pressure increases, the MAP sensor generates a higher voltage or frequency return signal to the computer.

CONSTRUCTION OF MANIFOLD ABSOLUTE PRESSURE (MAP) SENSORS

The manifold absolute pressure (MAP) sensor is used by the engine computer to sense engine load. The typical MAP sensor consists of a ceramic or silicon wafer sealed on one side with a perfect vacuum and exposed to intake manifold vacuum on the other side. As the engine vacuum changes, the pressure difference on the wafer changes the output voltage or frequency of the MAP sensor.

A manifold absolute pressure (MAP) sensor is used on many engines for the PCM to determine the load on the engine. The relationship among barometer pressure, engine vacuum, and MAP sensor voltage includes:

- Absolute pressure is equal to barometric pressure minus intake manifold vacuum.
- A decrease in manifold vacuum means an increase in manifold pressure.
- The MAP sensor compares manifold vacuum to a perfect vacuum.
- Barometric pressure minus MAP sensor reading equals intake manifold vacuum. Normal engine vacuum is 17–21 in. Hg.
- Supercharged and turbocharged engines require a MAP sensor that is calibrated for pressures above atmospheric, as well as for vacuum.

SILICON-DIAPHRAGM STRAIN GAUGE MAP SENSOR

This is the most commonly used design for a MAP sensor and the output is a DC analog (variable) voltage. One side of a silicon wafer is exposed to engine vacuum and the other side is exposed to a perfect vacuum.

There are four resistors attached to the silicon wafer, which changes in resistance when strain is applied to the wafer. This change in resistance due to strain is called **piezoresistivity.** The resistors are electrically connected to a Wheatstone bridge circuit and then to a differential amplifier, which creates a voltage in proportion to the vacuum applied.

A typical General Motors MAP sensor voltage varies from 0.88 to 1.62 at engine idle.

- 17 in. Hg is equal to about 1.62 volts
- 21 in. Hg is equal to about 0.88 volts

Therefore, a good reading should be about 1.0 volt from the MAP sensor on a sound engine at idle speed. See the following chart that shows engine load, engine vacuum, and MAP.

TECH TIP

If It's Green, It's a Signal Wire

Ford-built vehicles usually use a green wire as the signal wire back to the computer from the sensors. It may not be a solid green, but if there is green somewhere on the wire, then it is the signal wire. The other wires are the power and ground wires to the sensor.

Engine Load	Manifold Vacuum	Manifold Absolute Pressure	MAP Sensor Volt Signal
Heavy (WOT)	Low (almost 0 in. Hg)	High (almost atmospheric)	High (4.6–4.8 V)
Light (idle)	High (17–21 in. Hg)	Low (lower than atmospheric)	Low (0.8–1.6 V)

CAPACITOR-CAPSULE MAP SENSOR

A capacitor-capsule is a type of MAP sensor used by Ford which uses two ceramic (alumina) plates with an insulating washer spacer in the center to create a capacitor. Changes in engine vacuum cause the plates to deflect, which changes the capacitance. The electronics in the sensor then generate a varying digital frequency output signal, which is proportional to the engine vacuum. ● **SEE FIGURE 74–3.** ● **SEE FIGURE 74–4** for a scope waveform of a digital MAP sensor. Also see the Ford MAP sensor chart.

Ford MAP Sensor Chart

MAP Sensor Output (Hz)	Engine Operating Conditions	Intake Manifold Vacuum (in. Hg)
156–159 Hz	Key on, engine off	0 in. Hg
102–109 Hz	Engine at idle (sea level)	17–21 in. Hg
156–159 Hz	Engine at wide-open throttle (WOT)	About 0 in. Hg

CERAMIC DISC MAP SENSOR

The ceramic disc MAP sensor is used by Chrysler and it converts manifold pressure into a capacitance discharge. The discharge controls the amount of voltage delivered by the sensor to the PCM. The output is the same as the previously used strain gauge/Wheatstone bridge design and is interchangeable. ● **SEE FIGURE 74–5.** See the Chrysler MAP sensor chart.

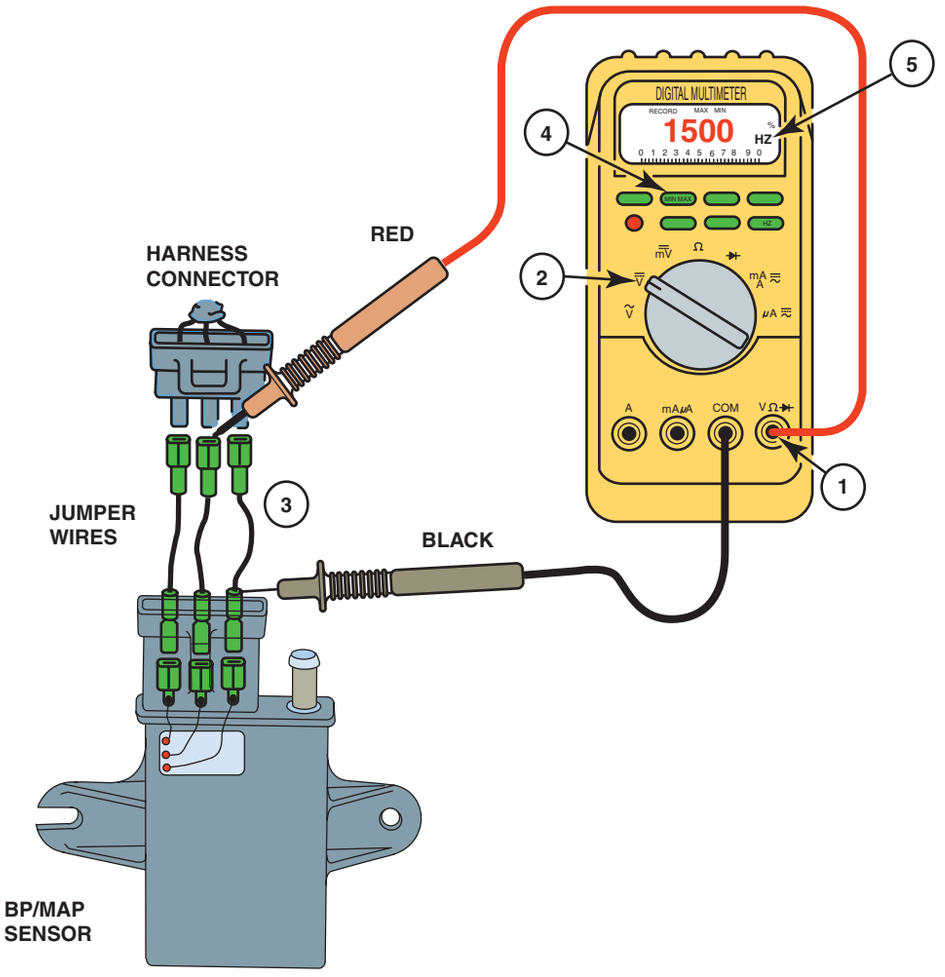


FIGURE 74–3 MAP sensors use three wires: 1. 5-volt reference from the PCM 2. Sensor signal (output signal) 3. Ground. A DMM set to test a MAP sensor. (1) Connect the red meter lead to the V meter terminal and the black meter lead to the COM meter terminal. (2) Select DC volts. (3) Connect the test leads to the sensor signal wire and the ground wire. (4) Select hertz (Hz) if testing a MAP sensor whose output is a varying frequency; otherwise keep it on DC volts. (5) Read the change of voltage (frequency) as the vacuum is applied to the sensor. Compare the vacuum reading and the frequency (or voltage) reading to the specifications.

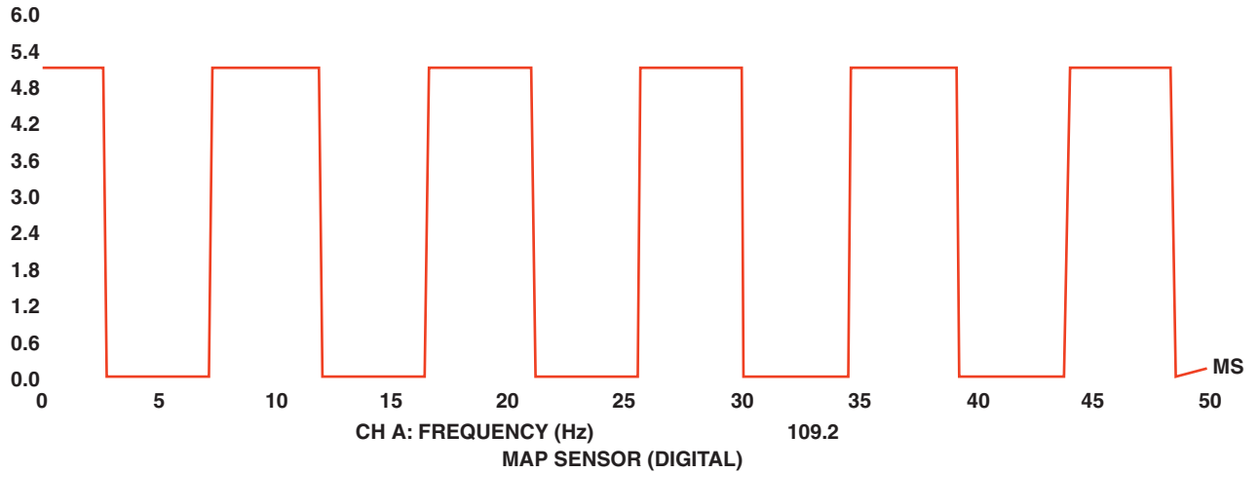


FIGURE 74–4 A waveform of a typical digital MAP sensor.

Chrysler MAP Sensor Chart

Vacuum (in. Hg)	MAP Sensor Signal Voltage (V)
0.5	4.8
1.0	4.6
3.0	4.1
5.0	3.8
7.0	3.5
10.0	2.9
15.0	2.1
20.0	1.2
25.0	0.5

PCM USES OF THE MAP SENSOR

The PCM uses the MAP sensor to determine the following:

- **The load on the engine.** The MAP sensor is used on a **speed density**-type fuel-injection system to determine the load on the engine, and therefore the amount of fuel needed. On engines equipped with a mass air flow (MAF) sensor, the MAP is used as a backup to the MAF, for diagnosis of other sensors, and systems such as the EGR system.

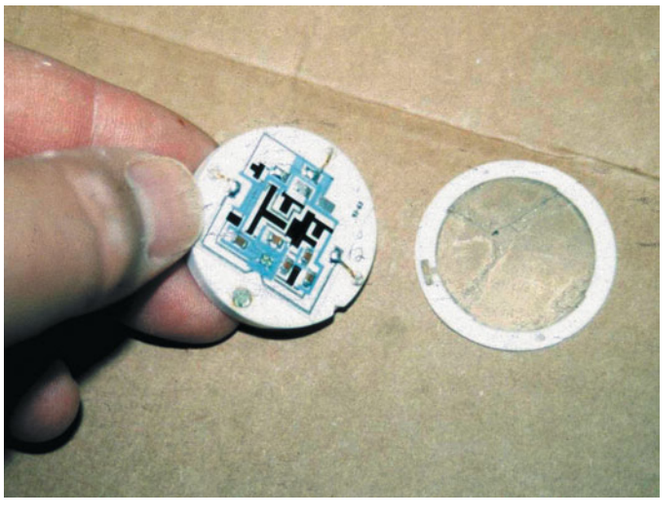


FIGURE 74–5 Shown is the electronic circuit inside a ceramic disc MAP sensor used on many Chrysler engines. The black areas are carbon resistors that are applied to the ceramic, and lasers are used to cut lines into these resistors during testing to achieve the proper operating calibration.

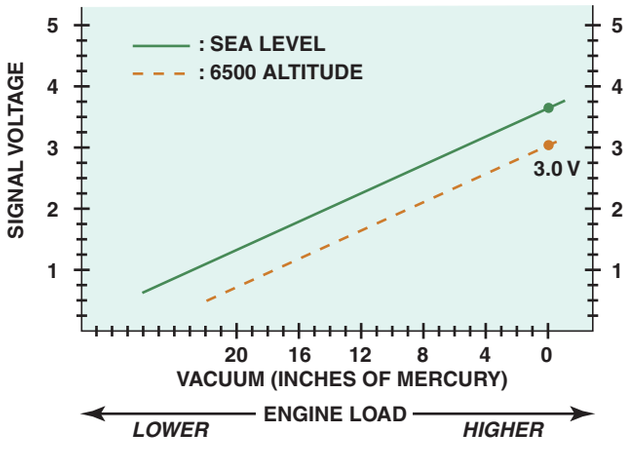


FIGURE 74–6 Altitude affects the MAP sensor voltage.

- **Altitude, fuel, and spark control calculations.** At key on, the MAP sensor determines the altitude (acts as a BARO sensor) and adjusts the fuel delivery and spark timing accordingly.
  - If the altitude is high, generally over 5,000 feet (1,500 meters), the PCM will reduce fuel delivery and advance the ignition timing.
  - The altitude is also reset when the engine is accelerated to wide-open throttle and the MAP sensor is used to reset the altitude reading. ● **SEE FIGURE 74–6.**
- **EGR system operation.** As part of the OBD-II standards, the exhaust gas recirculation (EGR) system must be checked for proper operation. One method used by many vehicle manufacturers is to command the EGR valve on and then watch the MAP sensor signal. The opening of the EGR pintle should decrease engine vacuum. If the MAP sensor does not react with the specified drop in manifold vacuum (increase in manifold pressure), an EGR flow rate problem diagnostic trouble code is set.
- **Detect deceleration (vacuum increases).** The engine vacuum rises when the accelerator is released, which changes the MAP sensor voltage. When deceleration is detected by the PCM, fuel is either stopped or greatly reduced to improve exhaust emissions.

TECH TIP

Use the MAP Sensor as a Vacuum Gauge

A MAP sensor measures the pressure inside the intake manifold compared with absolute zero (perfect vacuum). For example, an idling engine that has 20 inches of mercury (in. Hg) of vacuum has a lower pressure inside the intake manifold than when the engine is under a load and the vacuum is at 10 in. Hg. A decrease in engine vacuum results in an increase in manifold pressure. A normal engine should produce between 17 and 21 in. Hg at idle. Comparing the vacuum reading with the voltage reading output of the MAP sensor indicates that the reading should be between 1.62 and 0.88 volt or 109 to 102 Hz or lower on Ford MAP sensors. Therefore, a digital multimeter (DMM), scan tool, or scope can be used to measure the MAP sensor voltage and be used instead of a vacuum gauge.

NOTE: This chart was developed by testing a MAP sensor at a location about 600 feet above sea level. For best results, a chart based on your altitude should be made by applying a known vacuum, and reading the voltage of a known-good MAP sensor. Vacuum usually drops about 1 inch per 1,000 feet of altitude.

Vacuum (in. Hg)	GM (DC volts)	Ford (Hz)
0	4.80	156–159
1	4.52	
2	4.46	
3	4.26	
4	4.06	
5	3.88	141–143
6	3.66	
7	3.50	
8	3.30	
9	3.10	
10	2.94	127–130
11	2.76	
12	2.54	
13	2.36	
14	2.20	
15	2.00	114–117
16	1.80	
17	1.62	
18	1.42	108–109
19	1.20	
20	1.10	102–104
21	0.88	
22	0.66	

- **Monitor engine condition.** As an engine wears, the intake manifold vacuum usually decreases. The PCM is programmed to detect the gradual change in vacuum and is able to keep the air–fuel mixture in the correct range. If the PCM were not

capable of making adjustments for engine wear, the lower vacuum could be interpreted as increased load on the engine, resulting in too much fuel being injected, thereby reducing fuel economy and increasing exhaust emissions.

- **Load detection for returnless-type fuel injection.** On fuel delivery systems that do not use a return line back to the fuel tank, the engine load calculation for the fuel needed is determined by the signals from the MAP sensor.
- **Altitude and MAP sensor values.** On an engine equipped with a speed-density-type fuel injection, the MAP sensor is the most important sensor needed to determine injection pulse width. Changes in altitude change the air density as well as weather conditions. Barometric pressure and altitude are inversely related:
  - As altitude increases—barometric pressure decreases
  - As altitude decreases—barometric pressure increases

  As the ignition switch is turned from off to the start position, the PCM reads the MAP sensor value to determine atmospheric and air pressure conditions. This barometric pressure reading is updated every time the engine is started and whenever wide-open throttle is detected. The barometric pressure reading at that time is updated. See the chart that compares altitude to MAP sensor voltage.

Altitude and MAP Sensor Voltage

Altitude	MAP Sensor Voltage (key on, engine off)
Sea level	4.6 to 4.8 volts
2,500 (760 m)	4.0 volts
5,000 (1,520 m)	3.7 volts
7,500 (2,300 m)	3.35 volts
10,000 (3,050 m)	3.05 volts
12,500 (3,800 m)	2.80 volts
15,000 (4,600 m)	2.45 volts

BAROMETRIC PRESSURE SENSOR

A **barometric pressure (BARO) sensor** is similar in design, but senses more subtle changes in barometric absolute pressure (atmospheric air pressure). It is vented directly to the atmosphere. The **barometric manifold absolute pressure (BMAP) sensor** is actually a combination of a BARO and MAP sensor in the same housing. The BMAP sensor has individual circuits to measure barometric and manifold pressure. This input not only allows the computer to adjust for changes in atmospheric pressure due to weather, but also is the primary sensor used to determine altitude.

NOTE: A MAP sensor and a BARO sensor are usually the same sensor, but the MAP sensor is connected to the manifold and a BARO sensor is open to the atmosphere. The MAP sensor is capable of reading barometric pressure just as the ignition switch is turned to the on position before the engine starts. Therefore, altitude and weather changes are available to the computer. During mountainous driving, it may be an advantage to stop and then restart the engine so that the engine computer can take another barometric pressure reading and recalibrate fuel delivery based on the new altitude. See the Ford/BARO altitude chart for an example of how altitude affects intake manifold pressure. The computer on some vehicles will monitor the throttle position sensor and use the MAP sensor reading at wide-open throttle (WOT) to update the BARO sensor if it has changed during driving.

REAL WORLD FIX

The Cavalier Convertible Story

The owner of a Cavalier convertible stated to a service technician that the "check engine" (MIL) was on. The technician found a diagnostic trouble code (DTC) for a MAP sensor. The technician removed the hose at the MAP sensor and discovered that gasoline had accumulated in the sensor and dripped out of the hose as it was being removed. The technician replaced the MAP sensor and test drove the vehicle to confirm the repair. Almost at once the check engine light came on with the same MAP sensor code. After several hours of troubleshooting without success in determining the cause, the technician decided to start over again. Almost at once, the technician discovered that no vacuum was getting to the MAP sensor where a vacuum gauge was connected with a T-fitting in the vacuum line to the MAP sensor. The vacuum port in the base of the throttle body was clogged with carbon. After a thorough cleaning, and clearing the DTC, the Cavalier again performed properly and the check engine light did not come on again. The technician had assumed that if gasoline was able to reach the sensor through the vacuum hose, surely vacuum could reach the sensor. The technician learned to stop assuming when diagnosing a vehicle and concentrate more on testing the simple things first.

Ford MAP/BARO Altitude Chart

Altitude (feet)	Volts (V)
0	1.59
1,000	1.56
2,000	1.53
3,000	1.50
4,000	1.47
5,000	1.44
6,000	1.41
7,000	1.39

NOTE: Some older Chrysler brand vehicles were equipped with a combination BARO and IAT sensor. The sensor was mounted on the bulkhead (firewall) and sensed the underhood air temperature.

TESTING THE MAP SENSOR

Most pressure sensors operate on 5 volts from the computer and return a signal (voltage or frequency) based on the pressure (vacuum) applied to the sensor. If a MAP sensor is being tested, make certain that the vacuum hose and hose fittings are sound

TECH TIP

Visual Check of the MAP Sensor

A defective vacuum hose to a MAP sensor can cause a variety of driveability problems including poor fuel economy, hesitation, stalling, and rough idle. A small air leak (vacuum leak) around the hose can cause these symptoms and often set a trouble code in the vehicle computer. When working on a vehicle that uses a MAP sensor, make certain that the vacuum hose travels consistently *downward* on its route from the sensor to the source of manifold vacuum. Inspect the hose, especially if another technician has previously replaced the factory-original hose. It should not be so long that it sags down at any point. Condensed fuel and/or moisture can become trapped in this low spot in the hose and cause all types of driveability problems and MAP sensor codes.

When checking the MAP sensor, if anything comes out of the sensor itself, it should be replaced. This includes water, gasoline, or any other substance.

and making a good, tight connection to a manifold vacuum source on the engine.

Four different types of test instruments can be used to test a pressure sensor:

1. A digital voltmeter with three test leads connected in series between the sensor and the wiring harness connector or back-probe the terminals.
2. A scope connected to the sensor output, power, and ground.
3. A scan tool or a specific tool recommended by the vehicle manufacturer.
4. A breakout box connected in series between the computer and the wiring harness connection(s). A typical breakout box includes test points at which pressure sensor values can be measured with a digital voltmeter set on DC volts (or frequency counter, if a frequency-type MAP sensor is being tested).

NOTE: Always check service information for the exact testing procedures and specifications for the vehicle being tested.

TESTING THE MAP SENSOR USING A DMM OR SCOPE

Use jumper wires, T-pins to back-probe the connector, or a breakout box to gain electrical access to the wiring to the pressure sensor. Most pressure sensors use three wires:

1. A 5-volt wire from the computer
2. A variable-signal wire back to the computer
3. A ground or reference low wire

The procedure for testing the sensor is as follows:

1. Turn the ignition on (engine off)
2. Measure the voltage (or frequency) of the sensor output
3. Using a hand-operated vacuum pump (or other variable vacuum source), apply vacuum to the sensor

A good pressure sensor should change voltage (or frequency) in relation to the applied vacuum. If the signal does not change or the values are out of range according to the manufacturers' specifications, the sensor must be replaced.



FIGURE 74–7 A typical hand-operated vacuum pump.

TESTING THE MAP SENSOR USING A SCAN TOOL

A scan tool can be used to test a MAP sensor by monitoring the injector pulse width (in milliseconds) when vacuum is being applied to the MAP sensor using a hand-operated vacuum pump. ● **SEE FIGURE 74–7.**

STEP 1 Apply about 20 in. Hg of vacuum to the MAP sensor and start the engine.

STEP 2 Observe the injector pulse width. On a warm engine, the injector pulse width will normally be 1.5 to 3.5 ms.

STEP 3 Slowly reduce the vacuum to the MAP sensor and observe the pulse width. A lower vacuum to the MAP sensor indicates a heavier load on the engine and the injector pulse width should increase.

NOTE: If 23 in. Hg or more vacuum is applied to the MAP sensor with the engine running, this high vacuum will often stall the engine. The engine stalls because the high vacuum is interpreted by the PCM to indicate that the engine is being decelerated, which shuts off the fuel. During engine deceleration, the PCM shuts off the fuel injectors to reduce exhaust emissions and increase fuel economy.

FUEL-RAIL PRESSURE SENSOR

A fuel-rail pressure (FRP) sensor is used on some vehicles such as Fords that are equipped with electronic returnless fuel injection. This sensor provides fuel pressure information to the PCM for fuel injection pulse width calculations.

MAP/BARO DIAGNOSTIC TROUBLE CODES

The diagnostic trouble codes (DTCs) associated with the MAP and BARO sensors include:

Diagnostic Trouble Code	Description	Possible Causes
P0106	BARO sensor out-of-range at key on	• MAP sensor fault • MAP sensor O-ring damaged or missing
P0107	MAP sensor low voltage	• MAP sensor fault • MAP sensor signal circuit shorted-to-ground • MAP sensor 5-volt supply circuit open
P0108	Map sensor high voltage	• MAP sensor fault • MAP sensor O-ring damaged or missing • MAP sensor signal circuit shorted-to-voltage

REVIEW QUESTIONS

1. What is the relationship among atmospheric pressure, vacuum, and boost pressure in PSI?
2. What are two types (construction) of MAP sensors?
3. What is the MAP sensor signal voltage or frequency at idle on a typical General Motors, Chrysler, and Ford engine?
4. What are three uses of a MAP sensor by the PCM?

CHAPTER QUIZ

1. As the load on an engine increases, the manifold vacuum decreases and the manifold absolute pressure _____.
   a. Increases
   b. Decreases
   c. Changes with barometric pressure only (altitude or weather)
   d. Remains constant (absolute)
2. A typical MAP sensor compares the vacuum in the intake manifold to _____.
   a. Atmospheric pressure
   b. A perfect vacuum
   c. Barometric pressure
   d. The value of the IAT sensor
3. Which statement is *false?*
   a. Absolute pressure is equal to barometric pressure plus intake manifold vacuum.
   b. A decrease in manifold vacuum means an increase in manifold pressure.
   c. The MAP sensor compares manifold vacuum to a perfect vacuum.
   d. Barometric pressure minus the MAP sensor reading equals intake manifold vacuum.
4. Which design of MAP sensor produces a frequency (digital) output signal?
   a. Silicon-diaphragm strain gauge
   b. Piezoresistivity design
   c. Capacitor-capsule
   d. Ceramic disc
5. The frequency output of a digital MAP sensor is reading 114 Hz. What is the approximate engine vacuum?
   a. Zero
   b. 5 in. Hg
   c. 10 in. Hg
   d. 15 in. Hg
6. Which is *not* a purpose or function of the MAP sensor?
   a. Measures the load on the engine
   b. Measures engine speed
   c. Calculates fuel delivery based on altitude
   d. Helps diagnose the EGR system
7. When measuring the output signal of a MAP sensor on a General Motors vehicle, the digital multimeter should be set to read _____.
   a. DC V
   b. AC V
   c. Hz
   d. DC A
8. Two technicians are discussing testing MAP sensors. Technician A says that the MAP sensor voltage on a General Motors vehicle at idle should be about 1.0 volt. Technician B says that the MAP sensor frequency on a Ford vehicle at idle should be about 105–108 Hz. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. Technician A says that MAP sensors use a 5-volt reference voltage from the PCM. Technician B says that the MAP sensor voltage will be higher at idle at high altitudes compared to when the engine is operating at near sea level. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. A P0107 DTC is being discussed. Technician A says that a defective MAP sensor could be the cause. Technician B says that a MAP sensor signal wire shorted-to-ground could be the cause. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

chapter 75

MASS AIR FLOW SENSORS

OBJECTIVES: **After studying Chapter 75, the reader will be able to:** • Prepare for ASE Engine Performance (A8) certification test content area "E" (Computerized Engine Controls Diagnosis and Repair). • Discuss how MAF sensors work. • List the methods that can be used to test MAF sensors. • Describe the symptoms of a failed MAF sensor. • List how the operation of the MAF sensor affects vehicle operation. • Discuss MAF sensor rationality tests.

KEY TERMS: False air 843 • Mass airflow (MAF) sensor 840 • Speed density 840 • Tap test 844 • Vane airflow (VAF) sensor 840

AIRFLOW SENSORS

Electronic fuel injection systems that do not use the "**speed density**" system for fuel calculation measure the airflow volume delivered to the engine. Older systems use a movable vane in the intake stream called a vane airflow (VAF) sensor. The vane is part of the **vane airflow (VAF) sensor.** The vane is deflected by intake airflow. ● **SEE FIGURE 75–1.**

The vane airflow sensor used in Bosch L-Jetronic, Ford, and most Japanese electronic port fuel-injection systems is a movable vane connected to a laser-calibrated potentiometer. The vane is mounted on a pivot pin and is deflected by intake airflow proportionate to air velocity. As the vane moves, it also moves the potentiometer. This causes a change in the signal voltage supplied to the computer. ● **SEE FIGURE 75–2.** For example, if the reference voltage is 5 volts, the potentiometer's signal to the computer will vary from a 0 voltage signal (no airflow) to almost a 5-volt signal (maximum airflow). In this way, the potentiometer provides the information the computer needs to vary the injector pulse width proportionate to airflow. There is a special "dampening chamber" built into the VAF to smooth out vane pulsations which would be created by intake manifold air-pressure fluctuations caused by the valve opening and closing. Many vane airflow sensors include a switch to energize the electric fuel pump. This is a safety feature that prevents the operation of the fuel pump if the engine stalls.

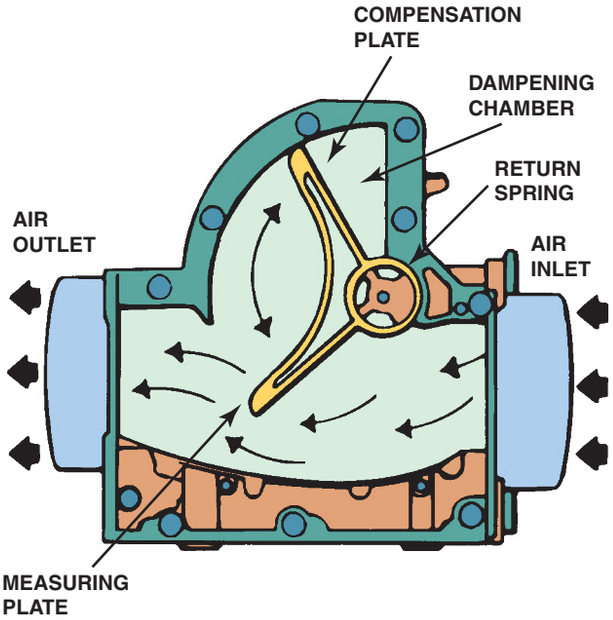


FIGURE 75–1 A vane air flow (VAF) sensor.

MASS AIRFLOW SENSOR TYPES

Most newer fuel injection systems use a **Mass Air Flow (MAF) sensor** to calculate the amount of air volume delivered to the engine.

There are several types of mass airflow sensors.

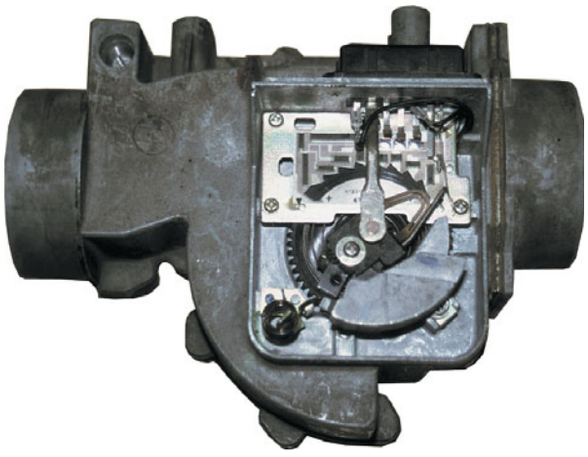


FIGURE 75–2 A typical air vane sensor with the cover removed. The movable arm contacts a carbon resistance path as the vane opens. Many air vane sensors also have contacts that close to supply voltage to the electric fuel pump as the air vane starts to open when the engine is being cranked and air is being drawn into the engine.

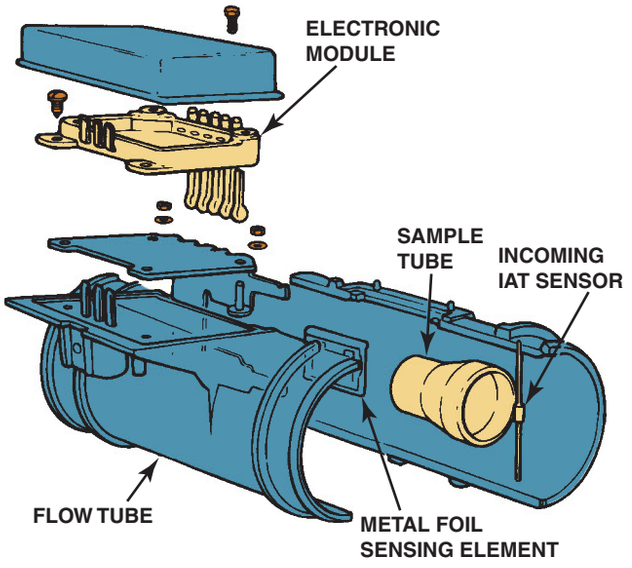


FIGURE 75–3 This five-wire mass air flow sensor consists of a metal foil sensing unit, an intake air temperature (IAT) sensor, and the electronic module.



FIGURE 75–4 The sensing wire in a typical hot wire mass air flow sensor.

FREQUENTLY ASKED QUESTION

What Is the Difference Between an Analog and a Digital MAF Sensor?

Some MAF sensors produce a digital DC voltage signal whose frequency changes with the amount of airflow through the sensor. The frequency range also varies with the make of sensor and can range from 0- to 300-Hz for older General Motors MAF sensors to 1,000- to 9,000-Hz for most newer designs.

Some MAF sensors, such as those used by Ford and others, produce a changing DC voltage, rather than frequency, and range from 0- to 5-volts DC.

HOT FILM SENSOR The hot film sensor uses a temperature-sensing resistor (thermistor) to measure the temperature of the incoming air. Through the electronics within the sensor, a conductive film is kept at a temperature 70°C above the temperature of the incoming air. ● **SEE FIGURE 75–3.**

Because the amount and density of the air both tend to contribute to the cooling effect as the air passes through the sensor, this type of sensor can actually produce an output based on the mass of the airflow. Mass equals volume times density. For example, cold air is denser than warm air so a small amount of cold air may have the same mass as a larger amount of warm air. Therefore, a mass airflow sensor is designed to measure the mass, not the volume, of the air entering the engine.

The output of this type of sensor is usually a frequency based on the amount of air entering the sensor. The more air that enters the sensor, the more the hot film is cooled. The electronics inside the sensor, therefore, increase the current flow through the hot film to maintain the 70°C temperature differential between the air temperature and the temperature of the hot film. This change in current flow is converted to a frequency output that the computer can use as a measurement of airflow. Most of these types of sensors are referred to as mass airflow (MAF) sensors because, unlike the air vane sensor, the MAF sensor takes into account relative humidity, altitude, and temperature of the air. The denser the air, the greater the cooling effect on the hot film sensor and the greater the amount of fuel required for proper combustion.

HOT WIRE SENSOR The hot wire sensor is similar to the hot film type, but uses a hot wire to sense the mass airflow instead of the hot film. Like the hot film sensor, the hot wire sensor uses a temperature-sensing resistor (thermistor) to measure the temperature of the air entering the sensor. ● **SEE FIGURE 75–4.** The electronic circuitry within the sensor keeps the temperature of the wire at 70°C above the temperature of the incoming air.

Both designs operate in essentially the same way. A resistor wire or screen installed in the path of intake airflow is heated to a constant temperature by electric current provided by the computer. Air flowing past the screen or wire cools it. The degree of cooling varies with air velocity, temperature, density, and humidity. These factors combine to indicate the mass of air entering the engine. As the screen or wire cools, more current is required to maintain the specified temperature. As the screen or wire heats up, less current is required. The operating principle can be summarized as follows:

- More intake air volume = cooler sensor, more current.
- Less intake air volume = warmer sensor, less current.

The computer constantly monitors the change in current and translates it into a voltage signal that is used to determine injector pulse width.

BURN-OFF CIRCUIT. Some hot wire-type MAF sensors use a burn-off circuit to keep the sensing wire clean of dust and dirt. A high current is passed through the sensing wire for a short time, but long enough to cause the wire to glow due to the heat. The burn-off circuit is turned on when the ignition switch is switched off after the engine has been operating long enough to achieve normal operating temperature.

KARMAN VORTEX SENSORS

In 1912, a Hungarian scientist named Theodore Van Karman observed that vortexes were created when air passed over a pointed surface. This type of sensor sends a sound wave through the turbulence created by incoming air passing through the sensor. Air mass

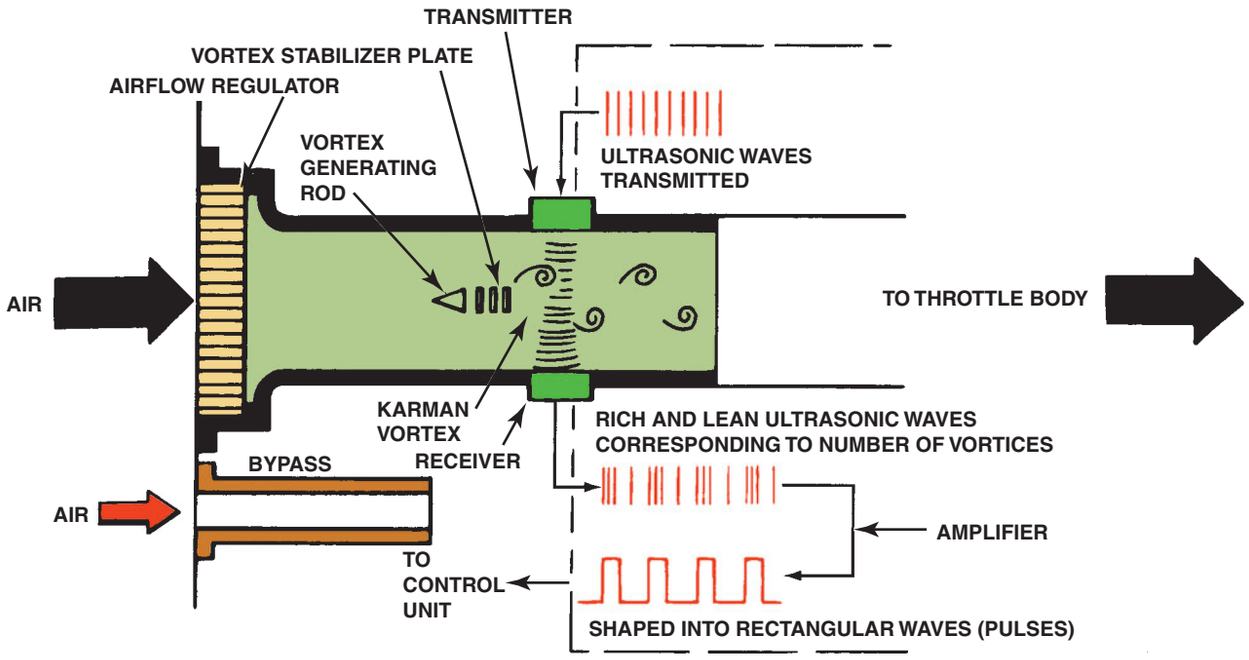


FIGURE 75–5 A Karman Vortex air flow sensor uses a triangle-shaped rod to create vortexes as the air flows through the sensor. The electronics in the sensor itself converts these vortexes to a digital square wave signal.

is calculated based on the time required for the sound waves to cross the turbulent air passage.

There are two basic designs of Karman Vortex air flow sensors. The two types include:

- **Ultrasonic.** This type of sensor uses ultrasonic waves to detect the vortexes that are produced, and produce a digital (on-and-off) signal where frequency is proportional to the amount of air passing through the sensor. ● **SEE FIGURE 75–5.**
- **Pressure-type.** Chrysler uses a pressure-type Karman Vortex sensor that uses a pressure sensor to detect the vortexes. As the airflow through the sensor increases, so do the number of pressure variations. The electronics in the sensor convert these pressure variations to a square wave (digital DC voltage) signal, whose frequency is in proportion to the airflow through the sensor.

PCM USES FOR AIRFLOW SENSORS

The PCM uses the information from the airflow sensor for the following purposes:

- Airflow sensors are used mostly to determine the amount of fuel needed and base pulse-width numbers. The greater the mass of the incoming air, the longer the injectors are pulsed on.
- Airflow sensors back up the TP sensor in the event of a loss of signal or an inaccurate throttle position sensor signal. If the MAF sensor fails, then the PCM will calculate the fuel delivery needs of the engine based on throttle position and engine speed (RPM).

REAL WORLD FIX

The Dirty MAF Sensor Story

The owner of a Buick Park Avenue equipped with a 3800 V-6 engine complained that the engine would hesitate during acceleration, showed lack of power, and seemed to surge or miss at times. A visual inspection found everything to be like new, including a new air filter. There were no stored diagnostic trouble codes (DTCs). A look at the scan data showed airflow to be within the recommended 3 to 7 grams per second. A check of the frequency output showed the problem.

Idle frequency = 2.177 kHz (2,177 Hz)

Normal frequency at idle speed should be 2.37 to 2.52 kHz. Cleaning the hot wire of the MAF sensor restored proper operation. The sensor wire was covered with what looked like fine fibers, possibly from the replacement air filter.

NOTE: Older GM MAF sensors operated at a lower frequency of 32 to 150 Hz, with 32 Hz being the average reading at idle and 150 Hz for wide-open throttle.

TESTING MASS AIRFLOW SENSORS

VISUAL INSPECTION Start the testing of a MAF sensor by performing a thorough visual inspection. Look at all the hoses that direct and send air, especially between the MAF

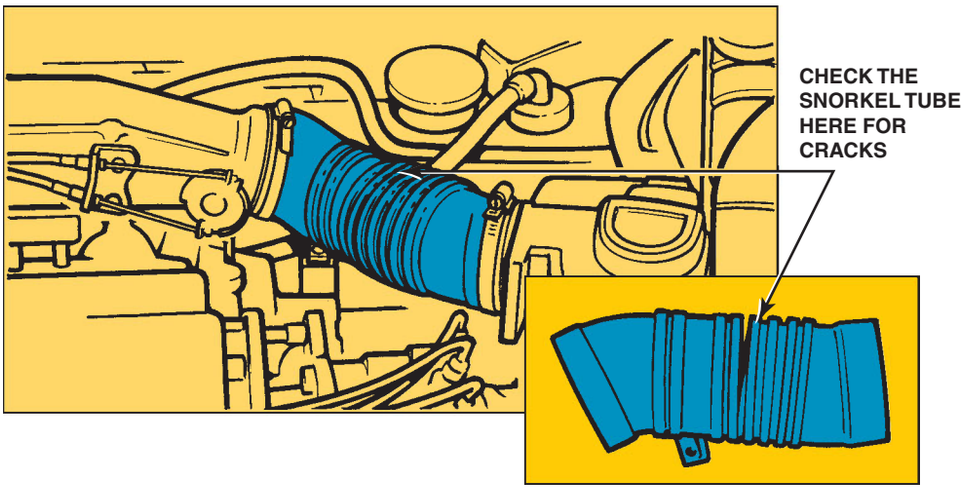


FIGURE 75–6 Carefully check the hose between the MAF sensor and the throttle body assembly for cracks or splits that could create extra (false) air into the engine that is not measured by the MAF sensor.

? FREQUENTLY ASKED QUESTION

What Is Meant By a "High-Authority Sensor"?

A high-authority sensor is a sensor that has a major influence over the amount of fuel being delivered to the engine. For example, at engine start-up, the engine coolant temperature (ECT) sensor is a high-authority sensor and the oxygen sensor (O2S) is a low-authority sensor. However, as the engine reaches operating temperature, the oxygen sensor becomes a high-authority sensor and can greatly affect the amount of fuel being supplied to the engine. See the chart.

High-Authority Sensors	Low-Authority Sensors
ECT (especially when the engine starts and is warming up)	IAT (intake air temperature) sensors modify and back up the ECT
O2S (after the engine reaches closed-loop operation)	TFT (transmission fluid temperature)
MAP	PRNDL (shift position sensor)
MAF	KS (knock sensor)
TP (high authority during acceleration and deceleration)	EFT (engine fuel temperature)

sensor and the throttle body. Also check the electrical connector for:

- Corrosion
- Terminals that are bent or pushed out of the plastic connector
- Frayed wiring

MAF SENSOR OUTPUT TEST

MAF sensors calculate air mass by weight in a given amount of time usually in grams per second (gm/sec). A digital multimeter, set to read DC volts on the signal wire circuit, can be used to check the MAF sensor. See the chart that shows the voltage output compared with the grams per second of airflow through the sensor. Normal airflow is 3 to 7 grams per second.

? FREQUENTLY ASKED QUESTION

What Is False Air?

Airflow sensors and mass airflow (MAF) sensors are designed to measure *all* the air entering the engine. If an air hose between the MAF sensor and throttle body was loose or had a hole, extra air could enter the engine without being measured. This extra air is often called **false air.** ● **SEE FIGURE 75–6.** Because this extra air is unmeasured, the computer does not provide enough fuel delivery and the engine operates too lean, especially at idle. A small hole in the air inlet hose would represent a fairly large percentage of false air at idle, but would represent a very small percentage of extra air at highway speeds.

To diagnose for false air, look at long-term fuel trim numbers at idle and at 3000 RPM.

NOTE: If the engine runs well in reverse, yet runs terrible in any forward gear, carefully look at the inlet hose for air leaks that would open when the engine torque moves the engine slightly on its mounts.

Analog MAF Sensor Grams per Second/Voltage Chart

Grams per Second	Sensor Voltage
0	0.2
2	0.7
4	1.0 (typical idle value)
8	1.5
15	2.0
30	2.5
50	3.0
80	3.5
110	4.0
150	4.5
175	4.8

TECH TIP

The Unplug It Test

If a sensor is defective yet still produces a signal to the computer, the computer will often accept the reading and make the required changes in fuel delivery and spark advance. If, however, the sensor is not reading correctly, the computer will process this wrong information and perform an action assuming that information being supplied is accurate. For example, if a mass airflow (MAF) sensor is telling the computer that 12 grams of air per second is going into the engine, the computer will then pulse the injector for 6.4 ms or whatever figure it is programmed to provide. However, if the air going into the engine is actually 14 grams per second, the amount of fuel supplied by the injectors will not be enough to provide proper engine operation. If the MAF sensor is unplugged, the computer knows that the sensor is not capable of supplying airflow information, so it defaults to a fixed amount of fuel based on the values of other sensors such as the TP and MAP sensors. "If in doubt, take it out."

If the engine operates better with a sensor unplugged, then suspect that the sensor is defective. A sensor that is not supplying the correct information is said to be skewed. The computer will not set a diagnostic trouble code for this condition because the computer can often not detect that the sensor is supplying wrong information.

REAL WORLD FIX

The Rich Running Toyota

A Toyota failed an enhanced emission test for excessive carbon monoxide, which is caused by a rich (too much fuel) air–fuel ratio problem. After checking all of the basics and not finding any fault in the fuel system, the technician checked the archives of the International Automotive Technicians Network (*www.iatn.net*) and discovered that a broken spring inside the air flow sensor was a possible cause. The sensor was checked and a broken vane return spring was discovered. Replacing the air flow sensor restored the engine to proper operating conditions and it passed the emission test.

TAP TEST With the engine running at idle speed, gently tap the MAF sensor with the fingers of an open hand. If the engine stumbles or stalls, the MAF sensor is defective. This test is commonly called the **tap test.**

DIGITAL METER TEST OF A MAF SENSOR A digital multimeter can be used to measure the frequency (Hz) output of the sensor and compare the reading with specifications.

The frequency output and engine speed in RPM can also be plotted on a graph to check to see if the frequency and RPM are proportional, resulting in a straight line on the graph.

MAF SENSOR CONTAMINATION

Dirt, oil, silicon, or even spiderwebs can coat the sensing wire. Because it tends to insulate the sensing wire at low airflow rates, a contaminated sensor often overestimates the amount of air entering the engine at idle, and therefore causes the fuel system to go rich. At higher engine speeds near wide-open throttle (WOT), the contamination can cause the sensor to underestimate the amount of air entering the engine. As a result, the fuel system will go lean, causing spark knock and lack of power concerns. To check for contamination, check the fuel trim numbers.

If the fuel trim is negative (removing fuel) at idle, yet is positive (adding fuel) at higher engine speeds, a contaminated MAF sensor is a likely cause. Other tests for a contaminated MAF sensor include:

- At WOT, the grams per second, as read on a scan tool, should exceed 100.
- At WOT, the voltage, as read on a digital voltmeter, should exceed 4 volts for an analog sensor.
- At WOT, the frequency, as read on a meter or scan tool, should exceed 7 kHz for a digital sensor.

If the readings do not exceed these values, then the MAF sensor is contaminated.

MAF-RELATED DIAGNOSTIC TROUBLE CODES

The diagnostic trouble codes (DTCs) associated with the mass airflow and air vane sensors include:

Diagnostic Trouble Code	Description	Possible Causes
P0100	Mass or volume airflow circuit problems	• Open or short in mass airflow circuit • Defective MAF sensor
P0101	Mass airflow circuit range problems	• Defective MAF sensor (check for false air)
P0102	Mass airflow circuit low output	• Defective MAF sensor • MAF sensor circuit open or shorted-to-ground • Open 12-volt supply voltage circuit
P0103	Mass airflow circuit high output	• Defective MAF sensor • MAF sensor circuit shorted-to-voltage

REVIEW QUESTIONS

1. How does a hot film MAF sensor work?
2. What type of voltage signal is produced by a MAF?
3. What change in the signal will occur if engine speed is increased?
4. How is a MAF sensor tested?
5. What is the purpose of a MAF sensor?
6. What are the types of airflow sensors?

CHAPTER QUIZ

1. A fuel-injection system that does not use a sensor to measure the amount (or mass) of air entering the engine is usually called a(n) _____ type of system.
   a. Air vane-controlled
   b. Speed density
   c. Mass airflow
   d. Hot wire
2. Which type of sensor uses a burn-off circuit?
   a. Hot wire MAF sensor
   b. Hot film MAF sensor
   c. Vane-type airflow sensor
   d. Both a and b
3. Which sensor has a switch that controls the electric fuel pump?
   a. VAF **c.** Hot filter MAF
   b. Hot wire MAF **d.** Karman Vortex sensor
4. Two technicians are discussing Karman Vortex sensors. Technician A says that they contain a burn-off circuit to keep them clean. Technician B says that they contain a movable vane. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
5. The typical MAF reading on a scan tool with the engine at idle speed and normal operating temperature is _____.
   a. 1 to 3 grams per second
   b. 3 to 7 grams per second
   c. 8 to 12 grams per second
   d. 14 to 24 grams per second
6. Two technicians are diagnosing a poorly running engine. There are no diagnostic trouble codes. When the MAF sensor is unplugged, the engine runs better. Technician A says that this means that the MAF is supplying incorrect airflow information to the PCM. Technician B says that this indicates that the PCM is defective. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. A MAF sensor on a General Motors 3800 V-6 is being tested for contamination. Technician A says that the sensor should show over 100 grams per second on a scan tool display when the accelerator is depressed to WOT on a running engine. Technician B says that the output frequency should exceed 7,000 Hz when the accelerator pedal is depressed to WOT on a running engine. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. Which airflow sensor has a dampening chamber?
   a. A vane airflow **c.** A hot wire MAF
   b. A hot film MAF **d.** A Karman Vortex
9. Air that enters the engine without passing through the airflow sensor is called _____.
   a. Bypass air **c.** False air
   b. Dirty air **d.** Measured air
10. A P0102 DTC is being discussed. Technician A says that a sensor circuit shorted-to-ground can be the cause. Technician B says that an open sensor voltage supply circuit could be the cause. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

chapter 76

OXYGEN SENSORS

OBJECTIVES: After studying Chapter 76, the reader will be able to: • Prepare for ASE Engine Performance (A8) certification test content area "E" (Computerized Engine Controls Diagnosis and Repair). • Discuss how oxygen sensors (O2S) work. • List the methods that can be used to test oxygen sensors. • Describe how a wide-band oxygen sensor works. • List how to test narrow- and wide-band oxygen sensors.

KEY TERMS: Air-fuel ratio sensor 857 • Ambient side electrode 846 • Bias voltage 848 • Closed loop 849 • Cup design 846 • Dual cell 855 • Exhaust side electrode 846 • False lean 851 • False rich 851 • Finger design 846 • Fuel trim 849 • HO2S 848 • Light-off time (LOT) 855 • Nernst cell 855 • Open loop 849 • Oxygen sensors (O2S) 846 • Planar 855 • Pump cell 855 • Reference 855 • Reference electrode 846 • RTV 853 • Signal electrode 846 • Single cell 857 • Thimble design 846 • Titania 848 • Wide-band O2S 853 • Zirconia 846 • ZrO2 846

OXYGEN SENSORS

PURPOSE AND FUNCTION

Automotive computer systems use a sensor in the exhaust system to measure the oxygen content of the exhaust. These sensors are called **oxygen sensors (O2S).** The oxygen sensor is installed in the exhaust manifold or located downstream from the manifold in the exhaust pipe. ● **SEE FIGURE 76–1.**

The oxygen sensor is directly in the path of the exhaust gas stream where it monitors oxygen levels in both the exhaust stream and the ambient air. A **zirconia** oxygen sensor is made of **zirconium dioxide (ZrO2),** an electrically conductive material capable of generating a small voltage in the presence of oxygen.

NARROW BAND

A conventional zirconia oxygen sensor (O2S) is only able to detect if the exhaust is richer or leaner than 14.7:1. A conventional oxygen sensor is therefore referred to as the following:

- *Two-step sensor* which is either rich or lean
- *Narrow-band sensor* which informs the PCM whether the exhaust is rich or lean only

The voltage value where a zirconia oxygen sensor switches from rich to lean or from lean to rich is 0.45 V (450 mV).

- Above 0.45 V = rich
- Below 0.45 V = lean

● **SEE FIGURE 76–2.**

CONSTRUCTION

A typical zirconia oxygen sensor has the sensing element in the shape of a thimble; therefore, it is often referred to as one of the following:

- **Thimble design**
- **Cup design**
- **Finger design**

● **SEE FIGURE 76–3.**

A typical zirconia oxygen sensor has a heater inside the thimble and does not touch the inside of the sensor. The sensor is similar to a battery that has two electrodes and an electrolyte. The electrolyte is solid and is the zirconia (zirconium dioxide). There are also two porous platinum electrodes, which have the following functions.

- **Exhaust side electrode** is exposed to the exhaust stream.
- **Ambient side electrode** is exposed to outside (ambient) air and is the **signal electrode,** also called the **reference electrode.**

● **SEE FIGURE 76–4.**

The electrolyte (zirconia) is able to conduct electrons as follows:

- If the exhaust is rich, O_2 from the reference (inner) electrode wants to flow to the exhaust side electrode, which results in the generation of a voltage.
- If the exhaust is lean, O_2 flow is not needed. As a result, there is little if any electron movement and, therefore, no voltage is produced.

OPERATION

Exhaust from the engine passes through the end of the sensor where the gases contact the outer side of the thimble. Atmospheric air enters through the other end of the sensor or through the wire of the sensor and contacts the inner side of the thimble. The inner and outer surfaces of the thimble are plated with platinum. The inner surface becomes a negative electrode and the outer surface is a positive electrode. The atmosphere contains a relatively constant 21% of oxygen. Exhaust gases created by burning a rich air-fuel mixture contain little oxygen. Exhaust gases from burning a lean air-fuel mixture contain more oxygen.

Negatively charged oxygen ions are drawn to the thimble where they collect on both the inner and outer surfaces.

Because the oxygen present in the atmosphere exceeds that in the exhaust gases, the air side of the thimble draws more negative oxygen ions than the exhaust side. The difference between the two sides creates an electrical potential, or voltage. When the concentration of oxygen on the exhaust side of the thimble is low, a high voltage (0.60 to 1.0 V) is generated between the electrodes. As the oxygen concentration on the exhaust side increases, the voltage generated drops low (0.0 to 0.3 V).

An O2S does not send a voltage signal until its tip reaches a temperature of about 572°F (300°C). Also, oxygen sensors provide their fastest response to mixture changes at about 1,472°F (800°C). When the engine starts and the O2S is cold, the PCM operates the engine in the open-loop mode, drawing on prerecorded data in the PROM for fuel control on a cold engine, or when O2S output is not within certain limits.

If the exhaust contains very little oxygen, the PCM assumes that the intake charge is rich (too much fuel) and reduces fuel delivery. However, when the oxygen level is high, the PCM assumes that the intake charge is lean (not enough fuel) and increases fuel delivery. ● **SEE FIGURE 76–5.**

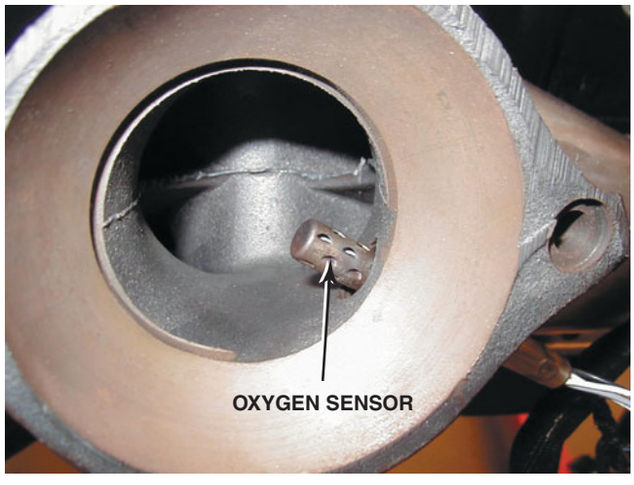


FIGURE 76–1 Many oxygen sensors are located in the exhaust manifold near its outlet so that the sensor can detect the presence or absence of oxygen in the exhaust stream for all cylinders that feed into the manifold.

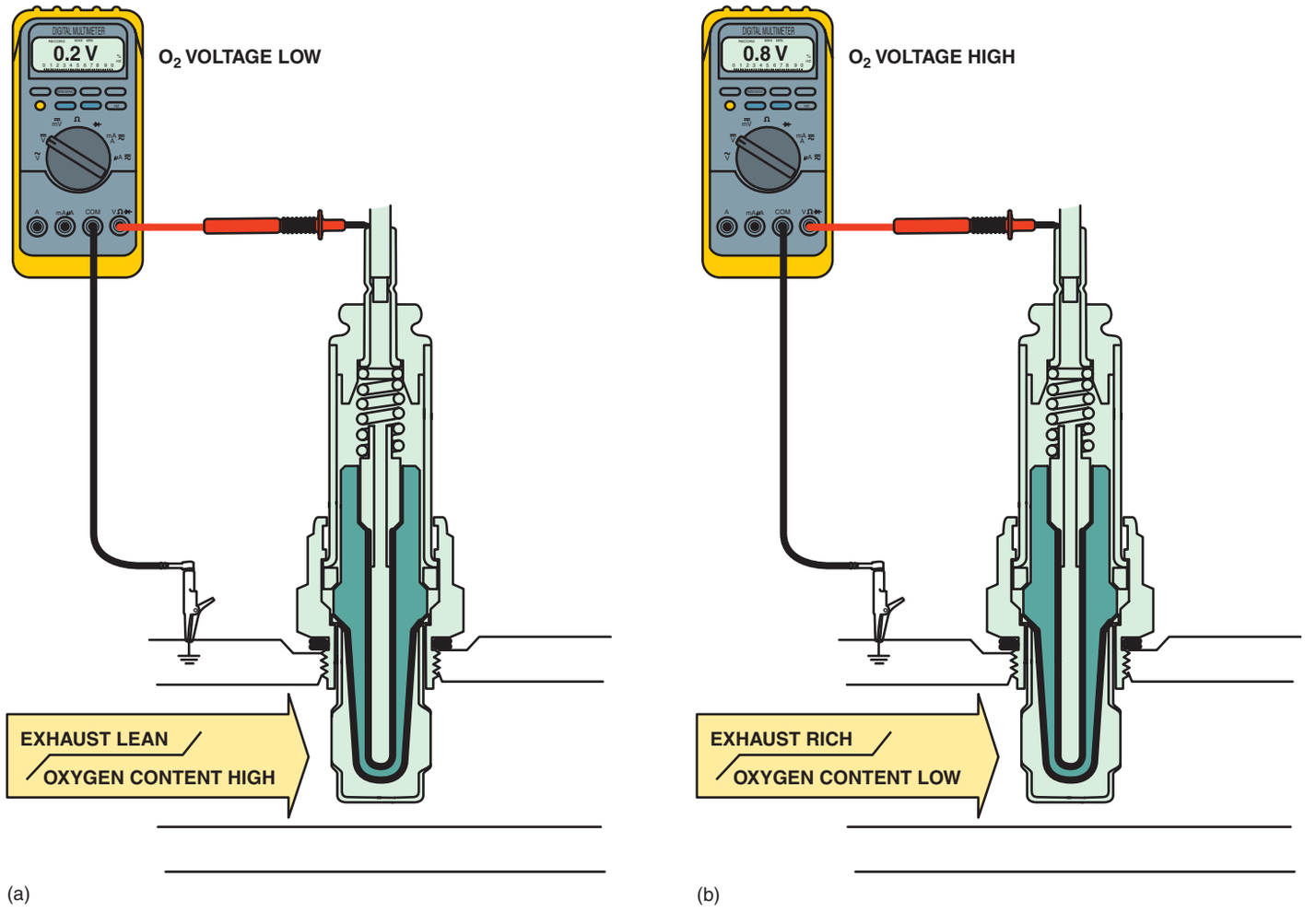


FIGURE 76–2 (a) When the exhaust is lean, the output of a zirconia oxygen sensor is below 450 mV. (b) When the exhaust is rich, the output of a zirconia oxygen sensor is above 450 mV.

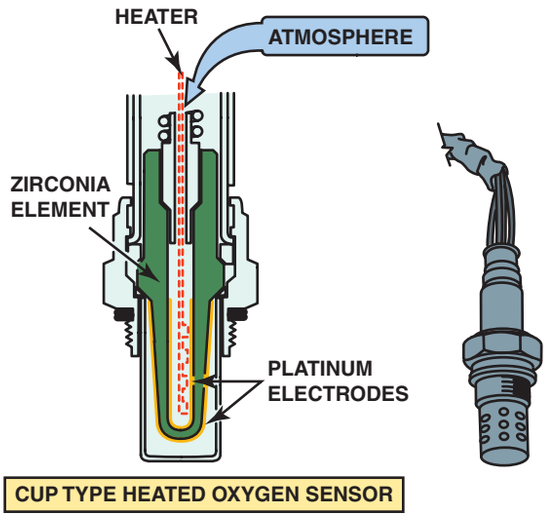


FIGURE 76–3 Most conventional zirconia oxygen sensors and some wide-band oxygen sensors use the cup (finger) type of design.

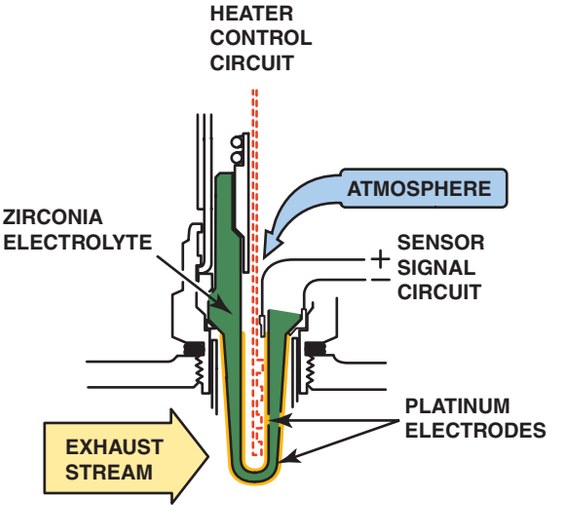


FIGURE 76–4 A typical heated zirconia oxygen sensor, showing the sensor signal circuit that uses the outer (exhaust) electrode as the negative and the ambient air side electrode as the positive.

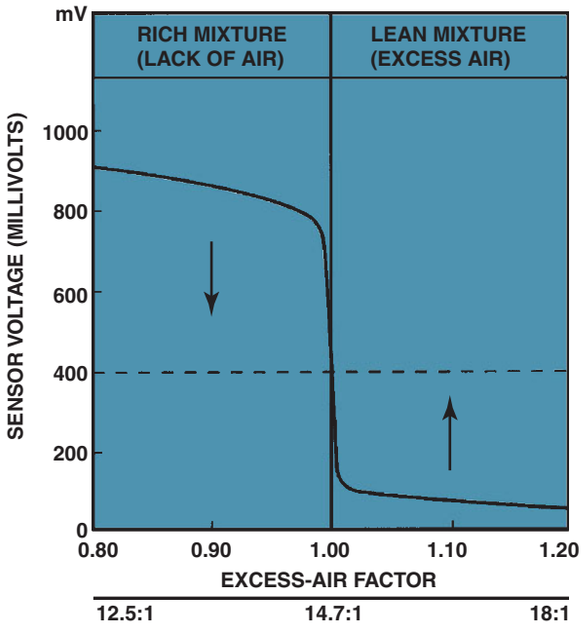


FIGURE 76–5 The oxygen sensor provides a quick response at the stoichiometric air-fuel ratio of 14.7:1.

There are several different designs of oxygen sensors, including:

- **One-wire oxygen sensor.** The single wire of the one-wire oxygen sensor is the O2S signal wire. The ground for the O2S is through the shell and threads of the sensor and through the exhaust manifold.
- **Two-wire oxygen sensor.** The two-wire sensor has a signal wire and a ground wire for the O2S.
- **Three-wire oxygen sensor.** The three-wire sensor design uses an electric resistance heater to help get the O2S up to temperature more quickly and to help keep the sensor at operating temperature even at idle speeds. The three wires include the O2S signal, the power, and ground for the heater.
- **Four-wire oxygen sensor.** The four-wire sensor is a **heated O2S (HO2S)** that uses an O2S signal wire and signal ground. The other two wires are the power and ground for the heater.

HEATER CIRCUITS The heater circuit on conventional oxygen sensors requires 0.8 to 2.0 amperes and keeps the sensor at about 600°F (315°C).

A wide-band oxygen sensor operates at a higher temperature than a conventional HO2S, from 1,200°F to 1,400°F (650°C to 760°C). The amount of electrical current needed for a wide-band oxygen sensor is about 8 to 10 amperes.

FREQUENTLY ASKED QUESTION

What Happens to the Bias Voltage?

Some vehicle manufacturers such as General Motors Corporation have the PCM apply 450 mV (0.45 V) to the O2S signal wire. This voltage is called the **bias voltage** and represents the threshold voltage for the transition from rich to lean.

This bias voltage is displayed on a scan tool when the ignition switch is turned on with the engine off. When the engine is started, the O2S becomes warm enough to produce a usable voltage, and bias voltage "disappears" as the O2S responds to a rich and lean mixture. What happens to the bias voltage that the PCM applies to the O2S? The voltage from the O2S simply overcomes the very weak voltage signal from the PCM. This bias voltage is so weak that even a 20 megohm impedance DMM will affect the strength enough to cause the voltage to drop to 426 mV. Other meters with only 10 megohms of impedance will cause the bias voltage to read less than 400 mV.

Therefore, even though the O2S voltage is relatively low powered, it is more than strong enough to override the very weak bias voltage the PCM sends to the O2S.

REAL WORLD FIX

The Chevrolet Pickup Truck Story

The owner of a 1996 Chevrolet pickup truck complained that the engine ran terribly. It would hesitate and surge, yet there were no diagnostic trouble codes (DTCs). After hours of troubleshooting, the technician discovered while talking to the owner that the problem started after the transmission had been repaired. However, the transmission shop said that the problem was an engine problem and not related to the transmission.

A thorough visual inspection revealed that the front and rear oxygen sensor connectors had been switched. The PCM was trying to compensate for an air-fuel mixture condition that did not exist. Reversing the O2S connectors restored proper operation of the truck.

TITANIA OXYGEN SENSOR

The **titania** (titanium dioxide) oxygen sensor does not produce a voltage but rather changes resistance due to the presence of oxygen in the exhaust. All titania oxygen sensors use a four-terminal variable resistance unit with a heating element. A titania sensor samples exhaust air only and uses a reference voltage from the PCM. Titania oxide oxygen sensors use a 14 mm thread and are not interchangeable with zirconia oxygen sensors, which use an 18 mm thread. One volt is applied to the sensor; the changing resistance of the titania oxygen sensor changes the voltage of the sensor circuit. As with a zirconia oxygen sensor, the voltage signal is above 450 mV when the exhaust is rich and low (below 450 mV) when the exhaust is lean.

FREQUENTLY ASKED QUESTION

Where Is HO2S1?

Oxygen sensors are numbered according to their location in the engine. On a V-type engine, heated oxygen sensor number 1 (HO2S1) is located in the exhaust manifold on the side of the engine where cylinder 1 is located. ● **SEE FIGURE 76–6.**

REAL WORLD FIX

The Oxygen Sensor Is Lying to You

A technician was trying to solve a driveability problem with an older V-6 passenger car. The car idled roughly, hesitated, and accelerated poorly. A thorough visual inspection did not indicate problems and there were no diagnostic trouble codes stored.

The technician checked the oxygen sensor activity using a DMM. The voltage stayed above 600 mV most of the time. If the technician removed a large vacuum hose, the oxygen sensor voltage would temporarily drop to below 450 mV and then return to a reading of over 600 mV. Remember:

- High O2S readings = rich exhaust (low O_2 content in the exhaust)
- Low O2S readings = lean exhaust (high O_2 content in the exhaust)

As part of a thorough visual inspection, the technician removed and inspected the spark plugs. All the spark plugs were white, indicating a lean mixture, not the rich mixture that the oxygen sensor was indicating. The high O2S reading signaled the PCM to reduce the amount of fuel, resulting in an excessively lean operation.

After replacing the oxygen sensor, the engine ran great. But what killed the oxygen sensor? The technician finally learned from the owner that the head gasket had been replaced over a year ago. The silicate and phosphate additives in the antifreeze coolant had coated the oxygen sensor. Because the oxygen sensor was coated, the oxygen content of the exhaust could not be detected, resulting in a false rich signal from the oxygen sensor.

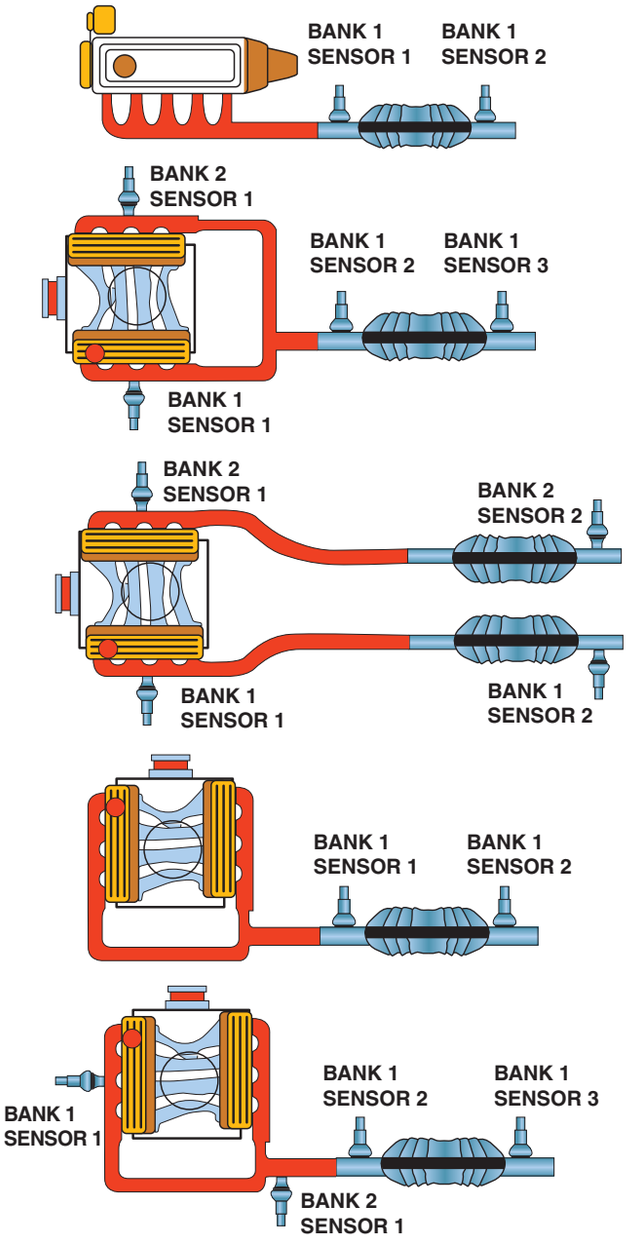


FIGURE 76–6 Number and label designations for oxygen sensors. Bank 1 is the bank where cylinder 1 is located.

PCM USES OF THE OXYGEN SENSOR

FUEL CONTROL The amount of fuel delivered to an engine is determined by the powertrain control module (PCM) based on inputs from the engine coolant temperature (ECT), throttle position (TP) sensor, and others until the oxygen sensor is capable of supplying a usable signal. When the PCM alone is determining the amount of fuel needed, it is called **open-loop** operation. As soon as the oxygen sensor (O2S) is capable of supplying rich and lean signals, PCM adjustments can be made to fine-tune the correct air-fuel mixture. This checking and adjusting of the PCM is called **closed-loop** operation.

The upstream oxygen sensors are among the high-authority sensors used for fuel control while operating in closed loop. Before the oxygen sensors are hot enough to give accurate exhaust oxygen information to the PCM, fuel control is determined by other sensors and the anticipated injector pulse width determined by those sensors. After the control system achieves closed-loop status, the oxygen sensor provides feedback to actual exhaust gas oxygen content.

FUEL TRIM The **fuel trim** numbers are determined from the signals by the oxygen sensor(s). If the engine has been operating too lean, short-term and long-term fuel time programming inside the

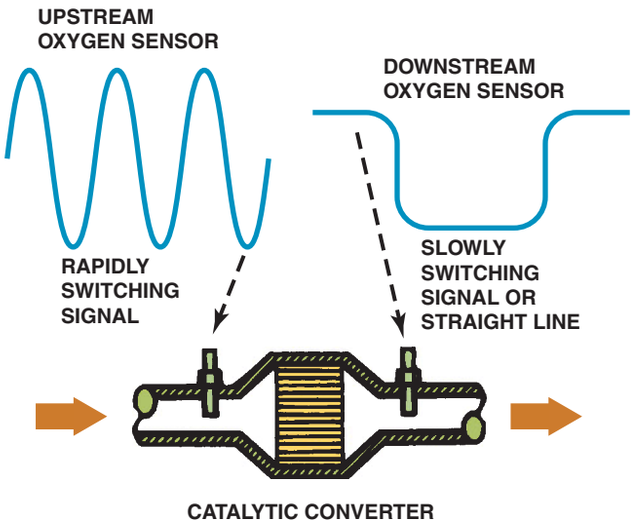


FIGURE 76–7 The OBD-II catalytic converter monitor compares the signals of the upstream and downstream oxygen sensor to determine converter efficiency.

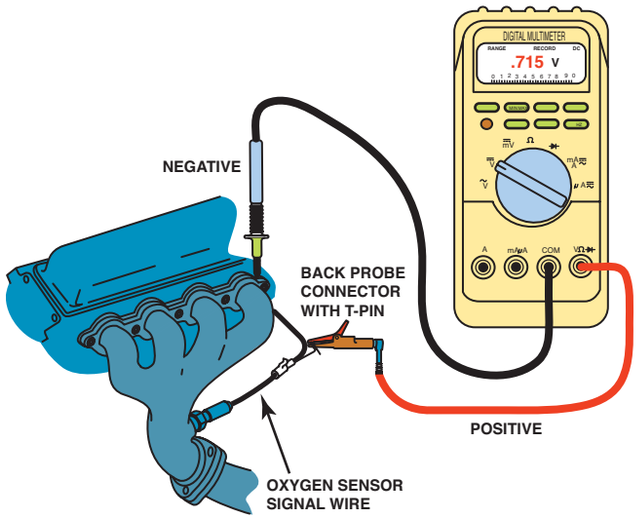


FIGURE 76–8 Testing an oxygen sensor using a DMM set on DC volts. With the engine operating in closed loop, the oxygen voltage should read over 800 mV and lower than 200 mV and be constantly fluctuating.

PCM can cause an increase in the commanded injector pulse width to bring the air-fuel mixture back into the proper range. Fuel trim can be negative (subtracting fuel) or positive (adding fuel).

OXYGEN SENSOR DIAGNOSIS

PCM SYSTEM TESTS The oxygen sensors are used for diagnosis of other systems and components. For example, the exhaust gas recirculation (EGR) system is tested by the PCM, by commanding the EGR valve to open during the test. Some PCMs determine whether enough exhaust gas flows into the engine by looking at the oxygen sensor response (fuel trim numbers). The upstream and downstream oxygen sensors are also used to determine the efficiency of the catalytic converter. Therefore, if a fault occurs with an oxygen sensor, the PCM may not be able to test other systems. ● **SEE FIGURE 76–7.**

VISUAL INSPECTION Whenever an oxygen sensor is replaced, the old sensor should be carefully inspected to help determine the cause of the failure. This is an important step because if the cause of the failure is not discovered, it could lead to another sensor failure.

Inspection may reveal the following:

1. Black sooty deposits usually indicate a rich air-fuel mixture.
2. White chalky deposits are characteristic of silica contamination. Usual causes for this type of sensor failure include silica deposits in the fuel or a technician having used the wrong type of silicone sealant during the servicing of the engine.
3. White sandy or gritty deposits are characteristic of antifreeze (ethylene glycol) contamination. A defective cylinder head or intake manifold gasket could be the cause, or a cracked cylinder head or engine block. Antifreeze may also cause the oxygen sensor to become green as a result of the dye used in antifreeze.
4. Dark brown deposits indicate excessive oil consumption. Possible causes include a defective positive crankcase ventilation (PCV) system or a mechanical engine problem such as defective valve stem seals or piston rings.

REAL WORLD FIX

The Missing Ford

A Ford was being analyzed for poor engine operation. The engine ran perfectly during the following conditions.

1. Engine cold or operating in open loop
2. Engine at idle
3. Engine operating at or near wide-open throttle

After hours of troubleshooting, the technician determined the cause to be a poor ground connection for the oxygen sensor. The engine ran okay during times when the PCM ignored the oxygen sensor. Unfortunately, the service technician did not have a definite plan during the diagnostic process and as a result checked and replaced many unnecessary parts. An oxygen sensor test early in the diagnostic procedure would have indicated that the oxygen (O2S) signal was not correct. The poor ground caused the oxygen sensor voltage level to be too high, indicating to the PCM that the mixture was too rich. The PCM then subtracted fuel which caused the engine to miss and run roughly as the result of the now too lean air-fuel mixture.

DIGITAL VOLTMETER TESTING The oxygen sensor can be checked for proper operation using a digital high-impedance voltmeter.

1. With the engine off, connect the red lead of the meter to the oxygen sensor signal wire and the black meter lead to a good engine ground. ● **SEE FIGURE 76–8.**
2. Start the engine and allow it to reach closed-loop operation.
3. In closed-loop operation, the oxygen sensor voltage should be constantly changing as the fuel mixture is being controlled.

The results should be interpreted as follows:

- If the oxygen sensor fails to respond, and its voltage remains at about 450 mV, the sensor may be defective and require replacement. Before replacing the oxygen sensor, check the manufacturer's recommended procedures.

TECH TIP

Do Not Solder Oxygen Sensor Wires

Oxygen sensors must have outside oxygen to compare with the oxygen content in the exhaust. Most oxygen sensors breathe through the signal wire and, if soldered, would block the flow of outside air to the sensor. If a replacement oxygen sensor is used, always use the factory replacement, using the original connectors or a crimp-and-seal connector that will seal out any moisture and still allow air to flow through the connector.

- If the oxygen sensor reads high all the time (above 550 mV), the fuel system could be supplying too rich a fuel mixture or the oxygen sensor may be contaminated. An oxygen sensor reading that is high could be due to other things besides a rich air-fuel mixture. When the O2S reads high as a result of other factors besides a rich mixture, it is often called a **false rich** indication.

False rich indications (high O2S readings) can be attributed to the following:

- Contaminated O2S due to additives in the engine coolant or due to silicon poisoning
- A stuck open EGR valve (especially at idle)
- A spark plug wire too close to the oxygen sensor signal wire, which can induce a higher than normal voltage in the signal wire, thereby indicating to the PCM a false rich condition
- A loose oxygen sensor ground connection, which can cause a higher than normal voltage and a false rich signal
- A break or contamination of the wiring and its connectors, which could prevent reference oxygen from reaching the oxygen sensor, resulting in a false rich indication (All oxygen sensors require an oxygen supply inside the sensor itself for reference to be able to sense exhaust gas oxygen.)

If the oxygen sensor voltage remains low (below 350 mV), the oxygen sensor itself could be bad or the fuel system could be supplying too lean a fuel mixture. Check for a vacuum leak or partially clogged fuel injector(s). Before replacing the oxygen sensor, check the manufacturer's recommended procedures. If an oxygen sensor reads low as a result of a factor besides a lean mixture, it is often called a **false lean** indication.

False lean indications (low O2S readings) can be attributed to the following:

1. **Ignition misfires.** An ignition misfire due to a defective spark plug wire, fouled spark plug, and so forth, causes no burned air and fuel to be exhausted past the O2S. The O2S "sees" the oxygen (not the unburned gasoline) and the O2S voltage is low.
2. **Exhaust leak in front of the O2S.** An exhaust leak between the engine and the oxygen sensor causes outside oxygen to be drawn into the exhaust and past the O2S. This oxygen is "read" by the O2S and produces a lower than normal voltage. The PCM interprets the lower than normal voltage signal from the O2S as meaning that the air-fuel mixture is lean. The PCM will cause the fuel system to deliver a richer air-fuel mixture.
3. **Spark plug misfire.** The PCM does not know that the extra oxygen going past the oxygen sensor is not due to a lean air-fuel mixture. The PCM commands a richer mixture, which could cause the spark plugs to foul, increasing the rate of misfiring.

FREQUENTLY ASKED QUESTION

Why Does the Oxygen Sensor Voltage Read 5 Volts on Many Chrysler Vehicles?

Many Chrysler vehicles apply a 5 volt reference to the signal wire of the oxygen sensor. The purpose of this voltage is to allow the PCM to detect if the oxygen sensor signal circuit is open or grounded.

- If the voltage on the signal wire is 4.5 volts or more, the PCM assumes that the sensor is open.
- If the voltage on the signal wire is zero, the PCM assumes that the sensor is shorted-to-ground.

If either condition exists, the PCM can set a diagnostic trouble code (DTC).

TECH TIP

The Key On, Engine Off Oxygen Sensor Test

This test works on General Motors vehicles and may work on others if the PCM applies a bias voltage to the oxygen sensors. Zirconia oxygen sensors become more electrically conductive as they get hot. To perform this test, be sure that the vehicle has not run for several hours.

STEP 1 Connect a scan tool and get the display ready to show oxygen sensor data.

STEP 2 Key the engine on *without* starting the engine. The heater in the oxygen sensor will start heating the sensor.

STEP 3 Observe the voltage of the oxygen sensor. The applied bias voltage of 450 mV should slowly decrease for all oxygen sensors as they become more electrically conductive as the bias voltage is flowing to ground.

STEP 4 A good oxygen sensor should indicate a voltage of less than 100 mV after three minutes. Any sensor that displays a higher than usual voltage or seems to stay higher longer than the others could be defective or skewed high.

MIN/MAX TESTING A digital meter set on DC volts can be used to record the minimum and maximum voltage with the engine running. A good oxygen sensor should be able to produce a value of less than 300 mV and a maximum voltage above 800 mV. ● **SEE FIGURE 76–9.**

Replace any oxygen sensor that fails to go above 700 mV or lower than 300 mV. ● **SEE CHART 76–1.**

SCAN TOOL TESTING A good oxygen sensor should sense the oxygen content and change voltage outputs rapidly. How fast an oxygen sensor switches from high (above 450 mV) to low (below 350 mV) is measured as frequency, or the number of times the voltage switches per second.

NOTE: On a fuel-injected engine at 2000 engine RPM, 1 to 5 Hz (one to five switches per second) is normal.

Using a scan tool, observe the oxygen sensor voltages with the engine running at 2000 RPM. Look for numbers higher than 800 mV and lower than 200 mV.

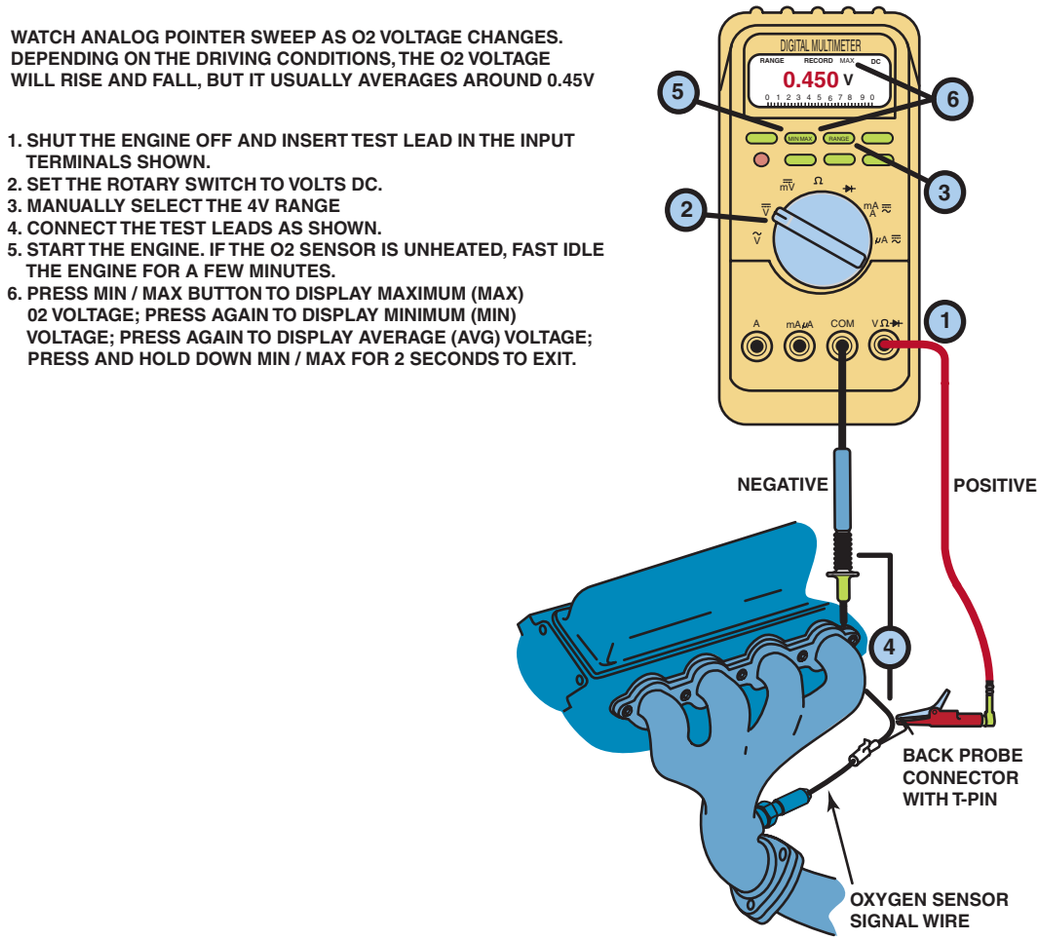


FIGURE 76–9 Using a digital multimeter to test an oxygen sensor using the MIN/MAX record function of the meter.

MIN/MAX OXYGEN SENSOR TEST CHART

MINIMUM VOLTAGE	MAXIMUM VOLTAGE	AVERAGE VOLTAGE	TEST RESULTS
Below 200 mV	Above 800 mV	400 to 500 mV	Oxygen sensor is okay.
Above 200 mV	Any reading	400 to 500 mV	Oxygen sensor is defective.
Any reading	Below 800 mV	400 to 500 mV	Oxygen sensor is defective.
Below 200 mV	Above 800 mV	Below 400 mV	System is operating lean.*
Below 200 mV	Below 800 mV	Below 400 mV	System is operating lean. (Add propane to the intake air to see if the oxygen sensor reacts. If not, the sensor is defective.)
Below 200 mV	Above 800 mV	Above 500 mV	System is operating rich.
Above 200 mV	Above 800 mV	Above 500 mV	System is operating rich. (Remove a vacuum hose to see if the oxygen sensor reacts. If not, the sensor is defective.)

CHART 76–1

The test results of using a digital meter set to read minimum and maximum values while testing a narrow-band oxygen sensor.
*Check for an exhaust leak upstream from the O2S or ignition misfire that can cause a false lean indication before further diagnosis.

If the frequency of switching is low, the oxygen sensor may be contaminated, or the fuel delivery system is delivering a constant rich or lean air-fuel mixture. If the frequency of switching is higher than 5 Hz, look for misfire conditions.

1. Connect the scan tool and start the engine.
2. Operate the engine at a fast idle (2,500 RPM) for two minutes to allow time for the oxygen sensor to warm to operating temperature.
3. Observe the oxygen sensor activity on the scan tool to verify closed-loop operation. Select the "snapshot" mode, hold the engine speed steady, and start recording.
4. Play back snapshot and place a mark beside each range of oxygen sensor voltage for each frame of the snapshot.

A good oxygen sensor and PCM should result in the most snapshot values at both ends (0 to 300 mV and 600 to 1,000 mV). If most of the readings are in the middle, the oxygen sensor is not working correctly.

SCOPE TESTING A scope can also be used to test an oxygen sensor. Connect the scope to the signal wire and ground for the sensor (if it is so equipped). ● **SEE FIGURE 76–10.**

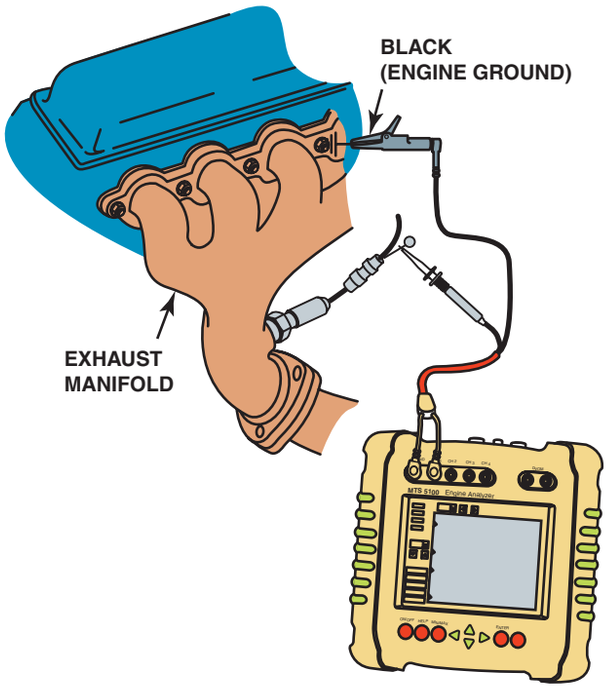


FIGURE 76–10 Connecting a handheld digital storage oscilloscope to an oxygen sensor signal wire. Check the instructions for the scope as some require the use of a filter to be installed in the test lead to reduce electromagnetic interference that can affect the oxygen sensor waveform.

With the engine operating in closed loop, the voltage signal of the sensor should be constantly changing. ● **SEE FIGURE 76–11.**

Check for rapid switching from rich to lean and lean to rich and change between once every two seconds and five times per second (0.5 to 5.0 Hz).

NOTE: General Motors warns not to base the diagnosis of an oxygen sensor problem solely on its scope pattern. The varying voltage output of an oxygen sensor can easily be mistaken for a fault in the sensor itself, rather than a fault in the fuel delivery system.

POST CATALYTIC CONVERTER OXYGEN SENSOR TESTING

The oxygen sensor located behind the catalytic converter is used on OBD-II vehicles to monitor converter efficiency. A changing air-fuel mixture is required for the most efficient operation of the converter. If the converter is working correctly, the oxygen content after the converter should be fairly constant. ● **SEE FIGURE 76–12.**

The post catalytic converter oxygen sensor also is used to modify the amount of fuel delivered to the engine to allow the converter to work efficiently. If, for example, the rear oxygen sensor voltage stayed high, the PCM will try to increase the amount of oxygen entering the converter by leaning the air-fuel mixture to the engine. This process is often called the target upstream fuel trim. Therefore, instead of the PCM commanding a target air-fuel mixture of 14.7:1, the new target may specify an air-fuel ratio of 14.9:1 or slightly leaner than normal to help provide a little extra oxygen for use by the catalytic converter. This target air-fuel ratio or fuel trim is displayed on scan tools.

TECH TIP

The Propane Oxygen Sensor Test

Adding propane to the air inlet of a running engine is an excellent way to check if the oxygen sensor is able to react to changes in air-fuel mixture. Follow these steps in performing the propane trick.

1. Connect a digital storage oscilloscope to the oxygen sensor signal wire.
2. Start and operate the engine until it reaches operating temperature and is in closed-loop fuel control.
3. While watching the scope display, add some propane to the air inlet. The scope display should read full rich (over 800 mV).
4. Shut off the propane. The waveform should drop to less than 200 mV (0.2 V).
5. Quickly add some propane while the oxygen sensor is reading low and watch for a rapid transition to rich. The transition should occur in less than 100 milliseconds (ms).

REAL WORLD FIX

How Could Using Silicone Sealer on a Valve Cover Gasket Affect the Oxygen Sensor?

The wrong type of silicone **room temperature vulcanization (RTV)** sealer on a valve cover gasket gives off harmful silica fumes during the curing process. These fumes enter the crankcase area by way of the oil drainback holes in the cylinder head as well as through pushrod openings and other passages in the engine. During engine operation, these fumes are drawn into the intake manifold through the positive crankcase ventilation (PCV) system and are burned in the engine. The harmful silica then exits through the exhaust system, where the contamination affects the oxygen sensor.

NOTE: Be careful not to spray any silicone lubricant near the engine vacuum, which might draw the fumes into the engine and cause silica damage to the oxygen sensor.

WIDE-BAND OXYGEN SENSORS

TERMINOLOGY **Wide-band oxygen sensors** have been used since 1992 on some Hondas. Today, they are used by most vehicle manufacturers to ensure that the exhaust emissions can meet the current standard. Wide-band oxygen sensors have various names, depending on the vehicle and/or oxygen sensor manufacturer, including:

- Wide-band oxygen sensor
- Broadband oxygen sensor
- Wide-range oxygen sensor
- Air-fuel ratio (AFR) sensor

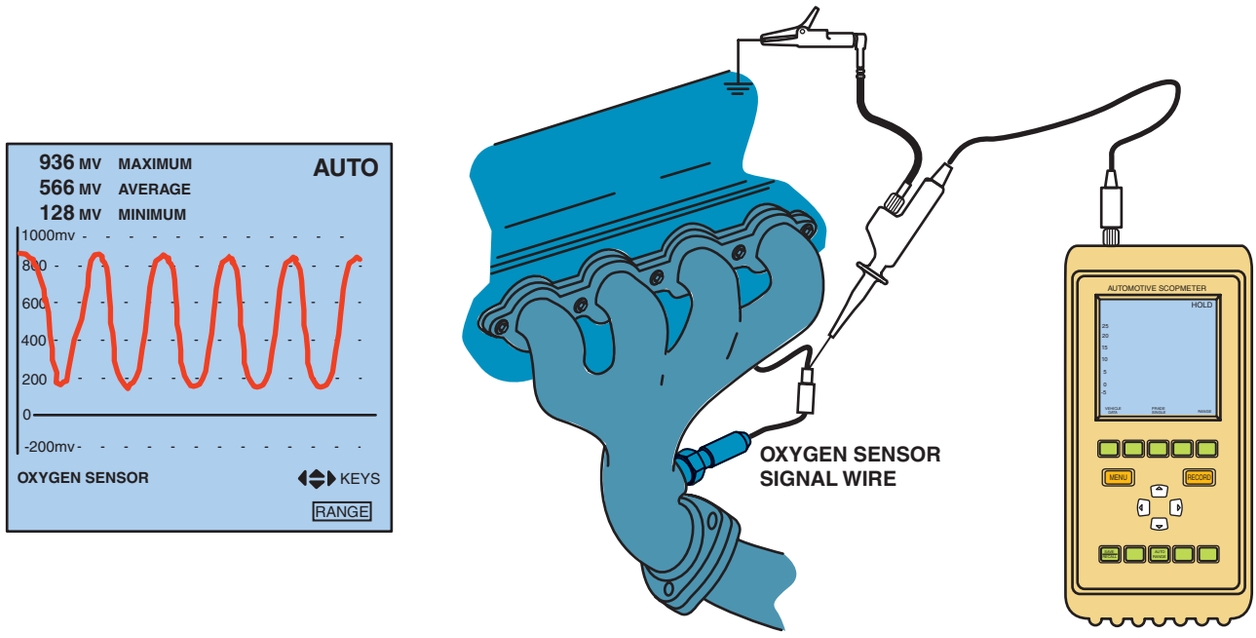


FIGURE 76–11 The waveform of a good oxygen sensor as displayed on a digital storage oscilloscope (DSO). Note that the maximum reading is above 800 mV and the minimum reading is less than 200 mV.

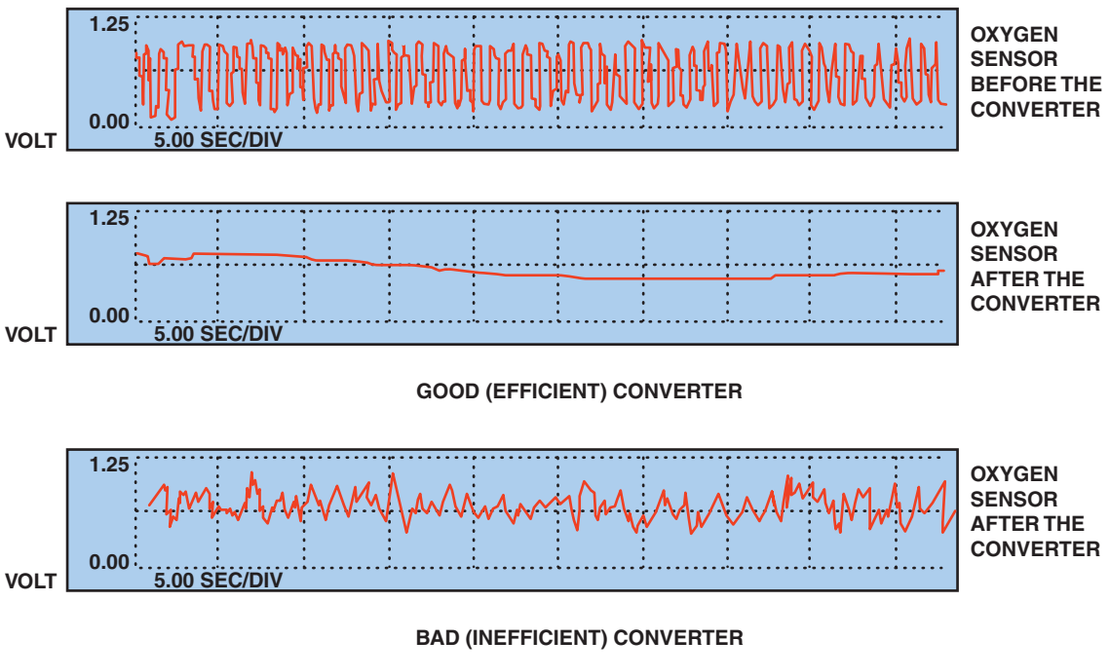


FIGURE 76–12 The post catalytic converter oxygen sensor should display very little activity if the catalytic converter is efficient.

- Wide-range air-fuel (WRAF) sensor
- Lean-air fuel (LAF) sensor
- Air-fuel (AF) sensor

Wide-band oxygen sensors are also manufactured in dual cell and single cell designs.

INTRODUCTION A conventional zirconia oxygen sensor reacts to an air-fuel mixture that is either richer or leaner than 14.7:1. This means that the sensor cannot be used to detect the exact air-fuel mixture. ● **SEE FIGURE 76–13.**

The need for more stringent exhaust emission standards such as the natural low emission vehicle (NLEV), plus the ultra low emission

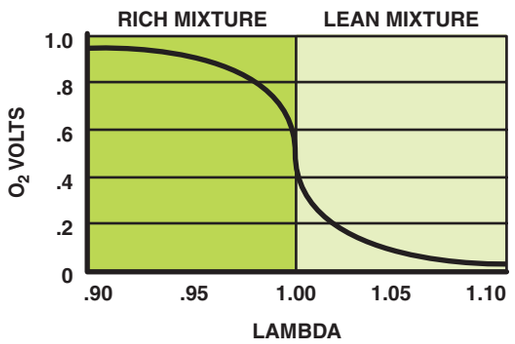


FIGURE 76–13 A conventional zirconia oxygen sensor can only reset to exhaust mixtures that are richer or leaner than 14.7:1 (lambda 1.00).

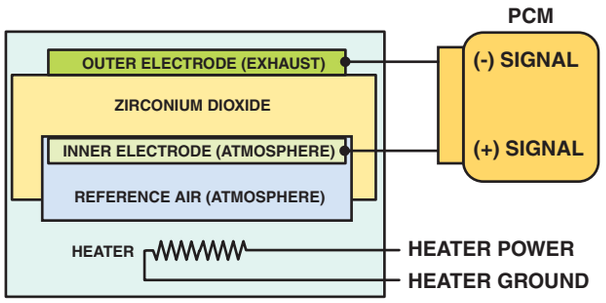


FIGURE 76–14 A planar design zirconia oxygen sensor places all of the elements together, which allows the sensor to reach operating temperature quickly.

vehicle (ULEV) and the super ultra low emission vehicle (SULEV) require more accurate fuel control than can be provided by a traditional oxygen sensor.

PURPOSE AND FUNCTION A wide-band oxygen sensor is capable of supplying air-fuel ratio information to the PCM over a much broader range. Compared with a conventional zirconia oxygen sensor, the wide-band oxygen sensor has the following features.

1. The ability to detect exhaust air-fuel ratio from as rich as 10:1 to as lean as 23:1 in some cases
2. Cold start activity within as little as 10 seconds

PLANAR DESIGN In 1998, Bosch introduced a wide-band oxygen sensor that is flat and thin (1.5 mm or 0.006 in.), known as a **planar** design and not in the shape of a thimble as previously constructed. Now several manufacturers produce a similar planar design wide-band oxygen sensor. Its thin design makes it easier to heat than older styles of oxygen sensors and, as a result, it can achieve closed loop in less than 10 seconds. This fast heating, called **light-off time (LOT),** helps improve fuel economy and reduces cold-start exhaust emissions. The type of construction is not noticed by the technician, nor does it affect the testing procedures.

A conventional oxygen sensor can also be constructed using a planar design instead of the thimble-type design. A planar design has the following features.

- The elements including the zirconia electrolyte and the two electrodes and heater are stacked together in a flat-type design.
- It allows faster warm-up because the heater is in direct contact with the other elements.
- Planar oxygen sensors are the most commonly used. Some planar designs are used as a conventional narrow-band oxygen sensor.

The sandwich-type designs of the planar style of oxygen sensor have the same elements and operate the same, but are stacked in the following way from the exhaust side to the ambient air side.

Exhaust stream
Outer electrode
Zirconia (Zr_2) (electrolyte)
Inner electrode (reference or signal)
Outside (ambient) air
Heater

● **SEE FIGURE 76–14.**

Another name for a conventional oxygen sensor is a **Nernst cell,** named for Walther Nernst, 1864–1941, a German physicist known for his work in electrochemistry.

FREQUENTLY ASKED QUESTION

How Quickly Can a Wide-Band Oxygen Sensor Achieve Closed Loop?

In a Toyota Highlander hybrid electric vehicle, the operation of the gasoline engine is delayed for a short time when the vehicle is first driven. During this time of electric operation, the oxygen sensor heaters are turned on in readiness for the gasoline engine starting. The gasoline engine often achieves closed-loop operation during *cranking* because the oxygen sensors are fully warm and ready to go at the same time the engine is started. Having the gasoline engine achieve closed loop quickly, allows it to meet the stringent SULEV standards.

DUAL CELL PLANAR WIDE-BAND SENSOR OPERATION

CONSTRUCTION In a conventional zirconia oxygen sensor, a bias or reference voltage can be applied to the two platinum electrodes, and then oxygen ions can be forced (pumped) from the ambient reference air side to the exhaust side of the sensor. If the polarity is reversed, the oxygen ion can be forced to travel in the opposite direction.

A **dual cell** planar-type wide-band oxygen sensor is made like a conventional planar O2S, or Nernst cell. Above the Nernst cell is another zirconia layer with two electrodes, called the **pump cell.** The two cells share a common ground, called the **reference.**

There are two internal chambers:

- The air reference chamber is exposed to ambient air.
- The diffusion chamber is exposed to the exhaust gases.

Platinum electrodes are on both sides of the zirconia electrolyte elements, which separate the air reference chamber and the exhaust exposed diffusion chamber.

OPERATION The basic principle of operation of a typical wide-band oxygen sensor is that it uses a positive or negative voltage signal to keep a balance between two sensors. Oxygen sensors do not measure the quantity of free oxygen in the exhaust. Instead, oxygen sensors produce a voltage that is based on the ion flow between the platinum electrodes of the sensor to maintain a stoichiometric balance.

For example:

- If there is a lean exhaust, there is oxygen in the exhaust and the ion flow from the ambient side to the exhaust side is low.
- If there is rich exhaust, the ion flow is increased to help maintain balance between the ambient air side and the exhaust side of the sensor.

The PCM can apply a small current to the pump cell electrodes, which causes oxygen ions through the zirconia into or out of the diffusion chamber. The PCM pumps O_2 ions in and out of the diffusion chamber to bring the voltage back to 0.45 V, using the pump cell.

The operation of a wide-band oxygen sensor is best described by looking at what occurs when the exhaust is stoichiometric, rich, and lean. ● **SEE FIGURE 76–15.**

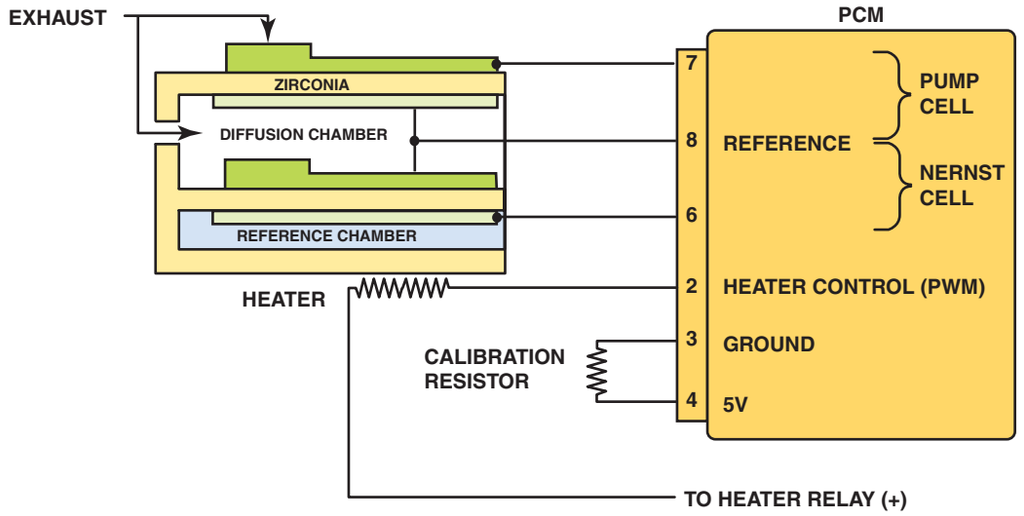


FIGURE 76–15 The reference electrodes are shared by the Nernst cell and the pump cell.

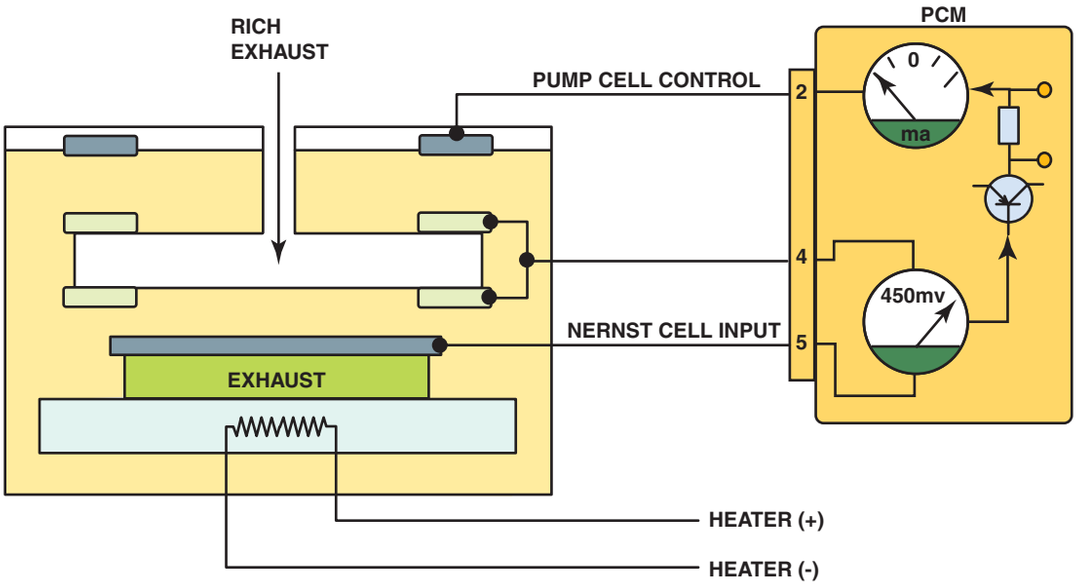


FIGURE 76–16 When the exhaust is rich, the PCM applies a negative current into the pump cell.

STOICHIOMETRIC

- When the exhaust is at stoichiometric (14.7:1 air-fuel ratio), the voltage of the Nernst cell is 450 mV (0.45 V).
- The voltage between the diffusion chamber and the air reference chamber changes from 0.45 V. This voltage will be:
  - Higher if the exhaust is rich
  - Lower if the exhaust is lean

The reference voltage remains constant, usually at 2.5 V, but can vary depending on the year, make, and model of vehicle and the type of sensor. Typical reference voltages include:

- 2.2 V
- 2.5 V
- 2.7 V
- 3.3 V
- 3.6 V

RICH EXHAUST. When the exhaust is rich, the voltage between the common (reference) electrode and the Nernst cell electrode that is exposed to ambient air is higher than 0.45 V. The PCM applies a negative current in milliamperes to the pump cell electrode to bring the circuit back into balance. ● **SEE FIGURE 76–16.**

LEAN EXHAUST. When the exhaust is lean, the voltage between the common (reference) electrode and the Nernst cell electrode is lower than 0.45 V. The PCM applies a positive current in milliamperes to the pump cell to bring the circuit back into balance. ● **SEE FIGURE 76–17.**

DUAL CELL DIAGNOSIS

SCAN TOOL DIAGNOSIS Most service information specifies that a scan tool be used to check the wide-band oxygen sensor, because the PCM performs tests of the unit and can identify faults. However, even wide-band oxygen sensors can be fooled if there is an exhaust manifold leak or other fault which could lead to false or inaccurate readings. If the oxygen sensor reading is false, the PCM will command an incorrect amount of fuel. The scan data shown on a generic (global) OBD-II scan tool will often be different than the reading on the factory scan tool. ● **SEE CHART 76–2** for an example of a

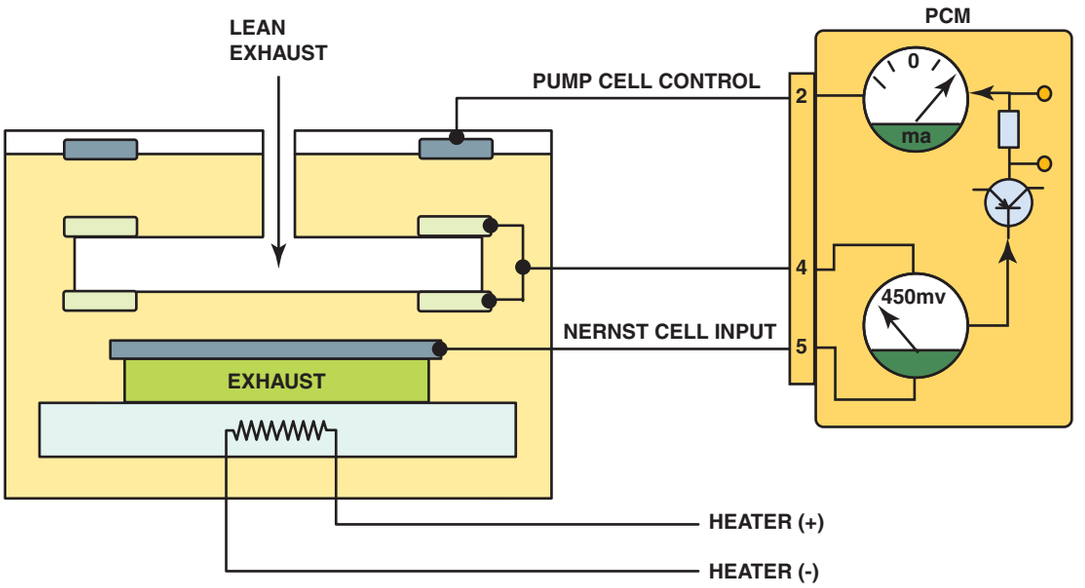


FIGURE 76–17 When the exhaust is lean, the PCM applies a positive current into the pump cell.

FACTORY SCAN TOOL	OBD II SCAN TOOL	AIR-FUEL RATIO
2.50 V	0.50 V	12.5:1
3.00 V	0.60 V	14.0:1
3.30 V	0.66 V	14.7:1
3.50 V	0.70 V	15.5:1
4.00 V	0.80 V	18.5:1

CHART 76–2

A comparison showing what a factory scan tool and a generic OBD-II scan tool might display at various air-fuel ratios.

Toyota wide-band oxygen sensor being tested using a factory scan tool and a generic OBD-II scan tool.

SCAN TOOL DATA (PID) The following information will be displayed as a scan tool when looking at data for a wide-band oxygen sensor.

H02S1 = _____ mA ÷	If the current is positive, this means that the PCM is pumping current in the diffusion gap due to a rich exhaust. If the current is negative, the PCM is pumping current out of the diffusion gap due to a lean exhaust.
Air-fuel ratio = _____	Usually expressed in lambda. One means that the exhaust is at stoichiometric (14.7:1 air-fuel ratio) and numbers higher than one indicate a lean exhaust and numbers lower than one indicate a rich exhaust.

DIGITAL METER TESTING When testing a wide-band oxygen sensor for proper operation, perform the following steps.

STEP 1 Check service information and determine the circuit and connector terminal identification.

STEP 2 Measure the calibration resistor. While the value of this resistor can vary widely depending on the type of sensor, the calibrating resistor should still be checked for opens and shorts.

NOTE: The calibration resistor is usually located within the connector itself.

- If open, the ohmmeter will read OL (infinity ohms).
- If shorted, the ohmmeter will read zero or close to zero.

STEP 3 Measure the heater circuit for proper resistance or current flow.

STEP 4 Measure the reference voltage relative to ground. This can vary but is generally 2.4 to 2.6 V.

STEP 5 Using jumper wires, connect an ammeter and measure the current in the pump cell control wire.

RICH EXHAUST When the exhaust is rich (lambda less than 1.00), the Nernst cell voltage will move higher than 0.45 V. The PCM will pump oxygen from the exhaust into the diffusion gap by applying a negative voltage to the pump cell.

LEAN EXHAUST When the exhaust is lean (lambda higher than 1.00), the Nernst cell voltage will move lower than 0.45 V. The PCM will pump oxygen out of the diffusion gap by applying a positive voltage to the pump cell.

Pump cell is used to pump oxygen into the diffusion gap when the exhaust is rich. The pump cell applies a negative voltage to do this.

- Positive current = lean exhaust
- Negative current = rich exhaust

SEE FIGURE 76–18.

SINGLE CELL WIDE-BAND OXYGEN SENSORS

CONSTRUCTION A typical **single cell** wide-band oxygen sensor looks similar to a conventional four-wire zirconia oxygen sensor. The typical single cell wide-band oxygen sensor, usually called an **air-fuel ratio sensor,** has the following construction features.

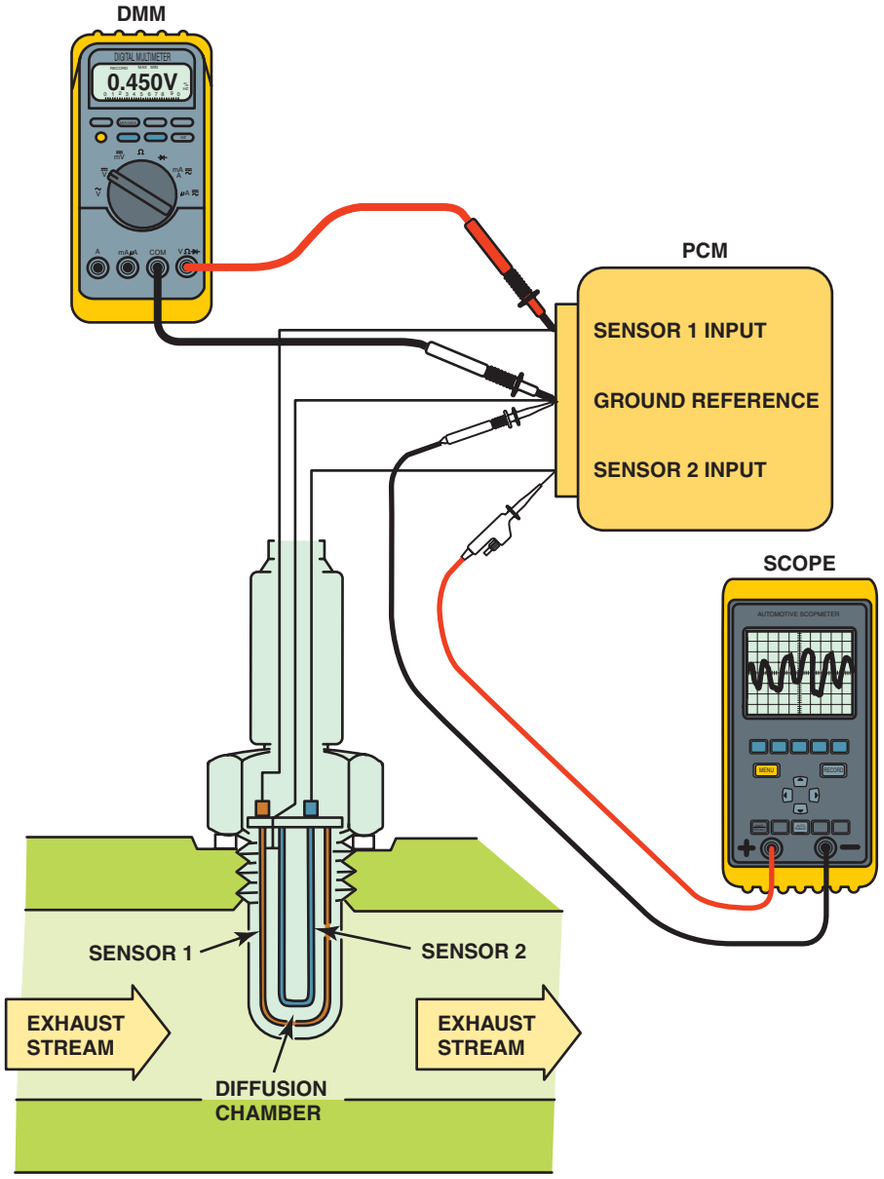


FIGURE 76–18 Testing a dual cell wide-band oxygen sensor can be done using a voltmeter or a scope. The meter reading is attached to the Nernst cell and should read stoichiometric (450 mV) at all times. The scope is showing activity to the pump cell with commands from the PCM to keep the Nernst cell at 14.7:1 air-fuel ratio.

- It can be made using the cup or planar design.
- Oxygen (O_2) is pumped into the diffusion layer similar to the operation of a dual cell wide-band oxygen sensor. ● **SEE FIGURE 76–19.**
- Current flow reverses positive and negative.
- There are two cell wires and two heater wires (power and ground).
- The heater usually requires 6 amperes and the ground side is pulse-width modulated.

MILLIAMMETER TESTING

The PCM controls the single cell wide-band oxygen sensor by maintaining a voltage difference of 300 mV (0.3 V) between the two sensor leads. The PCM keeps the voltage difference constant under all operating conditions by increasing or decreasing current between the element of the cell.

- Zero (0 mA) represents lambda or stoichiometric air-fuel ratio of 14.7:1
- +10 mA indicates a lean condition
- −10 mA indicates a rich condition

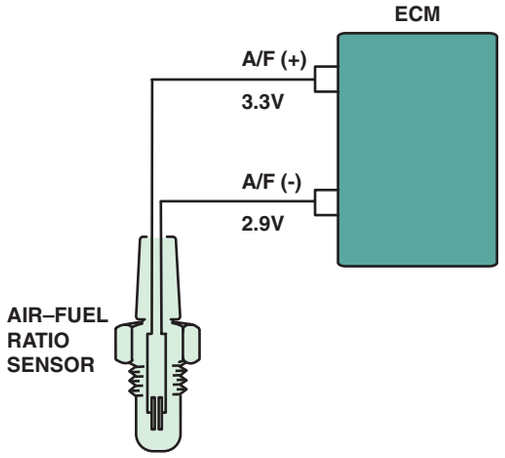


FIGURE 76–19 A single cell wide-band oxygen sensor has four wires with two for the heater and two for the sensor itself. The voltage applied to the sensor is 0.4 V (3.3 − 2.9 = 0.4) across the two leads of the sensor.

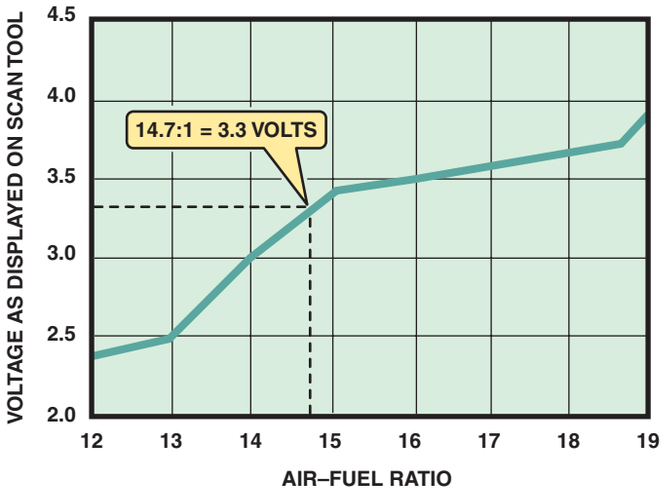


FIGURE 76–20 The scan can display various voltages but will often show 3.3 V because the PCM is controlling the sensor through applying a low current to the sensor to achieve balance.

SCAN TOOL TESTING A scan tool will display a voltage reading but can vary depending on the type and maker of scan tool. ● **SEE FIGURE 76–20.**

WIDE-BAND OXYGEN PATTERN FAILURES

Wide-band oxygen sensors have a long life, but they can fail. Most of the failures will cause a diagnostic trouble code (DTC) to set, usually causing the malfunction indicator (check engine) lamp to light.

However, one type of failure may not set a DTC, such as when the following occurs.

1. Voltage from the heater circuit bleeds into the Nernst cell.
2. This voltage will cause the engine to operate extremely lean and may or may not set a diagnostic trouble code.
3. When testing indicates an extremely lean condition, unplug the connector to the oxygen sensor. If the engine starts to operate correctly with the sensor unplugged, this is confirmation that the wide-band oxygen sensor has failed and requires replacement.

OXYGEN SENSOR–RELATED DIAGNOSTIC TROUBLE CODES

Diagnostic trouble codes (DTCs) associated with the oxygen sensor include the following:

Diagnostic Trouble Codes	Description	Possible Causes
P0131	Upstream HO2S grounded	• Exhaust leak upstream of HO2S (bank 1) • Extremely lean air-fuel mixture • HO2S defective or contaminated • HO2S signal wire shorted-to-ground
P0132	Upstream HO2S shorted	• Upstream HO2S (bank 1) shorted • Defective HO2S • Fuel-contaminated HO2S
P0133	Upstream HO2S slow response	• Open or short in heater circuit • Defective or fuel-contaminated HO2S • EGR or fuel system fault

REVIEW QUESTIONS

1. How does an oxygen sensor detect oxygen levels in the exhaust?
2. What are three basic designs of oxygen sensors and how many wires may be used for each?
3. What is the difference between open-loop and closed-loop engine operation?
4. What are three ways oxygen sensors can be tested?
5. How can the oxygen sensor be fooled and provide the wrong information to the PCM?
6. What is the purpose of a wide-band oxygen sensor?

CHAPTER QUIZ

1. The voltage output of a zirconia oxygen sensor when the exhaust stream is lean (excess oxygen) is _____.
   a. Relatively high (close to 1 volt)
   b. About in the middle of the voltage range
   c. Relatively low (close to 0 volt)
   d. Either a or b, depending on atmospheric pressure
2. A high O2S voltage could be due to a _____.
   a. Rich exhaust
   b. Lean exhaust
   c. Defective spark plug wire
   d. Both a and c

3. A low O2S voltage could be due to a _____.
   a. Rich exhaust **c.** Defective spark plug wire
   b. Lean exhaust **d.** Both b and c

4. An oxygen sensor is being tested with a digital multimeter (DMM), using the MIN/MAX function. The readings are: minimum = 78 mV; maximum = 932 mV; average = 442 mV. Technician A says that the engine is operating correctly. Technician B says that the oxygen sensor is skewed too rich. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B

5. An oxygen sensor is being tested using a digital storage oscilloscope (DSO). A good oxygen sensor should display how many transitions (switches) per second?
   a. 1 to 5 **c.** 10 to 15
   b. 5 to 10 **d.** 15 to 20

6. A wide-band oxygen sensor was first used on a Honda in what model year?
   a. 1992 **c.** 2000
   b. 1996 **d.** 2006

7. A wide-band oxygen sensor is capable of detecting the air-fuel mixture in the exhaust from _____ (rich) to _____ (lean).
   a. 12:1; 15:1 **c.** 10:1; 23:1
   b. 13:1; 16.7:1 **d.** 8:1; 18:1

8. A wide-band oxygen sensor needs to be heated to what operating temperature?
   a. 600°F (315°C) **c.** 1,400°F (760°C)
   b. 800°F (427°C) **d.** 2,000°F (1,093°C)

9. A wide-band oxygen sensor heater could draw how much current (amperes)?
   a. 0.8 to 2 A **c.** 6 to 8 A
   b. 2 to 4 A **d.** 8 to 10 A

10. A P0133 DTC is being discussed. Technician A says that a defective heater circuit could be the cause. Technician B says that a contaminated sensor could be the cause. Which technician is correct?
    a. Technician A only **c.** Both Technicians A and B
    b. Technician B only **d.** Neither Technician A nor B

chapter 77

FUEL PUMPS, LINES, AND FILTERS

OBJECTIVES: **After studying Chapter 77, the reader will be able to:** • Prepare for ASE Engine Performance (A8) certification test content area "C" (Fuel, Air Induction, and Exhaust Systems Diagnosis and Repair). • Discuss fuel tanks, lines and filters. • Describe how fuel pumps work. • Describe how to check an electric fuel pump for proper pressure and volume delivery. • Explain how to check a fuel-pressure regulator. • Describe how to test fuel injectors. • Explain how to diagnose electronic fuel-injection problems.

KEY TERMS: Accumulator 868 • Baffle 860 • Check valve 862 • Delivery system 860 • Filter basket 869 • Gerotor 866 • Hydrokinetic pump 866 • Inertia switch 862 • Onboard refueling vapor recovery (ORVR) 861 • Peripheral pump 866 • Residual or rest pressure 865 • Roller cell 865 • Rotary vane pump 865 • Side-channel pump 866 • Turbine pump 866 • Vacuum lock 862 • Vapor lock 862 • Volatile organic compound (VOC) 864

FUEL DELIVERY SYSTEM

Creating and maintaining a correct air–fuel mixture requires a properly functioning fuel and air **delivery system.** Fuel delivery (and return) systems use many if not all of the following components to make certain that fuel is available under the right conditions to the fuel-injection system:

- Fuel storage tank, filler neck, and gas cap
- Fuel tank pressure sensor
- Fuel pump
- Fuel filter(s)
- Fuel delivery lines and fuel rail
- Fuel-pressure regulator
- Fuel return line (if equipped with a return-type fuel delivery system)

FUEL TANKS

A vehicle fuel tank is made of corrosion-resistant steel or polyethylene plastic. Some models, such as sport utility vehicles (SUVs) and light trucks, may have an auxiliary fuel tank.

Tank design and capacity are a compromise between available space, filler location, fuel expansion room, and fuel movement. Some later-model tanks deliberately limit tank capacity by extending the filler tube neck into the tank low enough to prevent complete filling, or by providing for expansion room. ● **SEE FIGURE 77–1.** A vertical **baffle** in fuel tanks limits fuel sloshing as the vehicle moves.

Regardless of size and shape, all fuel tanks incorporate most if not all of the following features:

- Inlet or filler tube through which fuel enters the tank
- Filler cap with pressure holding and relief features

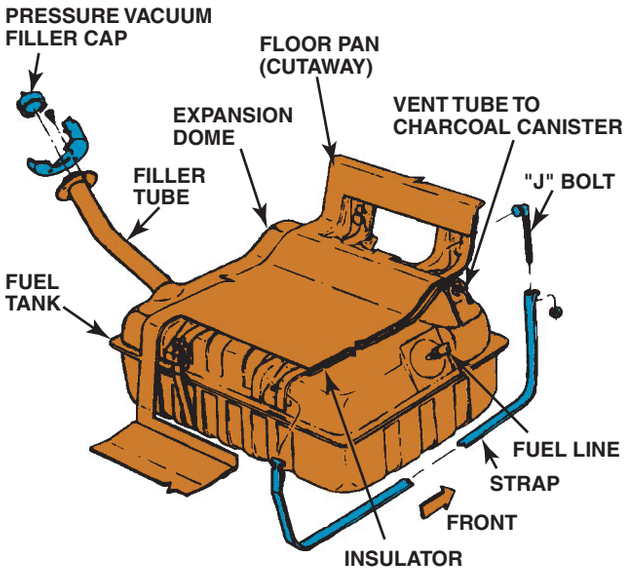


FIGURE 77–1 A typical fuel tank installation.

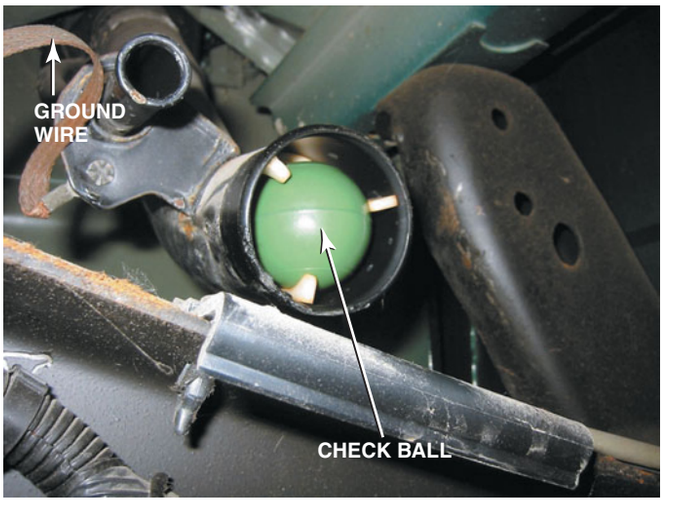


FIGURE 77–3 A view of a typical filler tube with the fuel tank removed. Notice the ground strap used to help prevent the buildup of static electricity as the fuel flows into the plastic tank. The check ball looks exactly like a ping-pong ball.

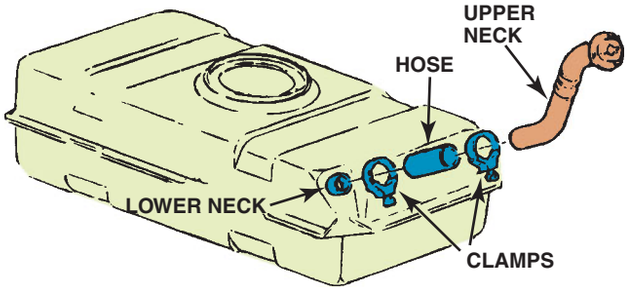


FIGURE 77–2 A three-piece filler tube assembly. The main three parts include the upper neck, hose, and lower neck.



FIGURE 77–4 Vehicles equipped with onboard refueling vapor recovery usually have a reduced-size fill tube.

- An outlet to the fuel line leading to the fuel pump or fuel injector
- Fuel pump mounted within the tank
- Tank vent system
- Fuel pickup tube and fuel level sending unit

TANK LOCATION AND MOUNTING Most vehicles use a horizontally suspended fuel tank, usually mounted below the rear of the floor pan, just ahead of or behind the rear axle. Fuel tanks are located there so that frame rails and body components protect the tank in the event of a crash. To prevent squeaks, some models have insulated strips cemented on the top or sides of the tank wherever it contacts the underbody.

Fuel inlet location depends on the tank design and filler tube placement. It is located behind a filler cap and is often a hinged door in the outer side of either rear fender panel.

Generally, a pair of metal retaining straps holds a fuel tank in place. Underbody brackets or support panels hold the strap ends using bolts. The free ends are drawn underneath the tank to hold it in place, then bolted to other support brackets or to a frame member on the opposite side of the tank.

FILLER TUBES Fuel enters the tank through a large tube extending from the tank to an opening on the outside of the vehicle. ● **SEE FIGURE 77–2.**

Effective in 1993, federal regulations require manufacturers to install a device to prevent fuel from being siphoned through the filler neck. Federal authorities recognized methanol as a poison, and methanol used in gasoline is a definite health hazard. Additionally, gasoline is a suspected carcinogen (cancer-causing agent). To prevent siphoning, manufacturers welded a filler-neck check-ball tube in fuel tanks. To drain check-ball-equipped fuel tanks, a technician must disconnect the check-ball tube at the tank and attach a siphon directly to the tank. ● **SEE FIGURE 77–3.**

Onboard refueling vapor recovery (ORVR) systems have been developed to reduce evaporative emissions during refueling. ● **SEE FIGURE 77–4.** These systems add components to the filler neck and the tank. One ORVR system utilizes a tapered filler neck with a smaller diameter tube and a check valve. When fuel flows down the neck, it opens the normally closed check valve. The vapor passage to the charcoal canister is opened. The decreased size neck and the opened air passage allow fuel and vapor to flow rapidly into the tank and the canister respectively. When the fuel has reached a predetermined level, the check valve closes, and the fuel tank pressure increases. This forces the nozzle to shut off, thereby preventing the tank from being overfilled.

PRESSURE-VACUUM FILLER CAP Fuel and vapors are sealed in the tank by the safety filler cap. The safety cap must release excess pressure or excess vacuum. Either condition could cause fuel tank damage, fuel spills, and vapor escape. Typically, the cap will release if the pressure is over 1.5 to 2.0 PSI (10 to 14 kPa) or if the vacuum is 0.15 to 0.30 PSI (1 to 2 kPa).

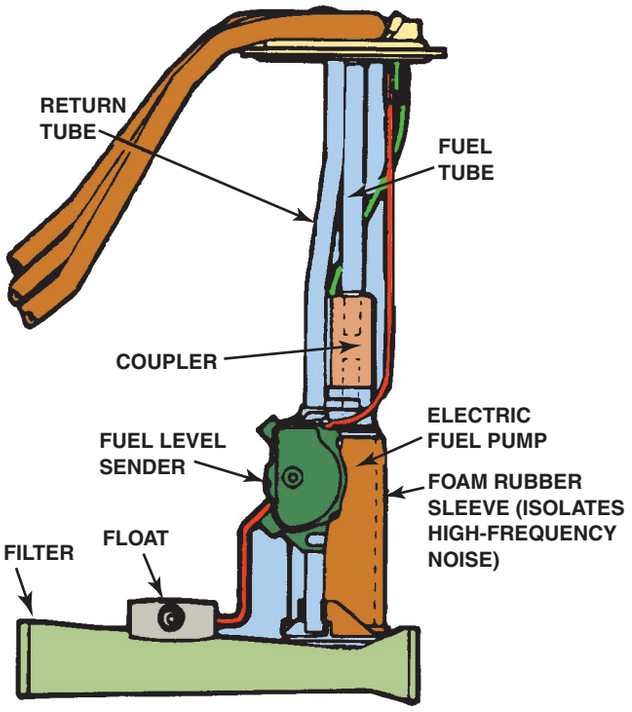


FIGURE 77–5 The fuel pickup tube is part of the fuel sender and pump assembly.

FUEL PICKUP TUBE The fuel pickup tube is usually a part of the fuel sender assembly or the electric fuel pump assembly. Since dirt and sediment eventually gather on the bottom of a fuel tank, the fuel pickup tube is fitted with a filter sock or strainer to prevent contamination from entering the fuel lines. The woven plastic strainer also acts as a water separator by preventing water from being drawn up with the fuel. The filter sock usually is designed to filter out particles that are larger than 70 to 100 microns, or 30 microns if a gerotor-type fuel pump is used. One micron is 0.000039 in. ● **SEE FIGURE 77–5.**

NOTE: The human eye cannot see anything smaller than about 40 microns.

The filter is made from woven Saran resin (copolymer of vinylidene chloride and vinyl chloride. The filter blocks any water that may be in the fuel tank, unless it is completely submerged in water. In that case, it will allow water through the filter. This filter should be replaced whenever the fuel pump is replaced.

TANK VENTING REQUIREMENTS Fuel tanks must be vented to prevent a **vacuum lock** as fuel is drawn from the tank. As fuel is used and its level drops in the tank, the space above the fuel increases. As the air in the tank expands to fill this greater space, its pressure drops. Without a vent, the air pressure inside the tank would drop below atmospheric pressure, developing a vacuum which prevents the flow of fuel. Under extreme pressure variance, the tank could collapse. Venting the tank allows outside air to enter as the fuel level drops, preventing a vacuum from developing.

An EVAP system vents gasoline vapors from the fuel tank directly to a charcoal-filled vapor storage canister, and uses an unvented filler cap. Many filler caps contain valves that open to relieve pressure or vacuum above specified safety levels. Systems that use completely sealed caps have separate pressure and vacuum relief valves for venting.

Because fuel tanks are not vented directly to the atmosphere, the tank must allow for fuel expansion, contraction, and overflow that can result from changes in temperature or overfilling. One way is to use a dome in the top of the tank. Many General Motors vehicles use a design that includes a vertical slosh baffle which reserves up to 12% of the total tank capacity for fuel expansion.

ROLLOVER LEAKAGE PROTECTION

All vehicles have one or more devices to prevent fuel leaks in case of vehicle rollover or a collision in which fuel may spill.

Variations of the basic one-way **check valve** may be installed in any number of places between the fuel tank and the engine. The valve may be installed in the fuel return line, vapor vent line, or fuel tank filler cap.

In addition to the rollover protection devices, some vehicles use devices to ensure that the fuel pump shuts off when an accident occurs. On some air vane sensors, a microswitch is built into the sensor to switch on the fuel pump as soon as intake airflow causes the vane to lift from its rest position. ● **SEE FIGURE 77–6.**

Ford vehicles use an **inertia switch.** ● **SEE FIGURE 77–7.** The inertia switch is installed in the rear of the vehicle between the electric fuel pump and its power supply. With any sudden impact, such as a jolt from another vehicle in a parking lot, the inertia switch opens and shuts off power to the fuel pump. The switch must be reset manually by pushing a button to restore current to the pump.

FUEL LINES

Fuel and vapor lines made of steel, nylon tubing, or fuel-resistant rubber hoses connect the parts of the fuel system. Fuel lines supply fuel to the throttle body or fuel rail. They also return excess fuel and vapors to the tank. Depending on their function, fuel and vapor lines may be either rigid or flexible.

Fuel lines must remain as cool as possible. If any part of the line is located near too much heat, the gasoline passing through it vaporizes and **vapor lock** occurs. When this happens, the fuel pump supplies only vapor that passes into the injectors. Without liquid gasoline, the engine stalls and a hot restart problem develops.

The fuel delivery system supplies 10 to 15 PSI (69 to 103 kPa) or up to 35 PSI (241 kPa) to many throttle-body injection units and up to 60 PSI (414 kPa) for multiport fuel-injection systems. Fuel-injection systems retain residual or rest pressure in the lines for a half hour or longer when the engine is turned off to prevent hot engine restart problems. Higher-pressure systems such as these require special fuel lines.

RIGID LINES All fuel lines fastened to the body, frame, or engine are made from nylon reinforced plastic or seamless steel tubing. Steel springs may be wound around the tubing at certain points to protect against impact damage.

Only steel tubing, or that recommended by the manufacturer, should be used when replacing rigid fuel lines. *Never substitute copper or aluminum tubing for steel tubing*. These materials do not withstand normal vehicle vibration and could combine with the fuel to cause a chemical reaction.

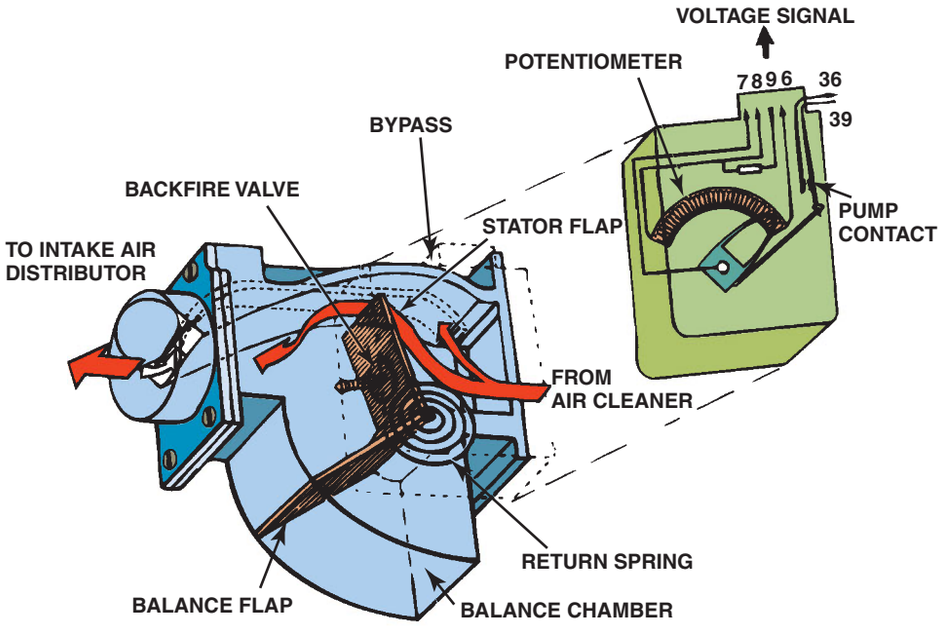


FIGURE 77–6 On some vehicles equipped with an airflow sensor, a switch is used to energize the fuel pump. In the event of a collision, the switch opens and the fuel flow stops.

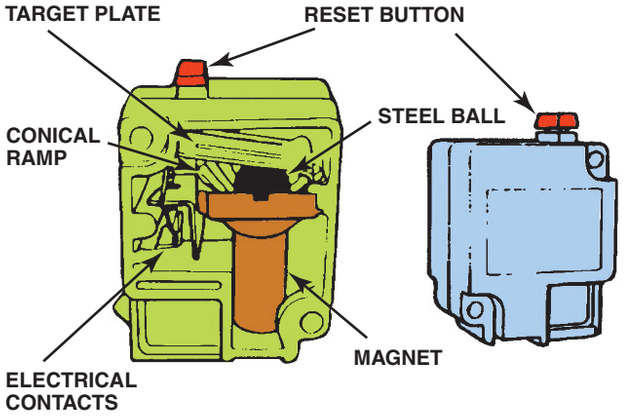


FIGURE 77–7 Ford uses an inertia switch to turn off the electric fuel pump in an accident.

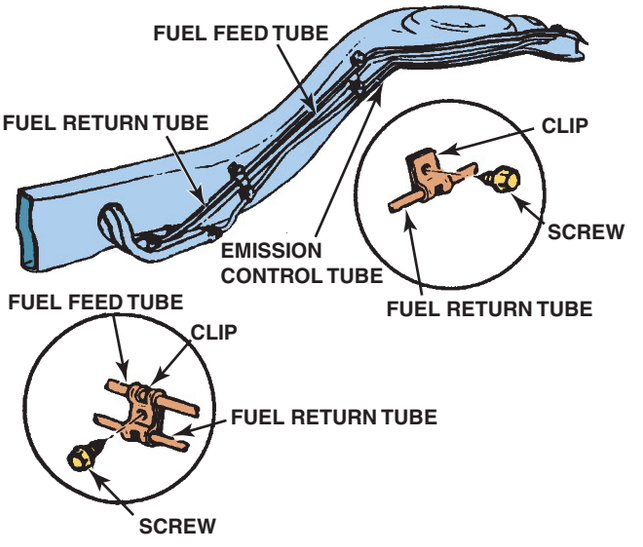


FIGURE 77–8 Fuel lines are routed along the frame or body and secured with clips.

FLEXIBLE LINES Most fuel systems use synthetic rubber hose sections where flexibility is needed. Short hose sections often connect steel fuel lines to other system components. The fuel delivery hose inside diameter (ID), is usually 3/16" or 3/8" (8 or 10 millimeters) and the return line ID is normally 1/4" (6 millimeters).

Fuel-injection systems require special-composition reinforced hoses specifically made for these higher-pressure systems. Similarly, vapor vent lines must be made of materials that resist fuel vapors. Replacement vent hoses are usually marked with the designation "EVAP" to indicate their intended use.

FUEL LINE MOUNTING Fuel supply lines from the tank to a throttle body or fuel rail are routed to follow the frame along the underbody of the vehicle. Vapor and return lines may be routed with the fuel supply line. All rigid lines are fastened to the frame rail or underbody with screws and clamps, or clips. ● **SEE FIGURE 77–8.**

FUEL-INJECTION LINES AND CLAMPS Hoses used for fuel-injection systems are made of materials with high resistance to oxidation and deterioration. Replacement hoses for injection systems should always be equivalent to original equipment manufacturer (OEM) hoses.

Screw-type clamps are essential on injected engines and should have rolled edges to prevent hose damage.

CAUTION: ***Do not use spring-type clamps on fuel-injected engines—they cannot withstand the fuel pressures involved.***

FUEL-INJECTION FITTINGS AND NYLON LINES Because of their operating pressures, fuel-injection systems often use special kinds of fittings to ensure leakproof connections. Some high-pressure fittings on GM vehicles with port fuel-injection systems use O-ring seals instead of the traditional flare connections. When disconnecting such a fitting, inspect the O-ring for damage and replace it if necessary. *Always* tighten O-ring fittings to the specified torque value to prevent damage.

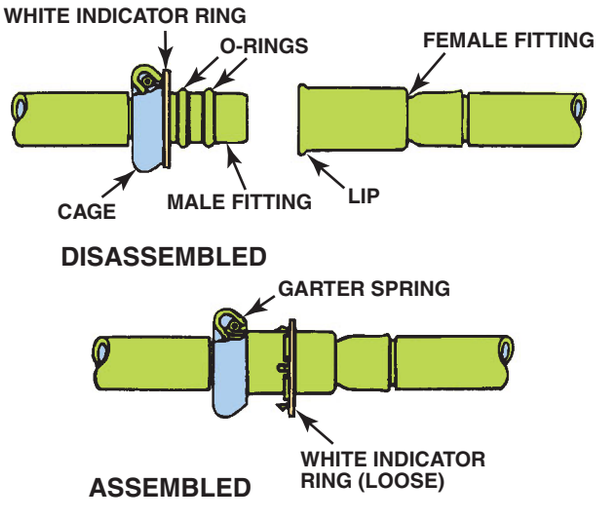


FIGURE 77–9 Some Ford metal line connections use spring-locks and O-rings.

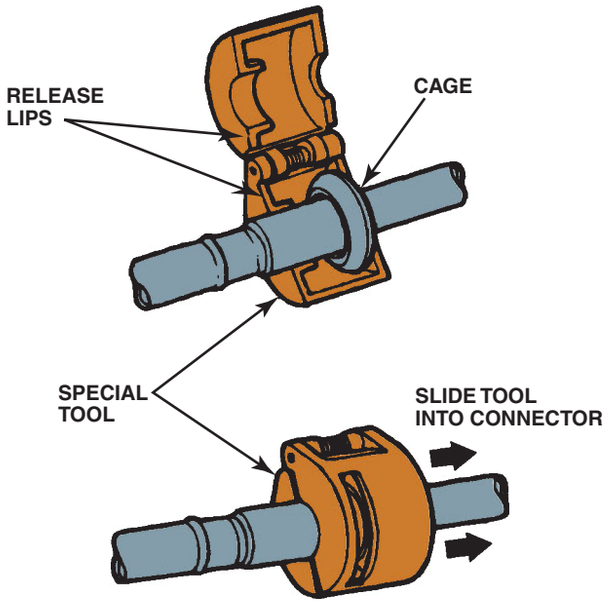


FIGURE 77–10 Ford spring-lock connectors require a special tool for disassembly.

? FREQUENTLY ASKED QUESTION

Just How Much Fuel Is Recirculated?

Approximately 80% of the available fuel-pump volume is released to the fuel tank through the fuel pressure regulator at idle speed. As an example, a passenger vehicle cruising down the road at 60 mph gets 30 mpg. With a typical return-style fuel system pumping about 30 gallons per hour from the tank, it would therefore burn 2 gallons per hour, and return about 28 gallons per hour to the tank!

? FREQUENTLY ASKED QUESTION

How Can an Electric Pump Work Inside a Gas Tank and Not Cause a Fire?

Even though fuel fills the entire pump, no burnable mixture exists inside the pump because there is no air and no danger of commutator brush arcing, igniting the fuel.

Other manufacturers also use O-ring seals on fuel line connections. In all cases, the O-rings are made of special materials that withstand contact with gasoline and oxygenated fuel blends. Some manufacturers specify that the O-rings be replaced every time the fuel system connection is opened. When replacing one of these O-rings, a new part specifically designed for fuel system service must be used.

Ford also uses spring-lock connectors to join male and female ends of steel tubing. ● **SEE FIGURE 77–9.** The coupling is held together by a garter spring inside a circular cage. The flared end of the female fitting slips behind the spring to lock the coupling together.

General Motors has used nylon fuel lines with quick-connect fittings at the fuel tank and fuel filter since the early 1990s. Like the GM threaded couplings used with steel lines, nylon line couplings use internal O-ring seals. Unlocking the metal connectors requires a special quick-connector separator tool; plastic connectors can be released without the tool. ● **SEE FIGURES 77–10 AND 77–11.**

FUEL LINE LAYOUT Fuel pressures have tended to become higher to prevent vapor lock, and a major portion of the fuel routed to the fuel-injection system returns to the tank by way of a fuel return line or return-type systems. This allows better control, within limits, of heat absorbed by the gasoline as it is routed through the engine compartment. Throttle-body and multiport injection systems have typically used a pressure regulator to control fuel pressure in the throttle body or fuel rail, and also allow excess fuel not used by the injectors to return to the tank. However, the warmer fuel in the tank may create problems, such as an excessive rise in fuel vapor pressures in the tank.

With late-model vehicles, there has been some concern about too much heat being sent back to the fuel tank, causing rising in-tank temperatures and increases in fuel vaporization and **volatile organic compound (VOC)** (hydrocarbon) emissions. To combat this problem, manufacturers have placed the pressure regulator back by the tank instead of under the hood on mechanical returnless systems. In this way, returned fuel is not subjected to the heat generated by the engine and the underhood environment. To prevent vapor lock in these systems, pressures have been raised in the fuel rail, and injectors tend to have smaller openings to maintain control of the fuel spray under pressure.

Not only must the fuel be filtered and supplied under adequate pressure, but there must also be a consistent *volume* of fuel to assure smooth engine performance even under the heaviest of loads.

ELECTRIC FUEL PUMPS

The electric fuel pump is a pusher unit. When the pump is mounted in the tank, the entire fuel supply line to the engine can be pressurized. Because the fuel, when pressurized, has a higher boiling point, it is unlikely that vapor will form to interfere with fuel flow.

Most vehicles use the impeller or turbine pumps. ● **SEE FIGURE 77–12.** All electrical pumps are driven by a small electric motor, but the turbine pump turns at higher speeds and is quieter than the others.

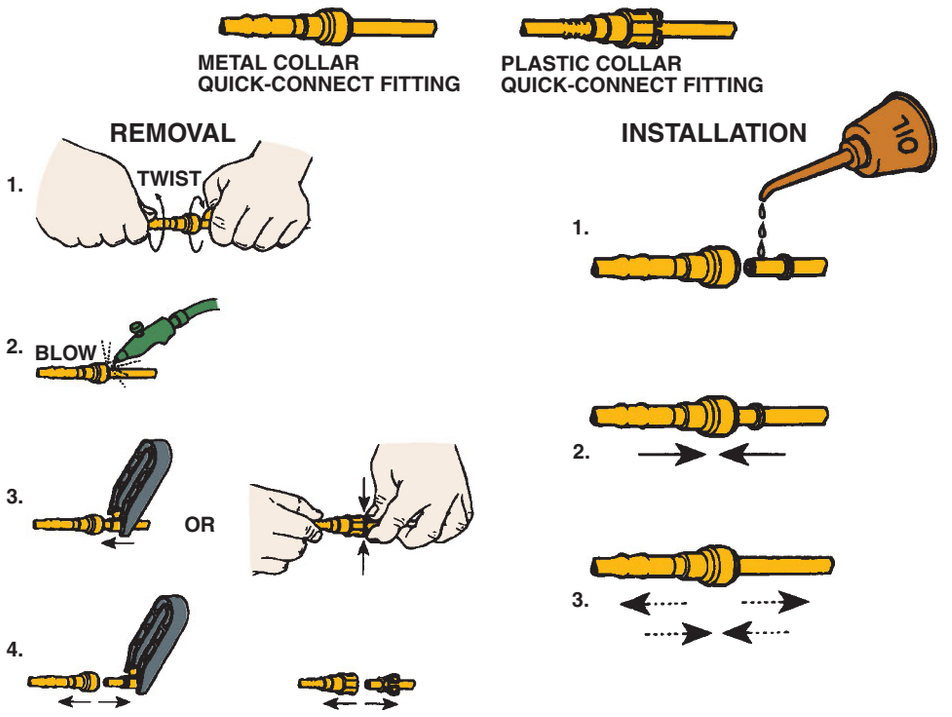


FIGURE 77–11 Typical quick-connect steps.

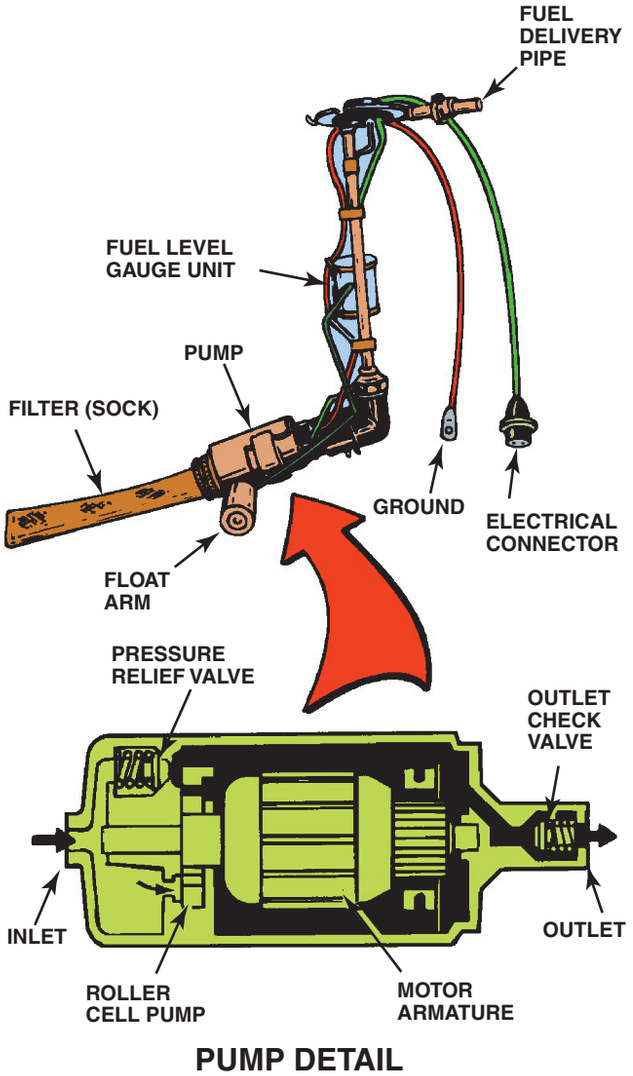


FIGURE 77–12 A roller cell-type electric fuel pump.

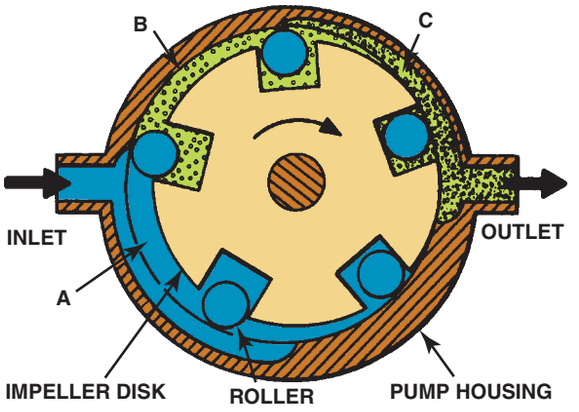


FIGURE 77–13 The pumping action of an impeller or rotary vane pump.

POSITIVE DISPLACEMENT PUMP

A positive displacement pump is a design that forces everything that enters the pump to leave the pump.

In the **roller cell** or vane pump, the impeller draws fuel into the pump, and then pushes it out through the fuel line to the injection system. All designs of pumps use a variable-sized chamber to draw in fuel. When the maximum volume has been reached, the supply port closes and the discharge opens. Fuel is then forced out the discharge as this volume decreases. The chambers are formed by rollers or gears in a rotor plate. Because this type of pump uses no valves to move the fuel, the fuel flows steadily through the entire pump housing, including the electrical portion which keeps the pump cool. Usually, only when a vehicle runs out of fuel is there a risk of pump damage.

Most electric fuel pumps are equipped with a fuel outlet check valve that closes to maintain fuel pressure when the pump shuts off. **Residual or rest pressure** prevents vapor lock and hot-start problems on these systems.

● **FIGURE 77–13** shows the pumping action of a **rotary vane pump.** The pump consists of a central impeller disk, several rollers

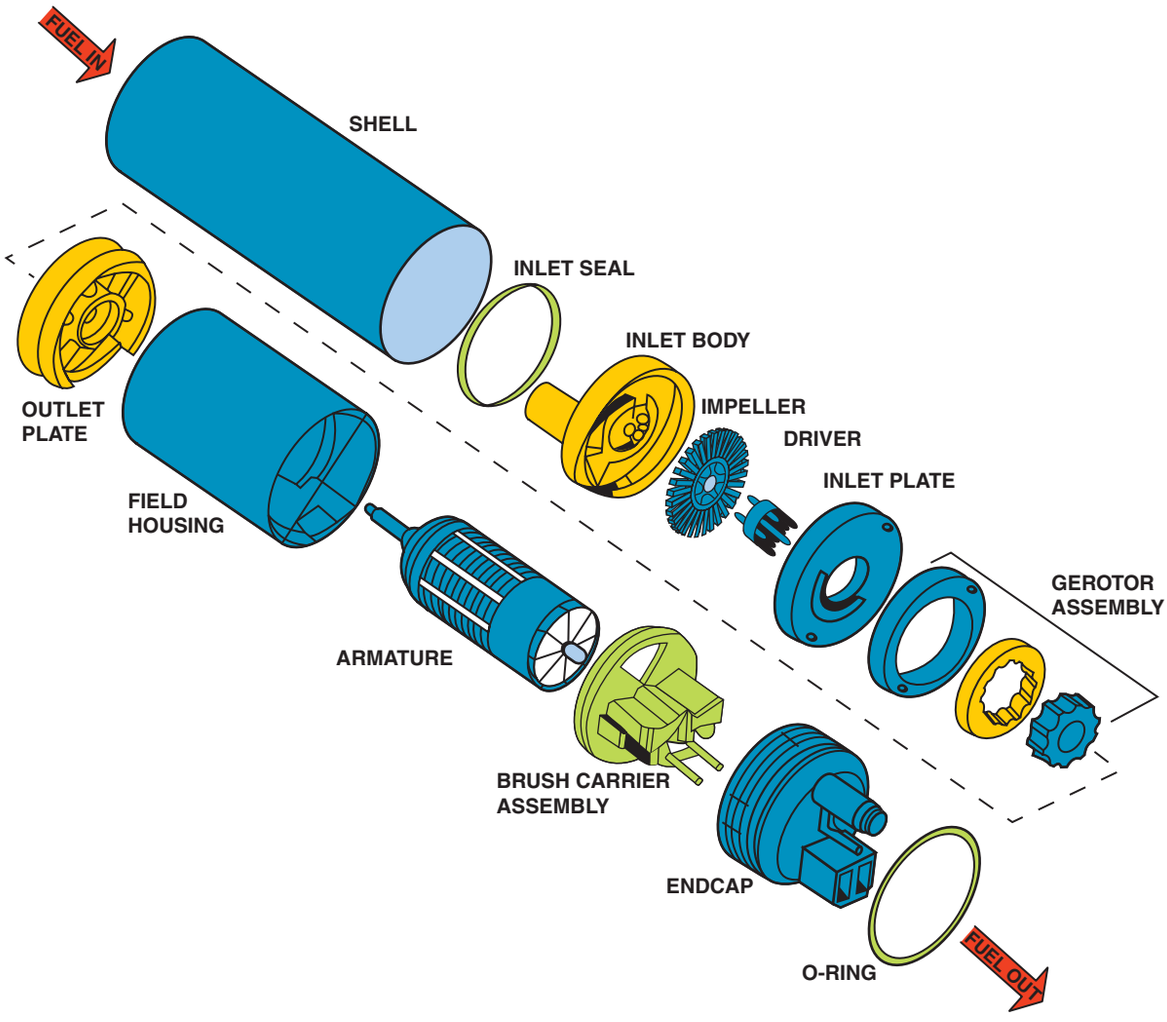


FIGURE 77–14 An exploded view of a gerotor electric fuel pump.

or vanes that ride in notches in the impeller, and a pump housing that is offset from the impeller centerline. The impeller is mounted on the end of the motor armature and spins whenever the motor is running. The rollers are free to slide in and out within the notches in the impeller to maintain sealing contact. Unpressurized fuel enters the pump, fills the spaces between the rollers, and is trapped between the impeller, the housing, and two rollers. An internal gear pump, called a **gerotor,** is another type of positive displacement pump that is often used in engine oil pumps. It uses the meshing of internal and external gear teeth to pressurize the fuel. ● **SEE FIGURE 77–14** for an example of a gerotor-type fuel pump that uses an impeller as the first stage and is used to move the fuel gerotor section where it is pressurized.

HYDROKINETIC FLOW PUMP DESIGN The word *hydro* means liquid and the term *kinetic* refers to motion, so the term **hydrokinetic pump** means that this design of pump rapidly moves the fuel to create pressure. This design of pump is a nonpositive displacement pump design.

A **turbine pump** is the most common because it tends to be less noisy. Sometimes called **turbine, peripheral,** and **side-channel,** these units use an impeller that accelerates the fuel particles before actually discharging them into a tract where they generate pressure via pulse exchange. Actual pump volume is controlled by using a different number of impeller blades, and in some cases a higher number of impellers, or different shapes along the side discharge channels. These units are fitted more toward lower operating pressures of less than 60 PSI. ● **SEE FIGURE 77–15** for an example of a two-stage turbine pump. The turbine impeller has a staggered blade design to minimize pump harmonic noise and to separate vapor from the liquid fuel. The end cap assembly contains a pressure relief valve and a radio-frequency interference (RFI) suppression module. The check valve is usually located in the upper fuel pipe connector assembly.

After fuel passes the strainer, it is drawn into the lower housing inlet port by the impellers. It is pressurized and delivered to the convoluted fuel tube for transfer through a check valve into the fuel feed pipe. A typical electric fuel pump used on a fuel-injection system delivers about 40 to 50 gallons per hour or 0.6 to 0.8 gallons per minute at a pressure of 70 to 90 PSI.

MODULAR FUEL SENDER ASSEMBLY The modular fuel sender consists of a fuel level sensor, a turbine pump, and a jet pump. The reservoir housing is attached to the cover containing fuel pipes and the electrical connector. Fuel is transferred from the pump to the fuel pipe through a convoluted (flexible) fuel pipe. The convoluted fuel pipe eliminates the need for rubber hoses, nylon pipes, and clamps. The reservoir dampens fuel slosh to maintain a constant fuel level available to the roller vane pump; it also reduces noise.

Some of the flow, however, is returned to the jet pump for recirculation. Excess fuel is returned to the reservoir through one of the three hollow support pipes. The hot fuel quickly mixes with the cooler fuel in the reservoir; this minimizes the possibility of vapor lock. In these modules, the reservoir is filled by the jet pump. Some of the fuel from the pump is sent through the jet pump to lift fuel from the tank into the reservoir.

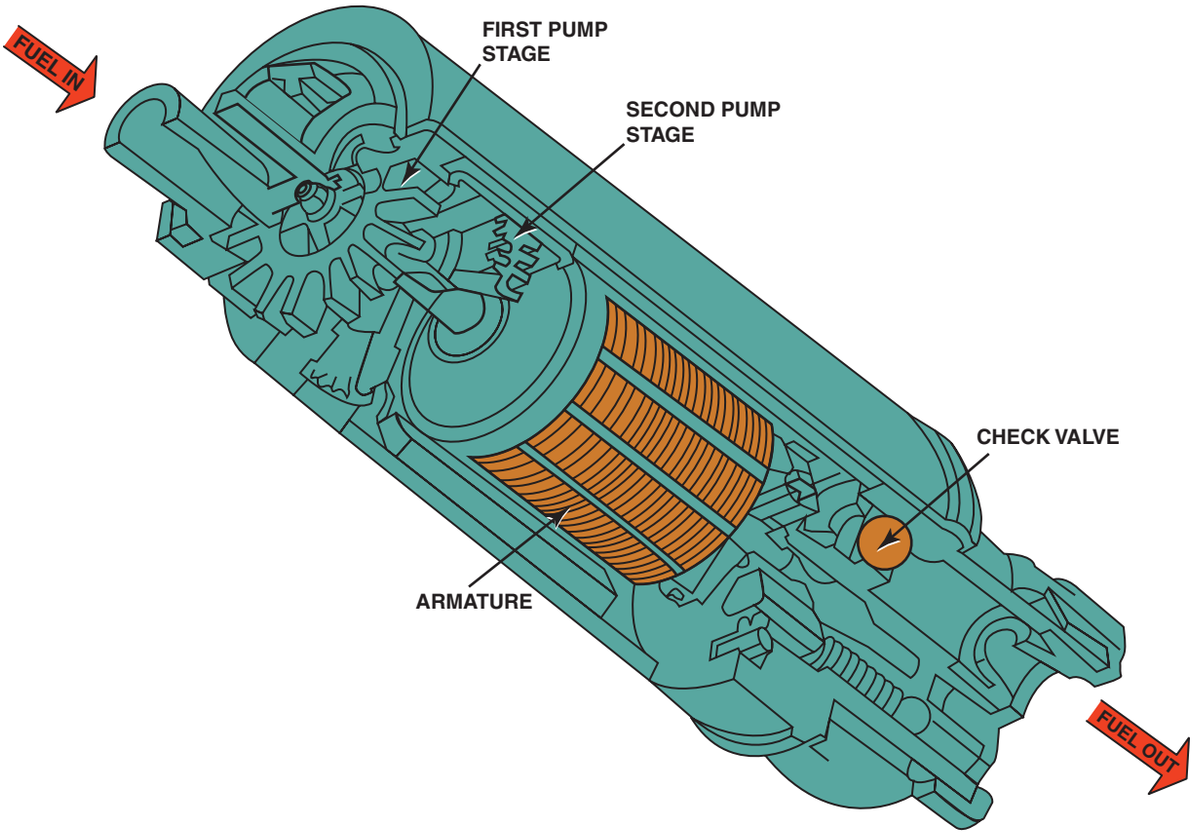


FIGURE 77–15 A cutaway view of a typical two-stage turbine electric fuel pump.

? FREQUENTLY ASKED QUESTION

Why Are Many Fuel-Pump Modules Spring-Loaded?

Fuel modules that contain the fuel pickup sock, fuel pump, and fuel level sensor are often spring-loaded when fitted to a plastic fuel tank. The plastic material shrinks when cold and expands when hot, so having the fuel module spring-loaded ensures that the fuel pickup sock will always be the same distance from the bottom of the tank. ● **SEE FIGURE 77–16.**



FIGURE 77–16 A typical fuel-pump module assembly, which includes the pickup strainer and fuel pump, as well as the fuel-pressure sensor and fuel level sensing unit.

ELECTRIC PUMP CONTROL CIRCUITS

Fuel-pump circuits are controlled by the fuel-pump relay. Fuel-pump relays are activated initially by turning the ignition key to on, which allows the pump to pressurize the fuel system. As a safety precaution, the relay de-energizes after a few seconds until the key is moved to the crank position. Once an ignition coil signal, or "tach" signal, is received by the engine control computer, indicating the engine is rotating, the relay remains energized even with the key released to the run position.

CHRYSLER. On Chrysler vehicles, the PCM must receive an engine speed (RPM) signal during cranking before it can energize a circuit driver inside the power module to activate an automatic shutdown (ASD) relay to power the fuel pump, ignition coil, and injectors. As a safety precaution, if the RPM signal to the logic module is interrupted, the logic module signals the power module to deactivate the ASD, turning off the pump, coil, and injectors. In some vehicles, the oil pressure switch circuit may be used as a safety circuit to activate the pump in the ignition switch run position.

GENERAL MOTORS. General Motors systems energize the pump with the ignition switch to initially pressurize the fuel lines, but then deactivate the pump if an RPM signal is not received within one or two seconds. The pump is reactivated as soon as engine cranking is detected. The oil pressure sending unit serves as a backup to the fuel-pump relay on some vehicles. In case of pump relay failure, the oil pressure switch will operate the fuel pump once oil pressure reaches about 4 PSI (28 kPa).

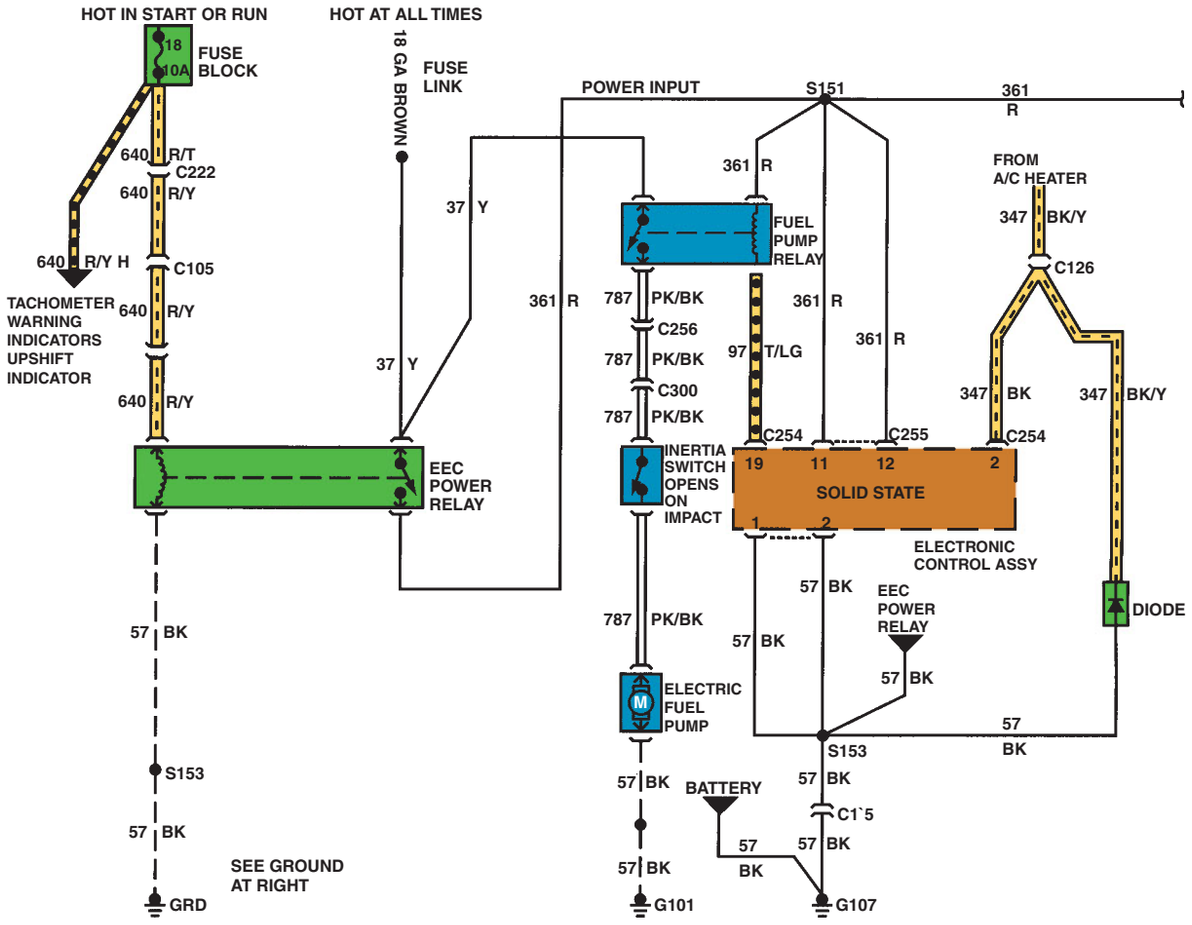


FIGURE 77–17 A schematic showing that an inertia switch is connected in series between the fuel-pump relay and the fuel pump.

FORD. Most Ford vehicles with fuel injection have an inertia switch between the fuel-pump relay and fuel pump. When the ignition switch is turned to the On position, the electronic engine control (EEC) power relay energizes, providing current to the fuel-pump relay and a timing circuit in the EEC module. If the RPM signal is not received by the PCM within one second, within about one second, the timing circuit opens the ground circuit to de-energize the fuel-pump relay and shut down the pump. This circuit is designed to prepressurize the system. Once the key is turned to the start position, power to the pump is sent through the relay and inertia switch.

The inertia switch opens under a specified impact, such as a collision. When the switch opens, current to the pump shuts off because the fuel-pump relay will not energize. The switch must be reset manually by opening the trunk and depressing the reset button before current flow to the pump can be restored. ● **SEE FIGURE 77–17** for a schematic of a typical fuel system that uses an inertia switch in the power feed circuit to the electric fuel pump.

PUMP PULSATION DAMPENING

Some manufacturers use an **accumulator** in the system to reduce pressure pulses and noise. Others use a pulsator located at the outlet of the fuel pump to absorb pressure pulsations that are created by the pump. These pulsators are usually used on roller vane pumps and are a source of many internal fuel leaks. ● **SEE FIGURE 77–18.**

NOTE: Some experts suggest that the pulsator be removed and replaced with a standard section of fuel line to prevent the loss of fuel pressure that results when the connections on the pulsator loosen and leak fuel back into the tank.

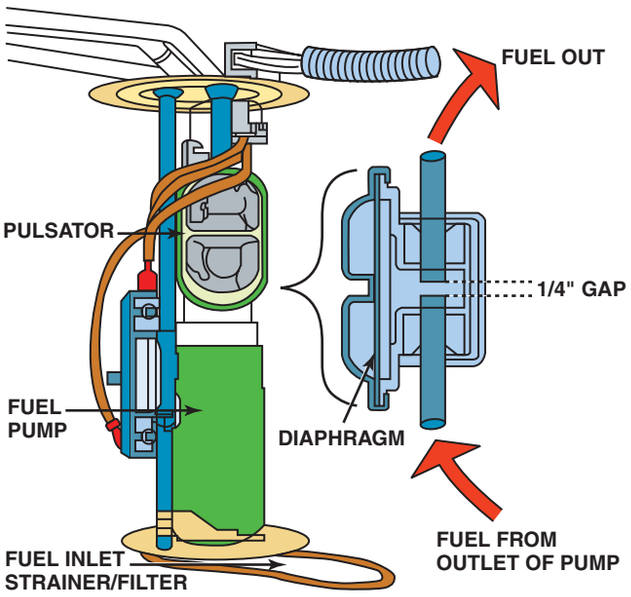


FIGURE 77–18 A typical fuel pulsator used mostly with roller vane-type pumps to help even out the pulsation in pressure that can cause noise.

VARIABLE SPEED PUMPS

Another way to help reduce noise, current draw, and pump wear is to reduce the speed of the pump when less than maximum output is required. Pump speed and pressure can be regulated by controlling the voltage supplied to the pump with a resistor switched into the circuit, or by letting the engine-control

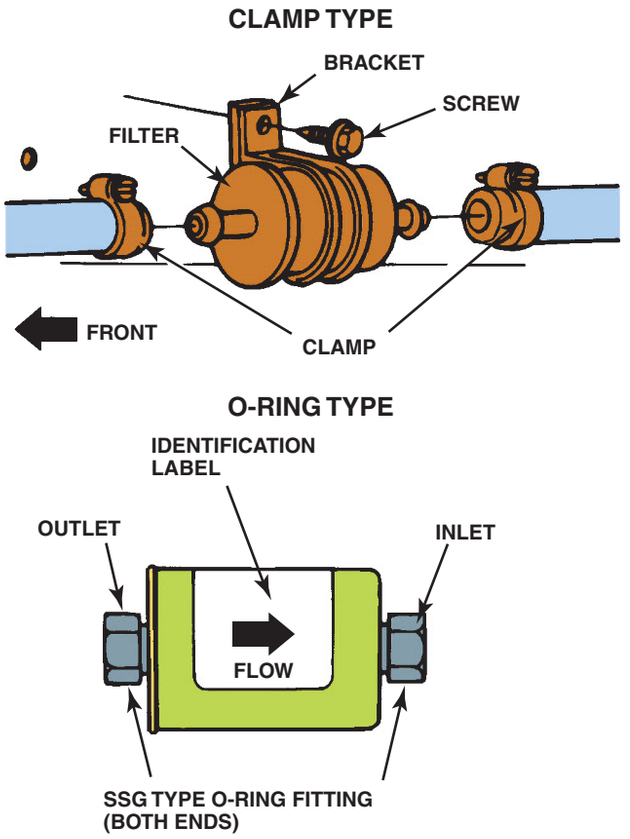


FIGURE 77–19 Inline fuel filters are usually attached to the fuel line with screw clamps or threaded connections. The fuel filter must be installed in the proper direction or a restricted fuel flow can result.

computer pulse-width modulate (PWM) the voltage supply to the pump, through a separate fuel pump driver electronic module. With slower pump speed and pressure, less noise is produced.

FUEL FILTERS

Despite the care generally taken in refining, storing, and delivering gasoline, some impurities get into the automotive fuel system. Fuel filters remove dirt, rust, water, and other contamination from the gasoline before it can reach the fuel injectors. Most fuel filters are designed to filter particles that are 10 to 20 microns or larger in size.

The useful life of many filters is limited, but vehicles that use a returnless-type fuel injection system usually use filters that are part of the fuel pump assembly and do have any specified replacement interval. This means that they should last the life of the vehicle. If fuel filters are not replaced according to the manufacturer's recommendations, they can become clogged and restrict fuel flow.

In addition to using several different types of fuel filters, a single fuel system may contain two or more filters. The inline filter is located in the line between the fuel pump and the throttle body or fuel rail. ● **SEE FIGURE 77–19.** This filter protects the system from contamination, but does not protect the fuel pump. The inline filter usually is a metal or plastic container with a pleated paper element sealed inside.

Fuel filters may be mounted on a bracket on the fender panel, a shock tower, or another convenient place in the engine compartment. They may also be installed under the vehicle near the fuel tank. Fuel filters should be replaced according to the vehicle manufacturer's recommendations, which range from every 30,000 miles (48,000 km) to 100,000 miles (160,000 km) or longer. Fuel filters that are part of the fuel-pump module assemblies usually do not have any specified service interval.

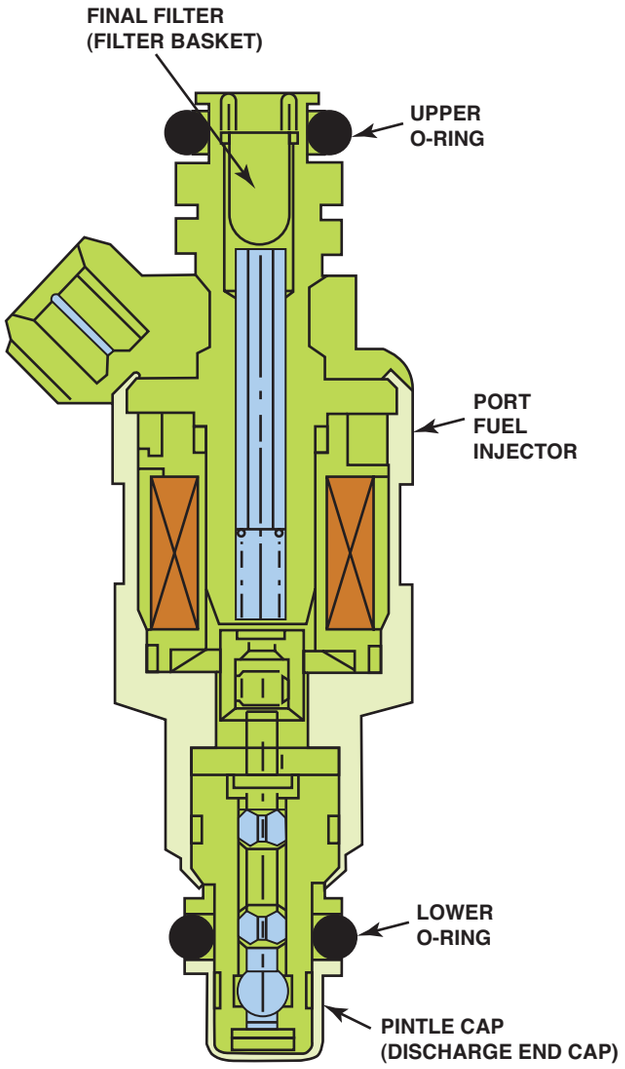


FIGURE 77–20 The final filter, also called a **filter basket,** is the last filter in the fuel system.

TECH TIP

Be Sure That the Fuel Filter Is Installed Correctly

The fuel filter has flow direction and if it is installed backwards, the vehicle will most likely have a restricted exhaust (low power at higher engine speeds and loads).

All injectors, throttle body or port, are fitted with one or more filter screens or strainers to remove any particles (generally 10 microns or 0.00039 in.) that might have passed through the other filters. These screens, which surround the fuel inlet, are on the side of throttle-body injectors and are inserted in the top of port injectors. ● **SEE FIGURE 77–20.**



(a)



(b)

FIGURE 77–21 (a) A funnel helps in hearing if the electric fuel pump inside the gas tank is working. (b) If the pump is not running, check the wiring and current flow before going through the process of dropping the fuel tank to remove the pump.

TECH TIP

The Ear Test

No, this is not a test of your hearing, but rather using your ear to check that the electric fuel pump is operating. The electric fuel pump inside the fuel tank is often difficult to hear running, especially in a noisy shop environment. A commonly used trick to better hear the pump is to use a funnel in the fuel filter neck. ● **SEE FIGURE 77–21.**

FUEL-PUMP TESTING

Fuel-pump testing includes many different tests and procedures. Even though a fuel pump can pass one test, it does not mean that there is not a fuel-pump problem. For example, if the pump motor is rotating slower than normal, it may be able to produce the specified pressure, but not enough volume to meet the needs of the engine while operating under a heavy load.

TESTING FUEL-PUMP PRESSURE Fuel-pump-regulated pressure has become more important than ever with a more exact fuel control. Although an increase in fuel pressure does increase fuel volume to the engine, this is *not* the preferred method to add additional fuel as some units will not open correctly at the increased fuel pressure. On the other side of the discussion, many newer engines will not start when fuel pressure is just a few PSI low. Correct fuel pressure is very important for proper engine operation. Most fuel-injection systems operate at either a low pressure of about 10 PSI or a high pressure of between 35 and 45 PSI.

Normal Operating Pressure	(PSI)	Maximum Pump Pressure (PSI)
Low-pressure TBI units	9–13	18–20
High-pressure TBI units	25–35	50–70
Port fuel-injection systems	35–45	70–90
Central port fuel injection (GM)	55–64	90–110

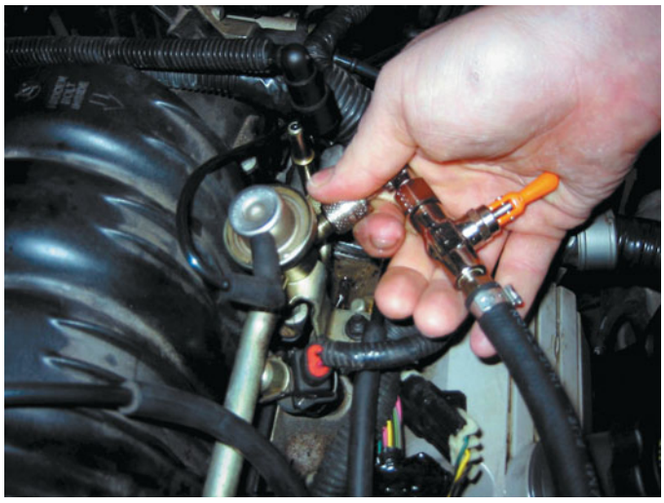


FIGURE 77–22 The Schrader valve on this General Motors 3800 V-6 is located next to the fuel-pressure regulator.

TECH TIP

The Rubber Mallet Trick

Often a no-start condition is due to an inoperative electric fuel pump. A common trick is to tap on the bottom of the fuel tank with a rubber mallet in an attempt to jar the pump motor enough to work. Instead of pushing a vehicle into the shop, simply tap on the fuel tank and attempt to start the engine. This is not a repair, but rather a confirmation that the fuel pump does indeed require replacement.

In both types of systems, maximum fuel-pump pressure is about double the normal operating pressure to ensure that a continuous flow of cool fuel is being supplied to the injector(s) to help prevent vapor from forming in the fuel system. Although vapor or foaming in a fuel system can greatly affect engine operation, the cooling and lubricating flow of the fuel must be maintained to ensure the durability of injector nozzles.

To measure fuel-pump pressure, locate the Schrader valve and attach a fuel-pressure gauge. ● **SEE FIGURE 77–22.**

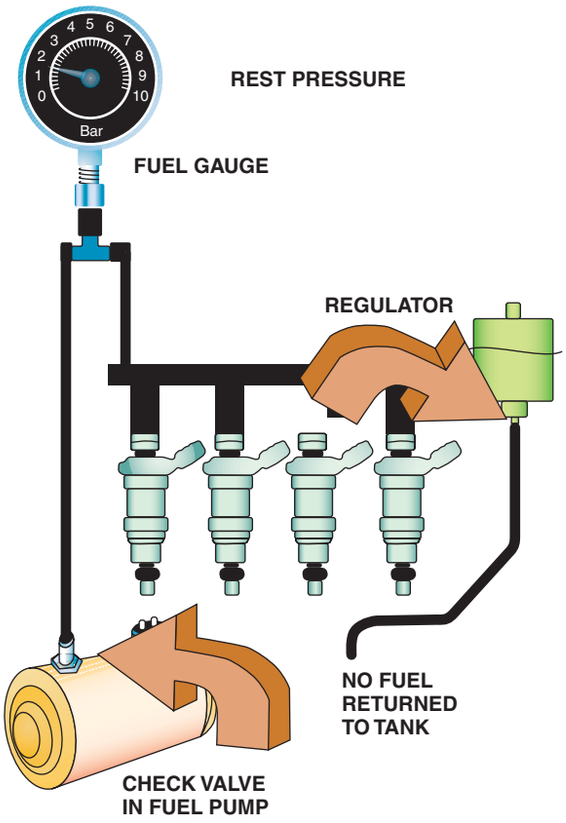


FIGURE 77–23 The fuel system should hold pressure if the system is leak free.

NOTE: Some vehicles, such as those with General Motors TBI fuel-injection systems, require a specific fuel-pressure gauge that connects to the fuel system. Always follow the manufacturers' recommendations and procedures.

REST PRESSURE TEST If the fuel pressure is acceptable, then check the system for leakdown. Observe the pressure gauge after five minutes. ● **SEE FIGURE 77–23.** The pressure should be the same as the initial reading. If not, then the pressure regulator, fuel-pump check valve, or the injectors are leaking.

DYNAMIC PRESSURE TEST To test the pressure dynamically, start the engine. If the pressure is vacuum referenced, then the pressure should change when the throttle is cycled. If it does not, then check the vacuum supply circuit. Remove the vacuum line from the regulator and inspect for any presence of fuel. ● **SEE FIGURE 77–24.** There should never be any fuel present on the vacuum side of the regulator diaphragm. When the engine speed is increased, the pressure reading should remain within the specifications.

TECH TIP

The Fuel-Pressure Stethoscope Test

When the fuel pump is energized and the engine is not running, fuel should be heard flowing back to the fuel tank at the outlet of the fuel-pressure regulator. ● **SEE FIGURE 77–25.** If fuel is heard flowing through the return line, the fuel-pump pressure is higher than the regulator pressure. If no sound of fuel is heard, either the fuel pump or the fuel-pressure regulator is at fault.

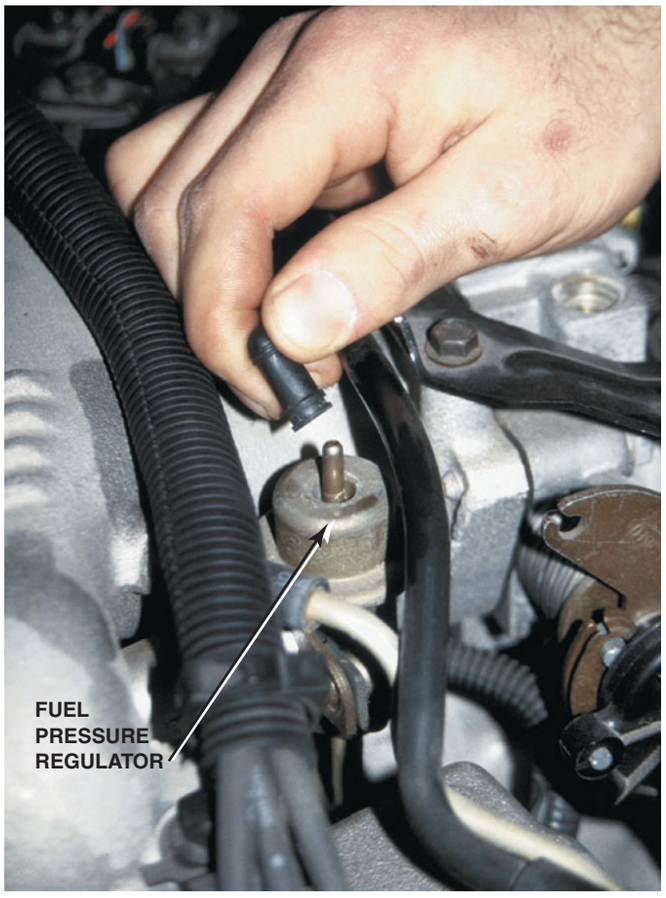


FIGURE 77–24 If the vacuum hose is removed from the fuel-pressure regulator when the engine is running, the fuel pressure should increase. If it does not increase, then the fuel pump is not capable of supplying adequate pressure or the fuel-pressure regulator is defective. If gasoline is visible in the vacuum hose, the regulator is leaking and should be replaced.

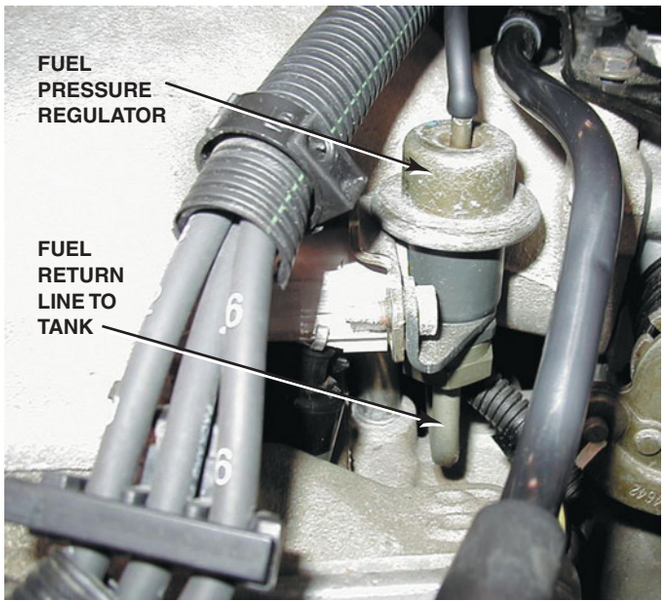


FIGURE 77–25 Fuel should be heard returning to the fuel tank at the fuel return line if the fuel pump and fuel-pressure regulator are functioning correctly.

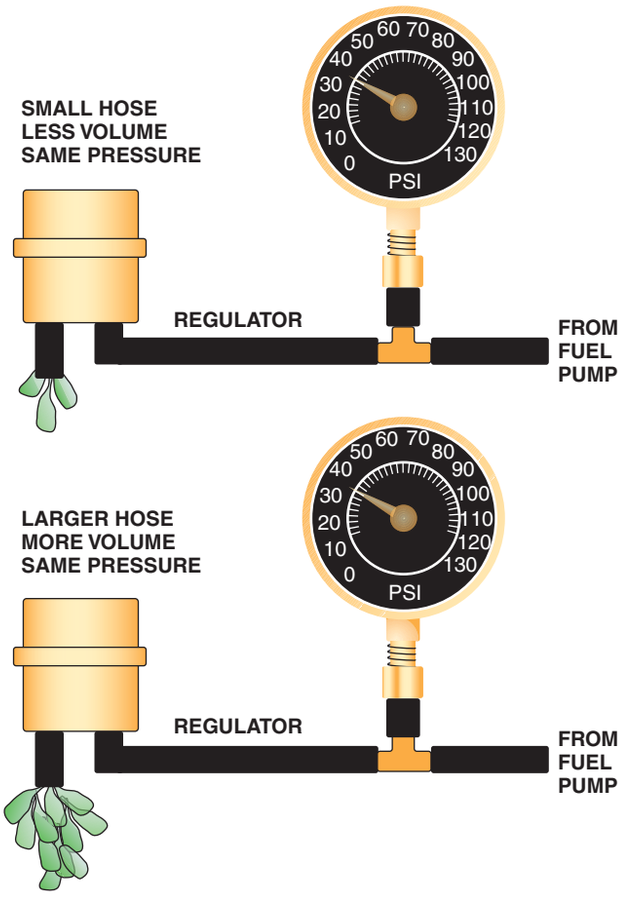


FIGURE 77–26 A fuel-pressure reading does not confirm that there is enough fuel volume for the engine to operate correctly.

Some engines do not use a vacuum-referenced regulator. The running pressure remains constant, which is typical for a mechanical returnless-type fuel system. On these systems, the pressure is higher than on return-type systems to help reduce the formation of fuel vapors in the system.

TESTING FUEL-PUMP VOLUME

Fuel pressure alone is not enough for proper engine operation. ● **SEE FIGURE 77–26.** Sufficient fuel capacity (flow) should be at least 2 pints (1 liter) every 30 seconds or 1 pint in 15 seconds. Fuel flow specifications are usually expressed in gallons per minute. A typical specification would be 0.5 gallons per minute or more. Volume testing is shown in ● **FIGURE 77–27.**

All fuel must be filtered to prevent dirt and impurities from damaging the fuel system components and/or engine. The first filter is inside the gas tank and is usually not replaceable separately but is attached to the fuel pump (if the pump is electric) and/or fuel gauge sending unit. The replaceable fuel filter is usually located between the fuel tank and the fuel rail or inlet to the fuel-injection system. Most vehicle manufacturers state in service information when to replace the fuel filter. Most newer vehicles, that use returnless-type fuel injection systems, do not have replaceable filters as they are built into the fuel pump module assembly. (Check the vehicle manufacturers' recommendations for exact time and mileage intervals.)

If the fuel filter becomes partially clogged, the following are likely to occur:

1. There will be low power at higher engine speeds. The vehicle usually will not go faster than a certain speed (engine acts as if it has a built-in speed governor).
2. The engine will cut out or miss on acceleration, especially when climbing hills or during heavy-load acceleration.



FIGURE 77–27 A fuel system tester connected in series in the fuel system so all of the fuel used flows through the meter which displays the rate-of-flow and the fuel pressure.

TECH TIP

Quick and Easy Fuel Volume Test

Testing for pump volume involves using a specialized tester or a fuel-pressure gauge equipped with a hose to allow the fuel to be drawn from the system into a container with volume markings to allow for a volume measurement. This test can be hazardous because of flammable gasoline vapors. An alternative test involves connecting a fuel-pressure gauge to the system with the following steps:

STEP 1 Start the engine and observe the fuel-pressure gauge. The reading should be within factory specifications (typically between 35 PSI and 45 PSI).

STEP 2 Remove the hose from the fuel-pressure regulator. The pressure should increase if the system uses a demand-type regulator.

STEP 3 Rapidly accelerate the engine while watching the fuel-pressure gauge. If the fuel volume is okay, the fuel pressure should not drop more than 2 PSI. If the fuel pressure drops more than 2 PSI, replace the fuel filter and retest.

STEP 4 After replacing the fuel filter, accelerate the engine and observe the pressure gauge. If the pressure drops more than 2 PSI, replace the fuel pump.

NOTE: The fuel pump could still be delivering less than the specified volume of fuel, but as long as the volume needed by the engine is met, the pressure will not drop. If, however, the vehicle is pulling a heavy load, the demand for fuel volume may exceed the capacity of the pump.

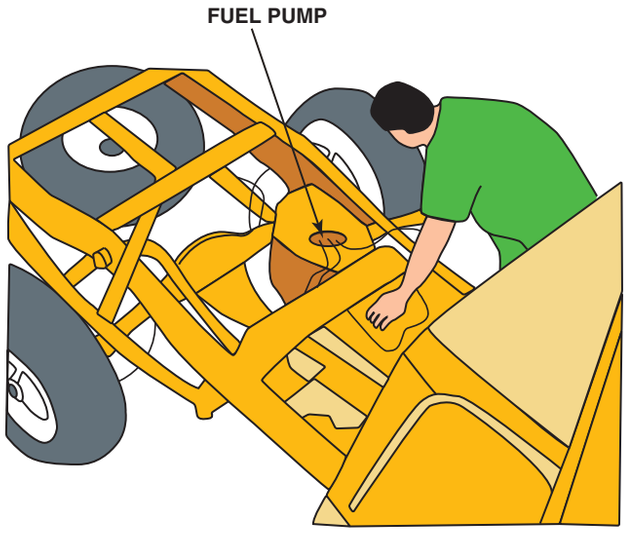


FIGURE 77–28 Removing the bed from a pickup truck makes gaining access to the fuel pump a lot easier.

TECH TIP

Remove the Bed to Save Time?

The electric fuel pump is easier to replace on many General Motors pickup trucks if the bed is removed. Access to the top of the fuel tank, where the access hole is located, for the removal of the fuel tank sender unit and pump is restricted by the bottom of the pickup truck bed. Rather than drop the tank, it is often much easier to use an engine hoist or a couple of other technicians to lift the bed from the frame after removing only a few fasteners. ● **SEE FIGURE 77–28.**

CAUTION: Be sure to clean around the fuel pump opening so that dirt or debris does not enter the tank when the fuel pump is removed.

A weak or defective fuel pump can also be the cause of the symptoms just listed. If an electric fuel pump for a fuel-injected engine becomes weak, additional problems include the following:

1. The engine may be hard to start.
2. There may be a rough idle and stalling.
3. There may be erratic shifting of the automatic transmission as a result of engine missing due to lack of fuel-pump pressure and/or volume.

CAUTION: Be certain to consult the vehicle manufacturers' recommended service and testing procedures before attempting to test or replace any component of a high-pressure electronic fuel-injection system.

FUEL-PUMP CURRENT DRAW TEST

Another test that can and should be performed on a fuel pump is to measure the current draw in amperes. This test is most often performed by connecting a digital multimeter set to read DC amperes and test the current draw. ● **SEE FIGURE 77–29** for the hookup for vehicles equipped with a fuel-pump relay. Compare the reading to factory specifications. See the chart for an example of typical fuel-pump current draw readings.

NOTE: Testing the current draw of an electric fuel pump may not indicate whether the pump is good. A pump that is not rotating may draw normal current.

Using a mini clamp-on ammeter is a quick and easy way to measure fuel pump current. Clamp the inductive probe around a wire to the fuel pump or add a fused jumper wire to replace the fuel pump fuse. Start the engine and read the meter display.

Fuel-Pump Current Draw Table

Amperage Reading	Expected Value	Amperage Too High	Amperage Too Low
Throttle-Body Fuel-Injection Engines	2 to 5 amps	• Check the fuel filter. • Check for restrictions in other fuel line areas. • Replace the fuel pump.	• Check for a high-resistance connection. • Check for a high-resistance ground fault. • Replace the fuel pump.
Port Fuel-Injection Engines	4 to 8 amps	• Check the fuel filter. • Check for restrictions in other fuel line areas. • Replace the fuel pump.	• Check for a high-resistance connection. • Check for a high-resistance ground fault. • Replace the fuel pump.
Turbo Engines	6 to 10 amps	• Check the fuel filter. • Check for restrictions in other fuel line areas. • Replace the fuel pump.	• Check for a high-resistance connection. • Check for a high-resistance ground fault. • Replace the fuel pump.
GM CPI Truck Engines	8 to 12 amps	• Check the fuel filter. • Check for restrictions in other fuel line areas. • Replace the fuel pump.	• Check for a high-resistance connection. • Check for a high-resistance ground fault. • Replace the fuel pump.

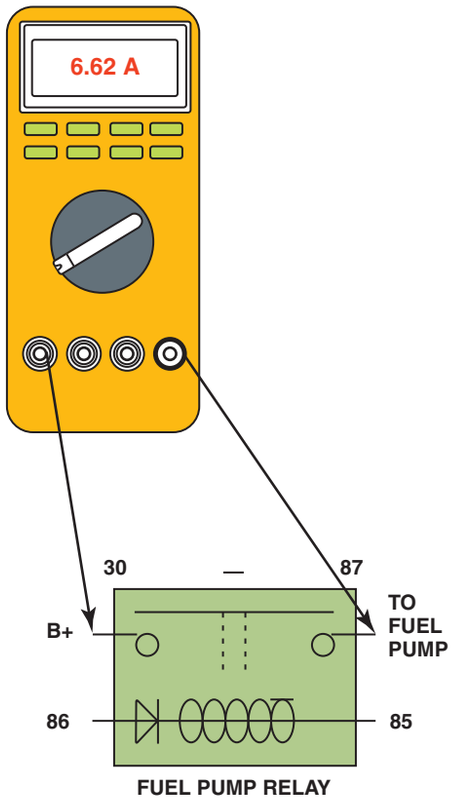


FIGURE 77–29 Hookup for testing fuel-pump current draw on any vehicle equipped with a fuel-pump relay.

FUEL-PUMP REPLACEMENT

The following recommendations should be followed whenever replacing an electric fuel pump:

- Clean around the fuel pump retainer area before removing the fuel pump assembly.
- The fuel-pump strainer (sock) should be replaced with the new pump.
- If the original pump had a defector shield, it should always be used to prevent fuel return bubbles from blocking the inlet to the pump.
- Always check the interior of the fuel tank for evidence of contamination or dirt.
- Double-check that the replacement pump is correct for the application.
- Check that the wiring and electrical connectors are clean and tight.

Fuel Supply-Related Symptom Guide

Problem	Possible Causes
Pressure too high after engine start-up.	1. Defective fuel-pressure regulator 2. Restricted fuel return line 3. Excessive system voltage 4. Wrong fuel pump
Pressure too low after engine start-up.	1. Stuck-open pressure regulator 2. Low voltage 3. Poor ground 4. Plugged fuel filter 5. Faulty inline fuel pump 6. Faulty in-tank fuel pump 7. Partially clogged filter sock 8. Faulty hose coupling 9. Leaking fuel line 10. Wrong fuel pump 11. Leaking pulsator 12. Restricted accumulator 13. Faulty pump check valves 14. Faulty pump installation
Pressure drops off with key on/engine off. With key off, the pressure does not hold.	1. Leaky pulsator 2. Leaking fuel-pump coupling hose 3. Faulty fuel pump (check valves) 4. Faulty pressure regulator 5. Leaking fuel injector 6. Faulty installation 7. Lines leaking

REVIEW QUESTIONS

1. What are the two materials used to construct fuel tanks?
2. What are the three most commonly used pump designs?
3. What is the proper way to disconnect and connect plastic fuel line connections?
4. Where are the fuel filters located in the fuel system?
5. What accident and rollover devices are installed in a fuel delivery system?
6. What three methods can be used to test a fuel pump?

CHAPTER QUIZ

1. The first fuel filter in the sock inside the fuel tank normally filters particles larger than _____.
   a. 0.001 to 0.003 in.
   b. 0.010 to 0.030 in.
   c. 10 to 20 microns
   d. 70 to 100 microns
2. If it is tripped, which type of safety device will keep the electric fuel pump from operating?
   a. Rollover valve
   b. Inertia switch
   c. Anti-siphoning valve
   d. Check valve

3. Fuel lines are constructed from _____.
   a. Seamless steel tubing
   b. Nylon plastic
   c. Copper and/or aluminum tubing
   d. Both a and b are used

4. What prevents the fuel pump inside the fuel tank from catching the gasoline on fire?
   a. Electricity is not used to power the pump
   b. No air is around the motor brushes
   c. Gasoline is hard to ignite in a closed space
   d. All of the above

5. A good fuel pump should be able to supply how much fuel per minute?
   a. 1/4 pint **c.** 1 pint
   b. 1/2 pint **d.** 0.5 to 0.8 gallons

6. Technician A says that fuel pump modules are spring-loaded so that they can be compressed to fit into the opening. Technician B says that they are spring-loaded to allow for expansion and contraction of plastic fuel tanks. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

7. Most fuel filters are designed to remove particles larger than _____.
   a. 10 microns **c.** 70 microns
   b. 20 microns **d.** 100 microns

8. The amperage draw of an electric fuel pump is higher than specified. All of the following are possible causes *except:*
   a. Corroded electrical connections at the pump motor
   b. Clogged fuel filter
   c. Restriction in the fuel line
   d. Defective fuel pump

9. A fuel pump is being replaced for the third time. Technician A says that the gasoline could be contaminated. Technician B says that wiring to the pump could be corroded. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B

10. A fuel filter has been accidentally installed backwards. What is the most likely result?
   a. Nothing will be noticed
   b. Reduced fuel economy
   c. Lower power at higher engine speeds and loads
   d. Fuel system pulsation noises may be heard

chapter 78

FUEL-INJECTION COMPONENTS AND OPERATION

OBJECTIVES: **After studying Chapter 78, the reader will be able to:** • Prepare for ASE Engine Performance (A8) certification test content area "C" (Fuel, Air Induction, and Exhaust Systems Diagnosis and Repair). • Describe how a port fuel-injection system works. • Describe the fuel injection modes of operation. • Discuss central port injection (CPI) systems. • Explain how a stepper motor works. • Discuss the purpose and function of the fuel-pressure regulator. • List the types of fuel-injection systems.

KEY TERMS: Demand delivery system (DDS) 882 • Electronic air control (EAC) 885 • Electronic returnless fuel system (ERFS) 881 • Flare 885 • Fuel rail 882 • Gang fired 878 • Idle speed control (ISC) motor 885 • Mechanical returnless fuel system (MRFS) 881 • Nonchecking 880 • Port fuel-injection 876 • Pressure control valve (PCV) 882 • Pressure vent valve (PVV) 881 • Sequential fuel injection (SFI) 878 • Throttle-body injection (TBI) 876

ELECTRONIC FUEL-INJECTION OPERATION

Electronic fuel-injection systems use the powertrain control module (PCM) to control the operation of fuel injectors and other functions based on information sent to the PCM from the various sensors. Most electronic fuel-injection systems share the following:

1. Electric fuel pump (usually located inside the fuel tank)
2. Fuel-pump relay (usually controlled by the computer)
3. Fuel-pressure regulator (mechanically operated spring-loaded rubber diaphragm maintains proper fuel pressure)
4. Fuel-injector nozzle or nozzles

SEE FIGURE 78–1. Most electronic fuel-injection systems use the computer to control these aspects of their operation:

1. **Pulsing the fuel injectors on and off.** The longer the injectors are held open, the greater the amount of fuel injected into the cylinder.
2. **Operating the fuel pump relay circuit.** The computer usually controls the operation of the electric fuel pump located inside (or near) the fuel tank. The computer uses signals from the ignition switch and RPM signals from the ignition module or system to energize the fuel-pump relay circuit.

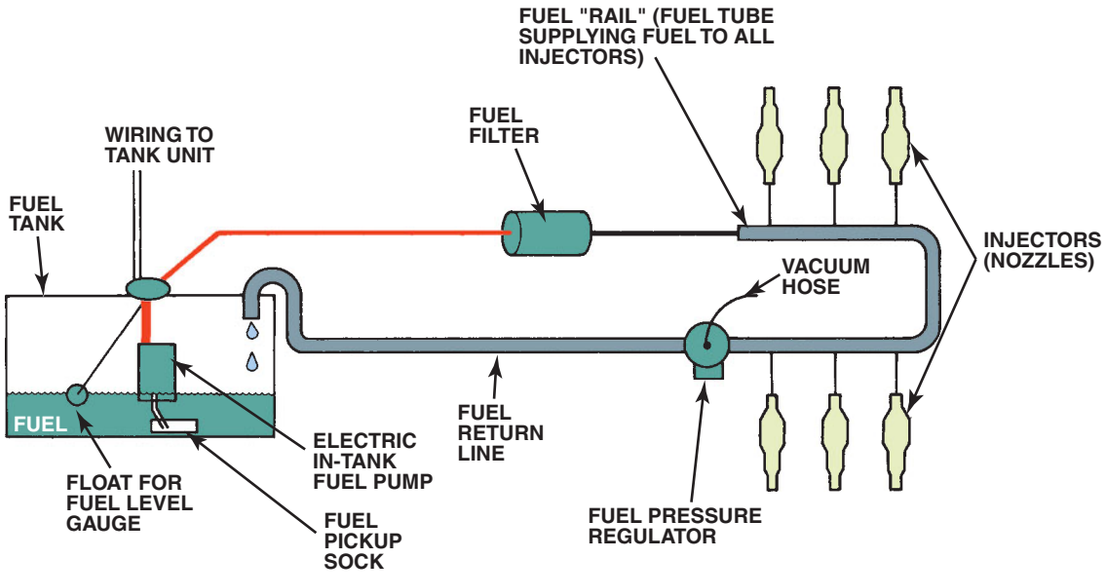


FIGURE 78–1 Typical port fuel-injection system, indicating the location of various components. Notice that the fuel-pressure regulator is located on the fuel return side of the system. The computer does not control fuel pressure. But does control the operation of the electric fuel pump (on most systems) and the pulsing on and off of the injectors.



FIGURE 78–2 A dual-nozzle TBI unit on a Chevrolet 4.3-L V-6 engine. The fuel is squirted above the throttle plate where the fuel mixes with air before entering the intake manifold.

NOTE: This is a safety feature, because if the engine stalls and the tachometer (engine speed) signal is lost, the computer will shut off (de-energize) the fuel-pump relay and stop the fuel pump.

Computer-controlled fuel-injection systems are normally reliable systems if the proper service procedures are followed. Fuel-injection systems use the gasoline flowing through the injectors to lubricate and cool the injector electrical windings and pintle valves.

NOTE: The fuel does not actually make contact with the electrical windings because the injectors have O-rings at the top and bottom of the winding spool to keep fuel out.

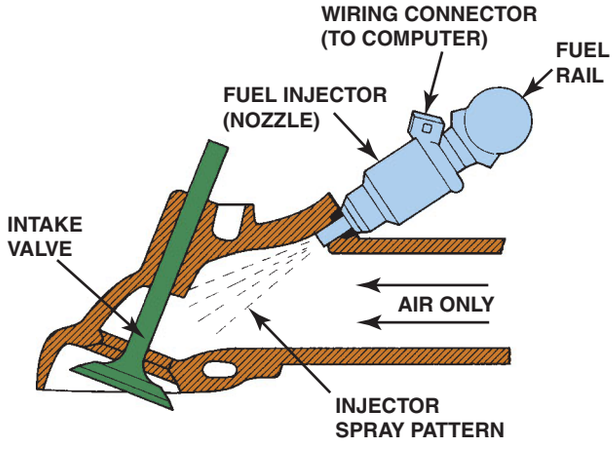


FIGURE 78–3 A typical port fuel-injection system squirts fuel into the low pressure (vacuum) of the intake manifold, about 2 to 3 in. (70 to 100 mm) from the intake valve.

There are two types of electronic fuel-injection systems:

- **Throttle-body-injection (TBI)** type. A TBI system delivers fuel from a nozzle(s) into the air above the throttle plate. ● **SEE FIGURE 78–2.**
- **Port fuel-injection**-type. A port fuel-injection design uses a nozzle for each cylinder and the fuel is squirted into the intake manifold about 2 to 3 inches (70 to 100 mm) from the intake valve. ● **SEE FIGURE 78–3.**

SPEED-DENSITY FUEL-INJECTION SYSTEMS

Fuel-injection computer systems require a method for measuring the amount of air the engine is breathing in, in order to match the correct fuel delivery. There are two basic methods used:

1. Speed density
2. Mass airflow

TECH TIP

"Two Must-Do's"

For long service life of the fuel system always do the following:

1. Avoid operating the vehicle on a near-empty tank of fuel. The water or alcohol that may be in the tank becomes more concentrated when the fuel level is low. Dirt that settles near the bottom of the fuel tank can be drawn through the fuel system and cause damage to the pump and injector nozzles.
2. Replace the fuel filter at regular service intervals.

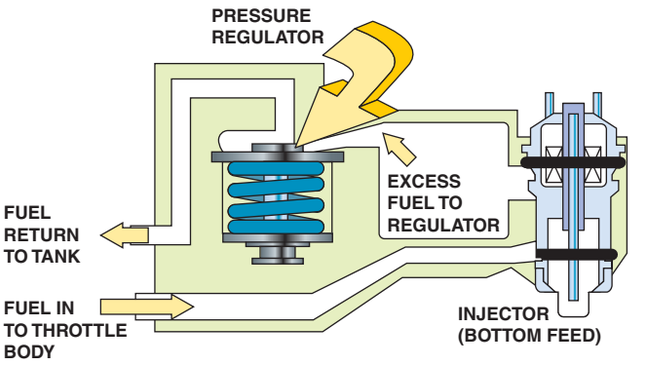


FIGURE 78–4 The tension of the spring in the fuel-pressure regulator determines the operating pressure on a throttle-body fuel-injection unit.

The speed-density method does not require an air quantity sensor, but rather calculates the amount of fuel required by the engine. The computer uses information from sensors such as the MAP and TP to calculate the needed amount of fuel.

- **MAP sensor.** The value of the intake (inlet) manifold pressure (vacuum) is a direct indication of engine load.
- **TP sensor.** The position of the throttle plate and its rate of change are used as part of the equation to calculate the proper amount of fuel to inject.
- **Temperature sensors.** Both engine coolant temperature (ECT) and intake air temperature (IAT) are used to calculate the density of the air and the need of the engine for fuel. A cold engine (low-coolant temperature) requires a richer air–fuel mixture than a warm engine.

On speed-density systems, the computer calculates the amount of air in each cylinder by using manifold pressure and engine RPM. The amount of air in each cylinder is the major factor in determining the amount of fuel needed. Other sensors provide information to modify the fuel requirements. The formula used to determine the injector pulse width (PW) in milliseconds (ms) is:

Injector pulse width = MAP/BARO × RPM/maximum RPM

The formula is modified by values from other sensors, including:

- Throttle position (TP)
- Engine coolant temperature (ECT)
- Intake air temperature (IAT)
- Oxygen sensor voltage (O2S)
- Adaptive memory

A fuel injector delivers atomized fuel into the airstream where it is instantly vaporized. All throttle-body (TB) fuel-injection systems and many multipoint (port) injection systems use the speed-density method of fuel calculation.

MASS AIRFLOW FUEL-INJECTION SYSTEMS

The formula used by fuel-injection systems that use a mass airflow (MAF) sensor to calculate the injection base pulse width is:

Injector pulse width = airflow/RPM

The formula is modified by other sensor values such as:

- Throttle position
- Engine coolant temperature
- Barometric pressure
- Adaptive memory

NOTE: Many four-cylinder engines do not use a MAF sensor because, due to the time interval between intake events, some reverse airflow can occur in the intake manifold. The MAF sensor would "read" this flow of air as being additional air entering the engine, giving the PCM incorrect airflow information. Therefore, most four-cylinder engines use the speed-density method of fuel control.

THROTTLE-BODY INJECTION

The computer controls injector pulses in one of two ways:

- Synchronized
- Nonsynchronized

If the system uses a synchronized mode, the injector pulses once for each distributor reference pulse. In some vehicles, when dual injectors are used in a synchronized system, the injectors pulse alternately. In a nonsynchronized system, the injectors are pulsed once during a given period (which varies according to calibration) completely independent of distributor reference pulses.

The injector always opens the same distance, and the fuel pressure is maintained at a controlled value by the pressure regulator. The regulators used on throttle-body injection systems are not connected to a vacuum like many port fuel-injection systems. The strength of the spring inside the regulator determines at what pressure the valve is unseated, sending the fuel back to the tank and lowering the pressure. **SEE FIGURE 78–4.** The amount of fuel delivered by the injector depends on the amount of time (on-time) that the nozzle is open. This is the injector pulse width—the on-time in milliseconds that the nozzle is open.

The PCM commands a variety of pulse widths to supply the amount of fuel that an engine needs at any specific moment.

- A long pulse width delivers more fuel.
- A short pulse width delivers less fuel.

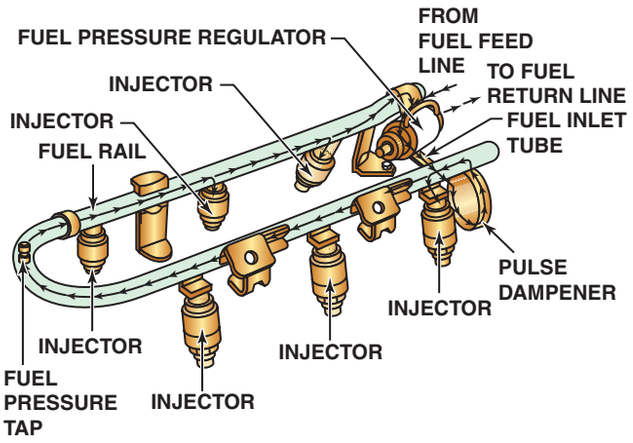


FIGURE 78–5 The injectors receive fuel and are supported by the fuel rail.

FREQUENTLY ASKED QUESTION

How Do the Sensors Affect the Pulse Width?

The base pulse width of a fuel-injection system is primarily determined by the value of the MAF or MAP sensor and engine speed (RPM). However, the PCM relies on the input from many other sensors to modify the base pulse width as needed. For example,

- **TP Sensor.** This sensor causes the PCM to command up to 500% (5 times) the base pulse width if the accelerator pedal is depressed rapidly to the floor. It can also reduce the pulse width by about 70% if the throttle is rapidly closed.
- **ECT.** The value of this sensor determines the temperature of the engine coolant, helps determine the base pulse width, and can account for up to 60% of the determining factors.
- **BARO.** The BARO sensor compensates for altitude and adds up to about 10% under high-pressure conditions and subtracts as much as 50% from the base pulse width at high altitudes.
- **IAT.** The intake air temperature is used to modify the base pulse width based on the temperature of the air entering the engine. It is usually capable of adding as much as 20% if very cold air is entering the engine or reduce the pulse width by up to 20% if very hot air is entering the engine.
- **O2S.** This is one of the main modifiers to the base pulse width and can add or subtract up to about 20% to 25% or more, depending on the oxygen sensor activity.

PORT-FUEL INJECTION

The advantages of port fuel-injection design also are related to characteristics of intake manifolds:

- Fuel distribution is equal to all cylinders because each cylinder has its own injector. ● **SEE FIGURE 78–5.**
- The fuel is injected almost directly into the combustion chamber, so there is no chance for it to condense on the walls of a cold intake manifold.

FREQUENTLY ASKED QUESTION

How Can It Be Determined If the Injection System Is Sequential?

Look at the color of the wires at the injectors. If a sequentially fired injector is used, then one wire color (the pulse wire) will be a different color for each injector. The other wire is usually the same color because all injectors receive voltage from some source. If a group- or batch-fired injection system is being used, then the wire colors will be the same for the injectors that are group fired. For example, a V-6 group-fired engine will have three injectors with a pink and blue wire (power and pulse) and the other three will have pink and green wires.

- Because the manifold does not have to carry fuel to properly position a TBI unit, it can be shaped and sized to tune the intake airflow to achieve specific engine performance characteristics.

An EFI injector is simply a specialized solenoid. ● **SEE FIGURE 78–6.** It has an armature winding to create a magnetic field, and a needle (pintle), a disc, or a ball valve. A spring holds the needle, disc, or ball closed against the valve seat, and when energized, the armature winding pulls open the valve when it receives a current pulse from the powertrain control module (PCM). When the solenoid is energized, it unseats the valve to inject fuel.

Electronic fuel-injection systems use a solenoid-operated injector to spray atomized fuel in timed pulses into the manifold or near the intake valve. ● **SEE FIGURE 78–7.** Injectors may be sequenced and fired in one of several ways, but their pulse width is determined and controlled by the engine computer.

Port systems have an injector for each cylinder, but they do not all fire the injectors in the same way. Domestic systems use one of three ways to trigger the injectors:

- Grouped double-fire
- Simultaneous double-fire
- Sequential

GROUPED DOUBLE-FIRE This system divides the injectors into two equalized groups. The groups fire alternately; each group fires once each crankshaft revolution, or twice per four-stroke cycle. The fuel injected remains near the intake valve and enters the engine when the valve opens. This method of pulsing injectors in groups is sometimes called **gang fired.**

SIMULTANEOUS DOUBLE-FIRE This design fires all of the injectors at the same time once every engine revolution: two pulses per four-stroke cycle. Many port fuel-injection systems on four-cylinder engines use this pattern of injector firing. It is easier for engineers to program this system and it can make relatively quick adjustments in the air–fuel ratio, but it still requires the intake charge to wait in the manifold for varying lengths of time.

SEQUENTIAL Sequential firing of the injectors according to engine firing order is the most accurate and desirable method of regulating port fuel injection. However, it is also the most complex and expensive to design and manufacture. In this system, the injectors are timed and pulsed individually, much like the spark plugs are sequentially operated in firing order of the engine. This system is often called **sequential fuel injection** or **SFI.** Each cylinder receives one charge every two crankshaft revolutions, just before the intake valve opens.

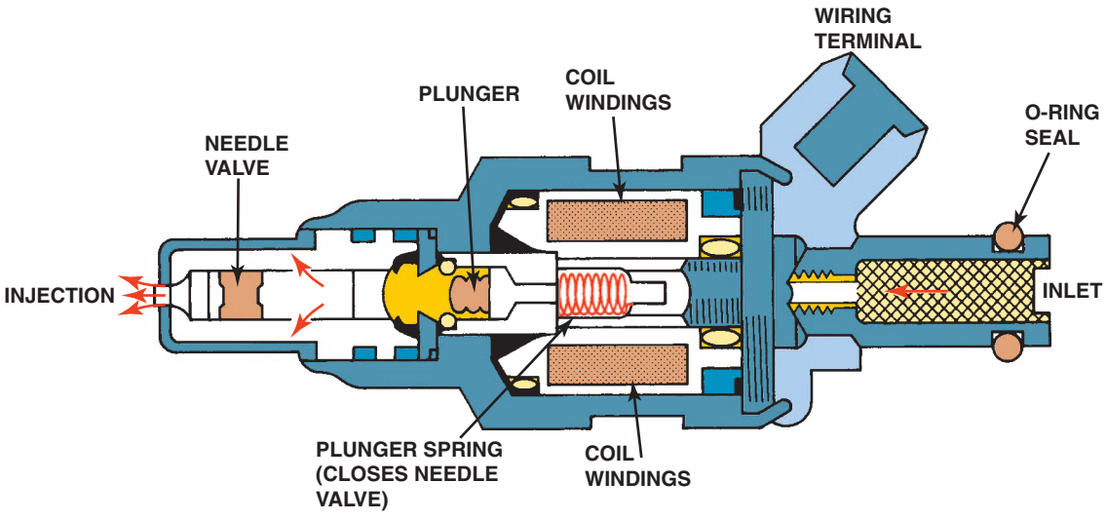


FIGURE 78–6 Cross-section of a typical port fuel-injection nozzle assembly. These injectors are serviced as an assembly only; no part replacement or service is possible except for replacement of external O-ring seals.

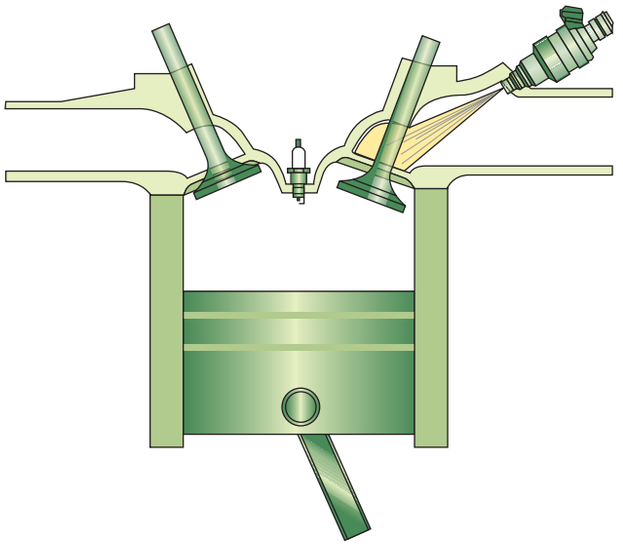


FIGURE 78–7 Port fuel injectors spray atomized fuel into the intake manifold about 3 inches (75 mm) from the intake valve.

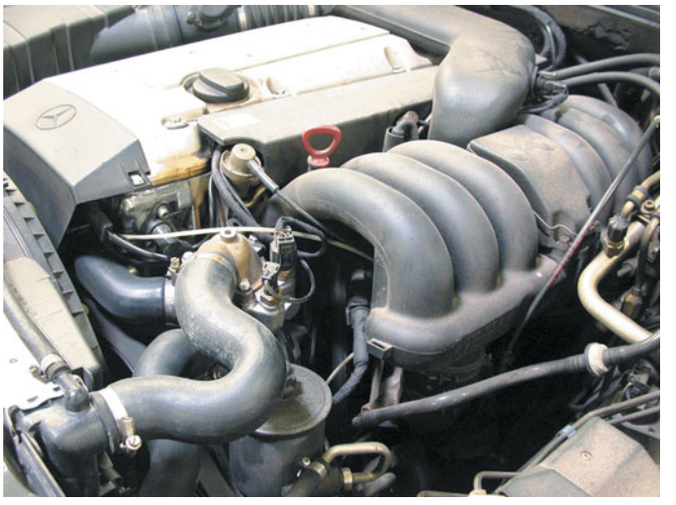


FIGURE 78–8 A port fuel-injected engine that is equipped with long, tuned intake manifold runners.

This means that the mixture is never static in the intake manifold and mixture adjustments can be made almost instantaneously between the firing of one injector and the next. A camshaft position sensor (CMP) signal or a special distributor reference pulse informs the PCM when the No. 1 cylinder is on its compression stroke. If the sensor fails or the reference pulse is interrupted, some injection systems shut down, while others revert to pulsing the injectors simultaneously.

The major advantage of using port injection instead of the simpler throttle-body injection is that the intake manifolds on port fuel-injected engines only contain air, not a mixture of air and fuel. This allows the engine design engineer the opportunity to design long, "tuned" intake-manifold runners that help the engine produce increased torque at low engine speeds. ● **SEE FIGURE 78–8.**

NOTE: Some port fuel-injection systems used on engines with four or more valves per cylinder may use two injectors per cylinder. One injector is used all the time, and the second injector is operated by the computer when high engine speed and high-load conditions are detected by the computer. Typically, the second injector injects fuel into the high-speed intake ports of the manifold. This system permits good low-speed power and throttle responses as well as superior high-speed power.

FUEL-PRESSURE REGULATOR

The pressure regulator and fuel pump work together to maintain the required pressure drop at the injector tips. The fuel-pressure regulator typically consists of a spring-loaded, diaphragm-operated valve in a metal housing.

Fuel-pressure regulators on fuel-return-type fuel-injection systems are installed on the return (downstream) side of the injectors at the end of the fuel rail, or are built into or mounted upon the throttle-body housing. Downstream regulation minimizes fuel-pressure pulsations caused by pressure drop across the injectors as the nozzles open. It also ensures positive fuel pressure at the injectors at all times and holds residual pressure in the lines when the engine is off. On mechanical returnless systems, the regulator is located back at the tank with the fuel filter.

In order for excess fuel (about 80% to 90% of the fuel delivered) to return to the tank, fuel pressure must overcome spring pressure on the spring-loaded diaphragm to uncover the return line to the

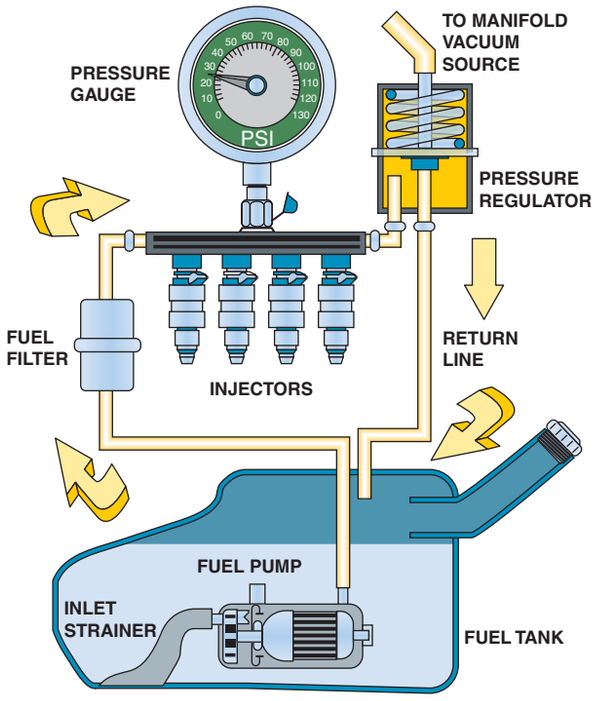


FIGURE 78–9 A typical port fuel-injected system showing a vacuum-controlled fuel-pressure regulator.

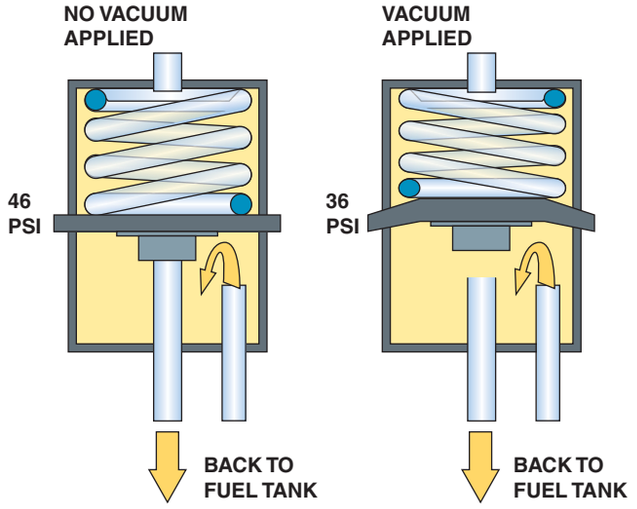


FIGURE 78–10 A typical fuel-pressure regulator that has a spring that exerts 46 pounds of force against the fuel. If 20 inches of vacuum are applied above the spring, the vacuum reduces the force exerted by the spring on the fuel, allowing the fuel to return to the tank at a lower pressure.

tank. This happens when system pressure exceeds operating requirements. With TBI, the regulator is close to the injector tip, so the regulator senses essentially the same air pressure as the injector.

The pressure regulator used in a port fuel-injection system has an intake manifold vacuum line connection on the regulator vacuum chamber. This allows fuel pressure to be modulated by a combination of spring pressure and manifold vacuum acting on the diaphragm. ● **SEE FIGURES 78–9 AND 78–10.**

In both TBI and port fuel-injection systems, the regulator shuts off the return line when the fuel pump is not running. This maintains pressure at the injectors for easy restarting after hot soak as well as reducing vapor lock.

NOTE: Some General Motors throttle-body units do not hold pressure and are called nonchecking.

Port fuel-injection systems generally operate with pressures at the injector of about 30 to 55 PSI (207 to 379 kPa), while TBI systems work with injector pressures of about 10 to 20 PSI (69 to 138 kPa). The difference in system pressures results from the difference in how the systems operate. Since injectors in a TBI system inject the fuel into the airflow at the manifold inlet (above the throttle), there is more time for atomization in the manifold before the air–fuel charge reaches the intake valve. This allows TBI injectors to work at lower pressures than injectors used in a port system.

TECH TIP

Don't Forget the Regulator

Some fuel-pressure regulators contain a 10-micron filter. If this filter becomes clogged, a lack of fuel flow would result. ● **SEE FIGURE 78–11.**

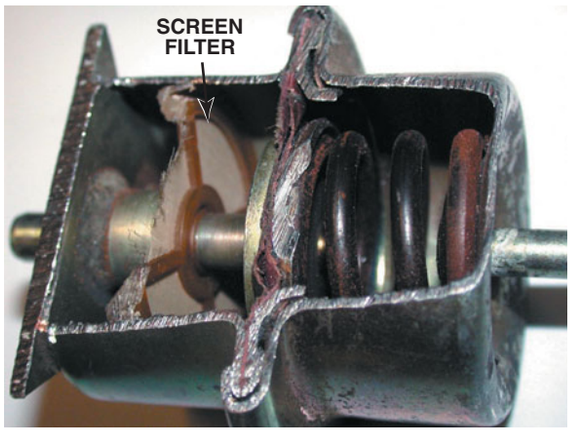


FIGURE 78–11 A lack of fuel flow could be due to a restricted fuel-pressure regulator. Notice the fine screen filter. If this filter were to become clogged, higher than normal fuel pressure would occur.

VACUUM-BIASED FUEL-PRESSURE REGULATOR

The primary reason why many port fuel-injected systems use a vacuum-controlled fuel-pressure regulator is to ensure that there is a constant pressure drop across the injectors. In a throttle-body fuel-injection system, the injector squirts into the atmospheric pressure regardless of the load on the engine. In a port fuel-injected engine, however, the pressure inside the intake manifold changes as the load on the engine increases.

Engine Operating Condition	Intake Manifold Vacuum	Fuel Pressure
Idle or cruise	High	Lower
Heavy load	Low	Higher

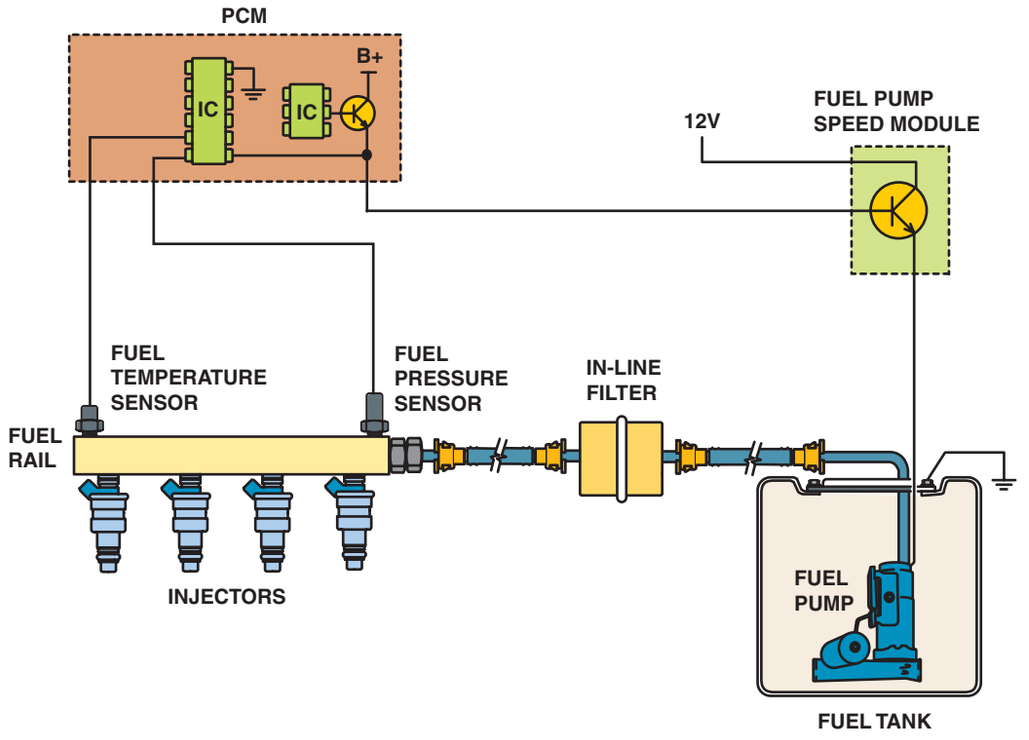


FIGURE 78–12 The fuel-pressure sensor and fuel-temperature sensor are often constructed together in one assembly to help give the PCM the needed data to control the fuel-pump speed.

The computer can best calculate injector pulse width based on all sensors if the pressure drop across the injector is the same under all operating conditions. A vacuum-controlled fuel-pressure regulator allows the equal pressure drop by reducing the force exerted by the regulator spring at high vacuum (low-load condition), yet allowing the full force of the regulator spring to be exerted when the vacuum is low (high-engine-load condition).

ELECTRONIC RETURNLESS FUEL SYSTEM

This system is unique because it does not use a mechanical valve to regulate rail pressure. Fuel pressure at the rail is sensed by a pressure transducer, which sends a low-level signal to a controller. The controller contains logic to calculate a signal to the pump power driver. The power driver contains a high-current transistor that controls the pump speed using pulse width modulation (PWM). This system is called the **electronic returnless fuel system (ERFS).** ● **SEE FIGURE 78–12.** This transducer can be differentially referenced to manifold pressure for closed-loop feedback, correcting and maintaining the output of the pump to a desired rail setting. This system is capable of continuously varying rail pressure as a result of engine vacuum, engine fuel demand, and fuel temperature (as sensed by an external temperature transducer, if necessary). A **pressure vent valve (PVV)** is employed at the tank to relieve overpressure due to thermal expansion of fuel. In addition, a supply-side bleed, by means of an in-tank reservoir using a supply-side jet pump, is necessary for proper pump operation.

MECHANICAL RETURNLESS FUEL SYSTEM

The first production returnless systems employed the **mechanical returnless fuel system (MRFS)** approach. This system has a bypass regulator to control rail pressure that is located in close proximity to the fuel tank. Fuel is sent by the in-tank pump to a chassis-mounted inline filter with excess fuel returning to the tank through a short return line. ● **SEE FIGURE 78–13.** The inline filter may be mounted directly to the tank, thereby eliminating the shortened return line. Supply pressure is regulated on the downstream side of the inline filter to accommodate changing restrictions throughout the filter's service life. This system is limited to constant rail pressure (*CRP) system calibrations, whereas with ERFS, the pressure transducer can be referenced to atmospheric pressure for CRP systems or differentially referenced to intake manifold pressure for constant differential injector pressure (**CIP) systems.

NOTE: *CRP is referenced to atmospheric pressure, has lower operating pressure, and is desirable for calibrations using speed/air density sensing. **CIP is referenced to manifold pressure, varies rail pressure, and is desirable in engines that use mass airflow sensing.

DEMAND DELIVERY SYSTEM (DDS)

Given the experience with both ERFS and MRFS, a need was recognized to develop new returnless technologies that could combine the speed control and constant injector pressure attributes of ERFS

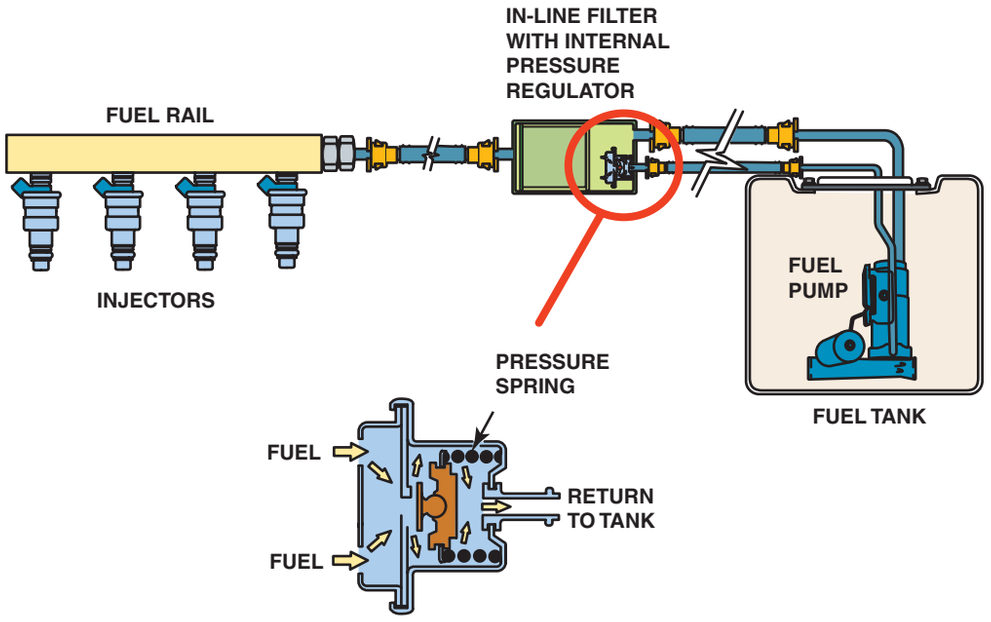


FIGURE 78–13 A mechanical returnless fuel system. The bypass regulator in the fuel filter controls fuel line pressure.

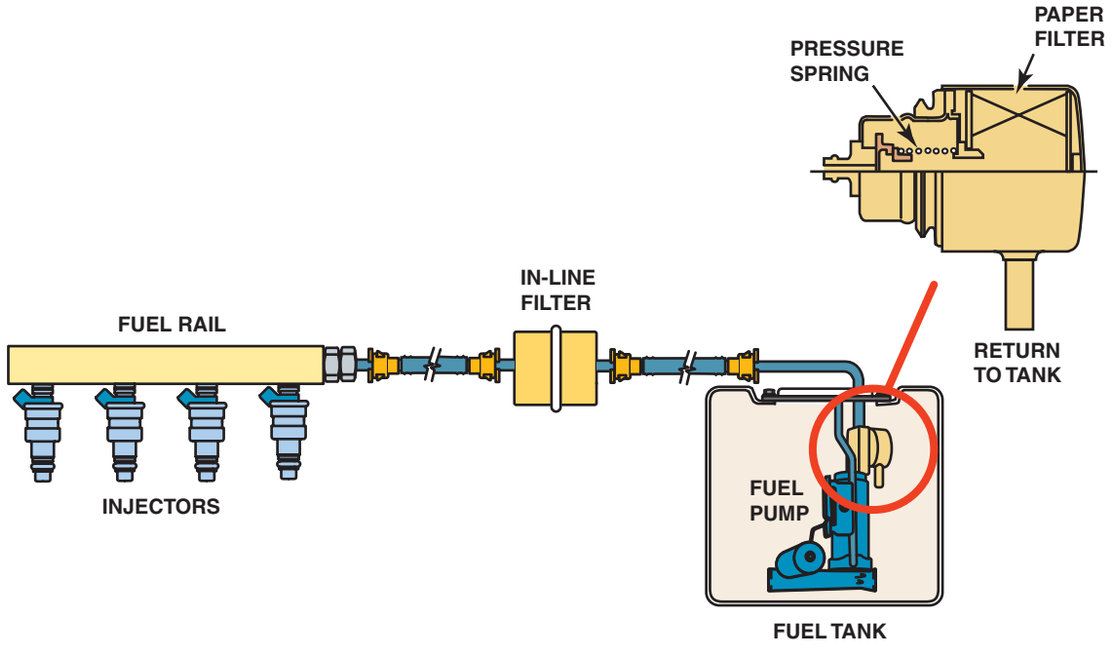


FIGURE 78–14 A demand delivery system uses a fuel pressure regulator attached to the fuel pump assembly.

together with the cost savings, simplicity, and reliability of MRFS. This new technology also needed to address pulsation dampening/hammering and fuel transient response. Therefore, the **demand delivery system (DDS)** technology was developed.

A different form of demand pressure regulator has been applied to the fuel rail. It mounts at the head or port entry and regulates the pressure downstream at the injectors by admitting the precise quantity of fuel into the rail as consumed by the engine. Having demand regulation at the rail improves pressure response to flow transients and provides rail pulsation dampening. A fuel pump and a low-cost, high-performance bypass regulator are used within the appropriate fuel sender. ● **SEE FIGURE 78–14.** They supply a pressure somewhat higher than the required rail set pressure to accommodate dynamic line and filter pressure losses. Electronic pump speed control is accomplished using a smart regulator as an integral flow sensor. A **pressure control valve (PCV)** may also be used and can readily reconfigure an existing design fuel sender into a returnless sender.

? **FREQUENTLY ASKED QUESTION**

Why Are Some Fuel Rails Rectangular Shaped?

A port fuel-injection system uses a pipe or tubes to deliver fuel from the fuel line to the intended fuel injectors. This pipe or tube is called the **fuel rail.** Some vehicle manufacturers construct the fuel rail in a rectangular cross-section. ● **SEE FIGURE 78–15.** The sides of the fuel rail are able to move in and out slightly, thereby acting as a fuel pulsator evening out the pressure pulses created by the opening and closing of the injectors to reduce underhood noise. A round cross-section fuel rail is not able to deform and, as a result, some manufacturers have had to use a separate dampener.



FIGURE 78–15 A rectangular-shaped fuel rail is used to help dampen fuel system pulsations and noise caused by the injectors opening and closing.

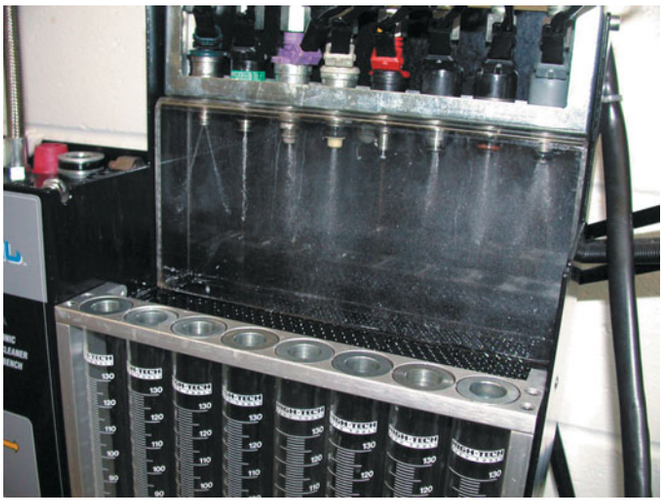


FIGURE 78–17 Each of the eight injectors shown are producing a correct spray pattern for the applications. While all throttle-body injectors spray a conical pattern, most port fuel injections do not.

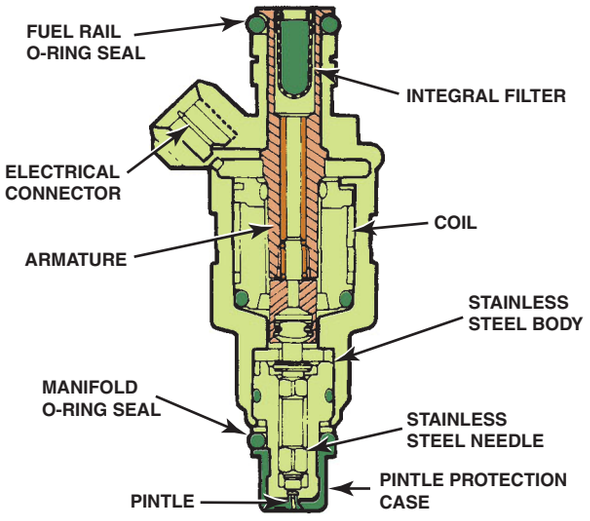


FIGURE 78–16 A multiport fuel injector. Notice that the fuel flows straight through and does not come in contact with the coil windings.

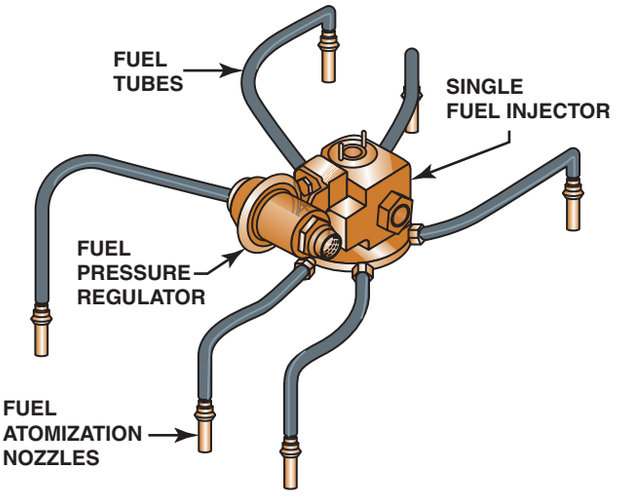


FIGURE 78–18 A central port fuel-injection system.

FUEL INJECTORS

EFI systems use a 12 volt solenoid-operated injectors. ● **SEE FIGURE 78–16.** This electromagnetic device contains an armature and a spring-loaded needle valve or ball valve assembly. When the computer energizes the solenoid, voltage is applied to the solenoid coil until the current reaches a specified level. This permits a quick pull-in of the armature during turn-on. The armature is pulled off of its seat against spring force, allowing fuel to flow through the inlet filter screen to the spray nozzle, where it is sprayed in a pattern that varies with application. ● **SEE FIGURE 78–17.** The injector opens the same amount each time it is energized, so the amount of fuel injected depends on the length of time the injector remains open. By angling the director hole plates, the injector sprays fuel more directly at the intake valves, which further atomizes and vaporizes the fuel before it enters the combustion chamber. PFI injectors typically are a top-feed design in which fuel enters the top of the injector and passes through its entire length to keep it cool before being injected.

Ford introduced two basic designs of deposit-resistant injectors on some engines. The design, manufactured by Bosch, uses a four-hole director/metering plate similar to that used by the Rochester Multec injectors. The design manufactured by Nippondenso uses an internal upstream orifice in the adjusting tube. It also has a re-designed pintle/seat containing a wider tip opening that tolerates deposit buildup without affecting injector performance.

CENTRAL PORT INJECTION

A cross between port fuel injection and throttle-body injection, CPI was introduced in the early 1990s by General Motors. The CPI assembly consists of a single fuel injector, a pressure regulator, and six poppet nozzle assemblies with nozzle tubes. ● **SEE FIGURE 78–18.** The central sequential fuel injection (CSFI) system has six injectors in place of just one used on the CPI unit.

When the injector is energized, its armature lifts off of the six fuel tube seats and pressurized fuel flows through the nozzle tubes to each poppet nozzle. The increased pressure causes each poppet nozzle ball to also lift from its seat, allowing fuel to flow from the nozzle. This

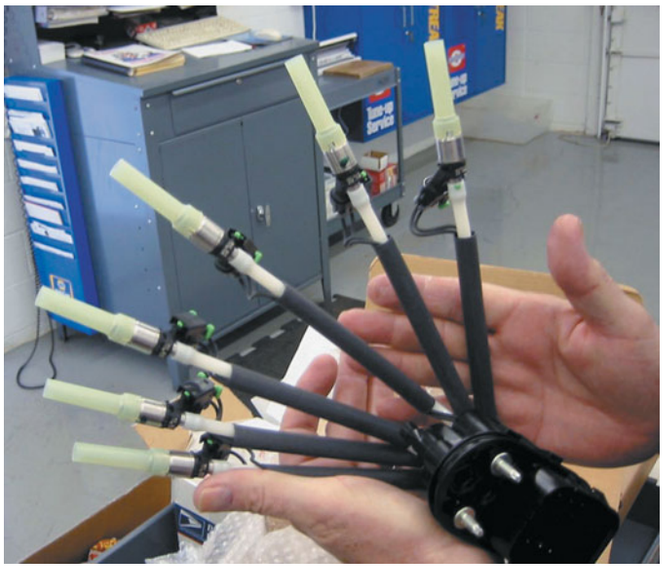


FIGURE 78–19 A factory replacement unit for a CSFI unit that has individual injectors at the ends that go into the intake manifold instead of poppet valves.

FREQUENTLY ASKED QUESTION

How Can the Proper injector Size Be Determined?

Most people want to increase the output of fuel to increase engine performance. Injector sizing can sometimes be a challenge, especially if the size of injector is not known. In most cases, manufacturers publish the rating of injectors, in pounds of fuel per hour (lb/hr). The rate is figured with the injector held open at 3 bars (43.5 PSI). An important consideration is that larger flow injectors have a higher minimum flow rating. Here is a formula to calculate injector sizing when changing the mechanical characteristics of an engine.

Flow rate = hp × BSFC/# of cylinders × maximum duty cycle (% of on-time of the injectors)

- **hp** is the projected horsepower. Be realistic!
- **BSFC** is brake-specific fuel consumption in pounds per horsepower-hour. Calculated values are used for this, 0.4 to 0.8 lb. In most cases, start on the low side for naturally aspirated engines and the high side for engines with forced induction.
- **# of cylinders** is actually the number of injectors being used.
- **Maximum duty cycle** is considered at 0.8 (80%). Above this, the injector may overheat, lose consistency, or not work at all.

For example:

5.7 liter V-8 = 240 hp × 0.65/8 cylinders × 8 = 24.37 lb/hr injectors required

hybrid injection system combines the single injector of a TBI system with the equalized fuel distribution of a PFI system. It eliminates the individual fuel rail while allowing more efficient manifold tuning than is otherwise possible with a TBI system. Newer versions use six individual solenoids to fire one for each cylinder. ● **SEE FIGURE 78–19.**

FREQUENTLY ASKED QUESTION

What Is Battery Voltage Correction?

Battery voltage correction is a program built into the PCM that causes the injector pulse width to increase if there is a drop in electrical system voltage. Lower battery voltage would cause the fuel injectors to open slower than normal and the fuel pump to run slower. Both of these conditions can cause the engine to run leaner than normal if the battery voltage is low. Because a lean air–fuel mixture can cause the engine to overheat, the PCM compensates for the lower voltage by adding a percentage to the injector pulse width. This richer condition will help prevent serious engine damage. The idle speed is also increased to turn the alternator faster if low battery voltage is detected.

FUEL-INJECTION MODES OF OPERATION

All fuel-injection systems are designed to supply the correct amount of fuel under a wide range of engine operating conditions. These modes of operation include:

Starting (cranking)	Acceleration enrichment
Clear flood	Deceleration enleanment
Idle (run)	Fuel shutoff

STARTING MODE When the ignition is turned to the start position, the engine cranks and the PCM energizes the fuel pump relay. The PCM also pulses the injectors on, basing the pulse width on engine speed and engine coolant temperature. The colder the engine is, the greater the pulse width. Cranking mode air–fuel ratio varies from about 1.5:1 at −40°F (−40°C) to 14.7:1 at 200°F (93°C).

CLEAR FLOOD MODE If the engine becomes flooded with too much fuel, the driver can depress the accelerator pedal to greater than 80% to enter the clear flood mode. When the PCM detects that the engine speed is low (usually below 600 RPM) and the throttle-position (TP) sensor voltage is high (WOT), the injector pulse width is greatly reduced or even shut off entirely, depending on the vehicle.

OPEN-LOOP MODE Open-loop operation occurs during warm-up before the oxygen sensor can supply accurate information to the PCM. The PCM determines injector pulse width based on values from the MAF, MAP, TP, ECT, and IAT sensors.

CLOSED-LOOP MODE Closed-loop operation is used to modify the base injector pulse width as determined by feedback from the oxygen sensor to achieve proper fuel control.

ACCELERATION ENRICHMENT MODE During acceleration, the throttle-position (TP) voltage increases, indicating that a richer air–fuel mixture is required. The PCM then supplies a longer injector pulse width and may even supply extra pulses to supply the needed fuel for acceleration.

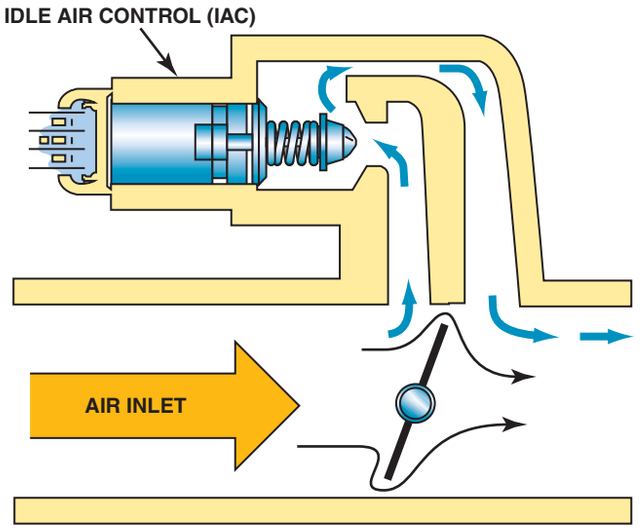


FIGURE 78–20 The small arrows indicate the air bypassing the throttle plate in the closed throttle position. This air is called minimum air. The air flowing through the IAC (blue arrows) is the airflow that determines the idle speed.

DECELERATION ENLEANMENT MODE When the engine decelerates, a leaner air–fuel mixture is required to help reduce emissions and to prevent deceleration backfire. If the deceleration is rapid, the injector may be shut off entirely for a short time and then pulsed on enough to keep the engine running.

FUEL SHUTOFF MODE Besides shutting off fuel entirely during periods of rapid deceleration, PCM also shuts off the injector when the ignition is turned off to prevent the engine from continuing to run.

IDLE CONTROL

Port fuel-injection systems generally use an auxiliary air bypass to control idle speed. ● **SEE FIGURE 78–20.** This air bypass or regulator provides needed additional airflow, and thus more fuel. The engine needs more power when cold to maintain its normal idle speed to overcome the increased friction from cold lubricating oil. It does this by opening an intake air passage to let more air into the engine just as depressing the accelerator pedal would open the throttle valve, allowing more air into the engine. The system is calibrated to maintain engine idle speed at a specified value regardless of engine temperature.

Most PFI systems use an idle air control (IAC) motor to regulate idle bypass air. The IAC is computer-controlled, and is either a solenoid-operated valve or a stepper motor that regulates the airflow around the throttle. The idle air control valve is also called an **electronic air control (EAC)** valve.

When the engine stops, most IAC units will retract outward to get ready for the next engine start. When the engine starts, the engine speed is high to provide for proper operation when the engine is cold. Then, as the engine gets warmer, the computer reduces engine idle speed gradually by reducing the number of counts or steps commanded by the IAC.

? FREQUENTLY ASKED QUESTION

Why Does the Idle Air Control Valve Use Milliamperes?

Some Chrysler vehicles, such as the Dodge minivan, use linear solenoid idle air control valves (LSIAC). The PCM uses regulated current flow through the solenoid to control idle speed and the scan tool display is in milliamperes (mA).

Closed position = 180 to 200 mA
Idle = 300 to 450 mA
Light cruise = 500 to 700 mA
Fully open = 900 to 950 mA

When the engine is warm and restarted, the idle speed should momentarily increase, then decrease to normal idle speed. This increase and then decrease in engine speed is often called an engine **flare.** If the engine speed does not flare, then the IAC may not be working (it may be stuck in one position).

STEPPER MOTOR OPERATION

A digital output is used to control stepper motors. Stepper motors are direct-current motors that move in fixed steps or increments from de-energized (no voltage) to fully energized (full voltage). A stepper motor often has as many as 120 steps of motion.

A common use for stepper motors is as an idle air control (IAC) valve, which controls engine idle speeds and prevents stalls due to changes in engine load. When used as an IAC, the stepper motor is usually a reversible DC motor that moves in increments, or steps. The motor moves a shaft back and forth to operate a conical valve. When the conical valve is moved back, more air bypasses the throttle plates and enters the engine, increasing idle speed. As the conical valve moves inward, the idle speed decreases.

When using a stepper motor that is controlled by the PCM, it is very easy for the PCM to keep track of the position of the stepper motor. By counting the number of steps that have been sent to the stepper motor, the PCM can determine the relative position of the stepper motor. While the PCM does not actually receive a feedback signal from the stepper motor, it does know how many steps forward or backward the motor should have moved.

A typical stepper motor uses a permanent magnet and two electromagnets. Each of the two electromagnetic windings is controlled by the computer. The computer pulses the windings and changes the polarity of the windings to cause the armature of the stepper motor to rotate 90 degrees at a time. Each 90-degree pulse is recorded by the computer as a "count" or "step"; therefore, the name given to this type of motor. ● **SEE FIGURE 78–21.**

Idle airflow in a TBI system travels through a passage around the throttle and is controlled by a stepper motor. In some applications, an externally mounted permanent magnet motor called the **idle speed control (ISC) motor** mechanically advances the throttle linkage to advance the throttle opening.

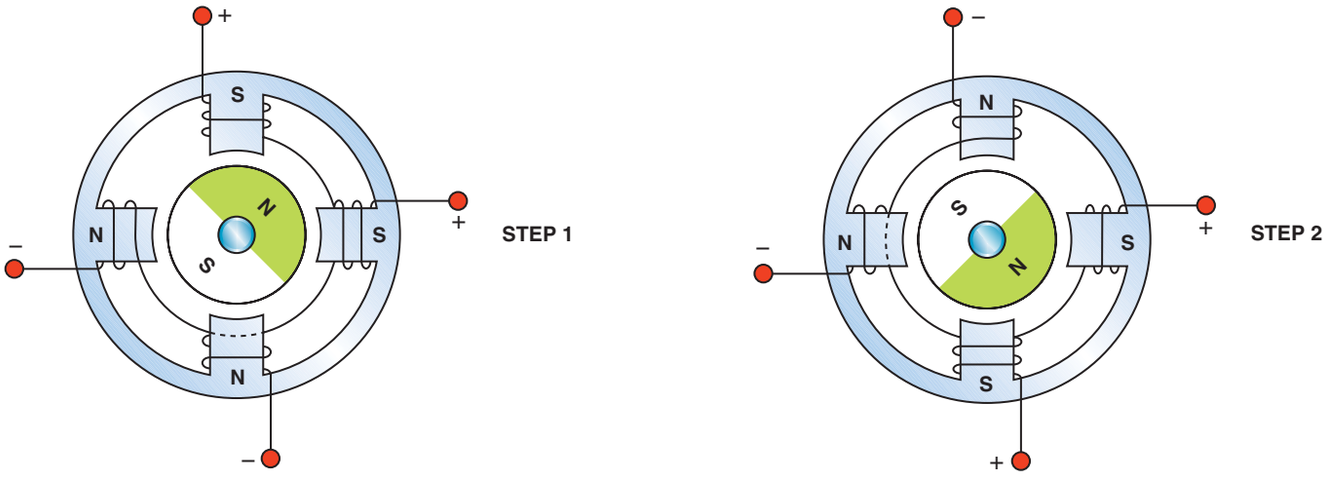


FIGURE 78–21 Most stepper motors use four wires, which are pulsed by the computer to rotate the armature in steps.

REVIEW QUESTIONS

1. What are the two basic types of fuel-injection systems?
2. What is the purpose of the vacuum-controlled (biased) fuel-pressure regulator?
3. How many sensors are used to determine the base pulse width on a speed-density system?
4. How many sensors are used to determine the base pulse width on a mass airflow system?
5. What are the three types of returnless fuel injection systems?

CHAPTER QUIZ

1. Technician A says that the fuel pump relay is usually controlled by the PCM. Technician B says that a TBI injector squirts fuel above the throttle plate. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. Why are some fuel rails rectangular in shape?
   a. Increases fuel pressure
   b. Helps keep air out of the injectors
   c. Reduces noise
   d. Increases the speed of the fuel through the fuel rail
3. Which fuel-injection system uses the MAP sensor as the primary sensor to determine the base pulse width?
   a. Speed density
   b. Mass airflow
   c. Demand delivery
   d. Mechanical returnless
4. Why is a vacuum line attached to a fuel-pressure regulator on many port-fuel-injected engines?
   a. To draw fuel back into the intake manifold through the vacuum hose
   b. To create an equal pressure drop across the injectors
   c. To raise the fuel pressure at idle
   d. To lower the fuel pressure under heavy engine load conditions to help improve fuel economy
5. Which sensor has the greatest influence on injector pulse width besides the MAF sensor?
   a. IAT
   b. BARO
   c. ECT
   d. TP
6. Technician A says that the port fuel-injection injectors operate using 5 volts from the computer. Technician B says that sequential fuel injectors all use a different wire color on the injectors. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. Which type of port fuel-injection system uses a fuel temperature and/or fuel-pressure sensor?
   a. All port-fuel-injected engines
   b. TBI units only
   c. Electronic returnless systems
   d. Demand delivery systems
8. Dampeners are used on some fuel rails to _____.
   a. Increase the fuel pressure in the rail
   b. Reduce (decrease) the fuel pressure in the rail
   c. Reduce noise
   d. Trap dirt and keep it away from the injectors
9. Where is the fuel-pressure regulator located on a vacuum-biased port fuel-injection system?
   a. In the tank
   b. At the inlet of the fuel rail
   c. At the outlet of the fuel rail
   d. Near or on the fuel filter
10. What type of device is used in a typical idle air control?
    a. DC motor
    b. Stepper motor
    c. Pulsator-type actuator
    d. Solenoid

chapter 79

GASOLINE DIRECT-INJECTION SYSTEMS

OBJECTIVES: **After studying Chapter 79, the reader will be able to:** • Prepare for the ASE certification test content area "C" (Fuel, Air Induction, and Exhaust Systems Diagnosis). • Describe the differences between port fuel-injection and gasoline direct-injection systems. • List the various modes of operation of a gasoline direct-injection system. • Explain how a gasoline direct-injection system works. • Perform a visual inspection of the gasoline direct-injection system and identify the parts.

KEY TERMS: Gasoline direct injection (GDI) 887 • Homogeneous mode 889 • Spark ignition direct injection (SIDI) 887 • Stratified mode 889

DIRECT FUEL INJECTION

Several vehicle manufacturers such as Audi, Mitsubishi, Mercedes, BMW, Toyota/Lexus, Mazda, Ford, and General Motors are using **gasoline direct injection (GDI)** systems, which General Motors refers to as a **Spark Ignition Direct Injection (SIDI)** system. A direct-injection system sprays high-pressure fuel, up to 2,900 PSI, into the combustion chamber as the piston approaches the top of the compression stroke. With the combination of high-pressure swirl injectors and modified combustion chamber, almost instantaneous vaporization of the fuel occurs. This combined with a higher compression ratio allows a direct-injected engine to operate using a leaner-than-normal air–fuel ratio, which results in improved fuel economy with higher power output and reduced exhaust emissions. ● **SEE FIGURE 79–1.**

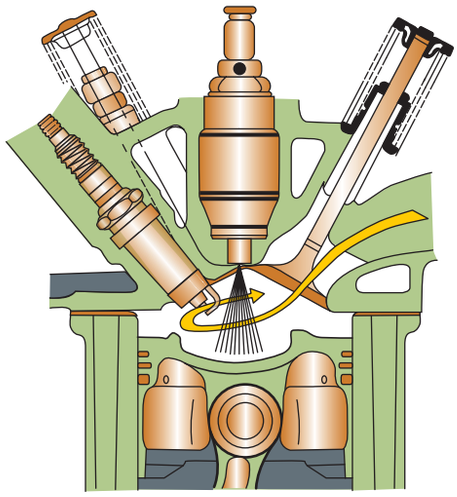


FIGURE 79–1 A gasoline direct-injection system injects fuel under high pressure directly into the combustion chamber.

ADVANTAGES OF GASOLINE DIRECT INJECTION

The use of direct injection compared with port fuel-injection has many advantages including:

- Improved fuel economy due to reduced pumping losses and heat loss
- Allows a higher compression ratio for higher engine efficiency
- Allows the use of lower-octane gasoline
- The volumetric efficiency is higher
- Less need for extra fuel for acceleration
- Improved cold starting and throttle response
- Allows the use of higher percentage of EGR to reduce exhaust emissions
- Up to 25% improvement in fuel economy
- 12% to 15% reduction in exhaust emissions

DISADVANTAGES OF GASOLINE DIRECT INJECTION

- Higher cost due to high-pressure pump and injectors
- More components compared with port fuel-injection
- Due to the high compression, a NO_x storage catalyst is sometimes required to meet emission standards, especially in Europe (● **SEE FIGURE 79–2).**
- Uses up to six operating modes depending on engine load and speed, which requires more calculations to be performed by the powertrain control module (PCM).

DIRECT-INJECTION FUEL DELIVERY SYSTEM

LOW-PRESSURE SUPPLY PUMP

The fuel pump in the fuel tank supplies fuel to the high-pressure fuel pump at a pressure of approximately 60 PSI. The fuel filter is located in the fuel tank and is part of the fuel pump assembly. It is not usually serviceable as a separate component. The engine control module (ECM) controls the output of the high-pressure pump, which has a range between 500 PSI (3,440 kPa) and 2,900 PSI (15,200 kPa) during engine operation. ● **SEE FIGURE 79–3.**

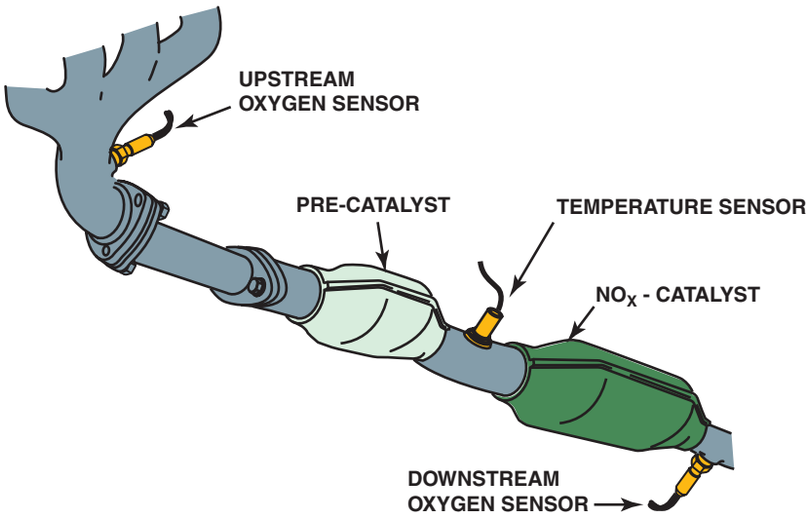


FIGURE 79–2 An engine equipped with a gasoline direct injection (GDI) sometimes requires a NO_x catalyst to meet exhaust emission standards.

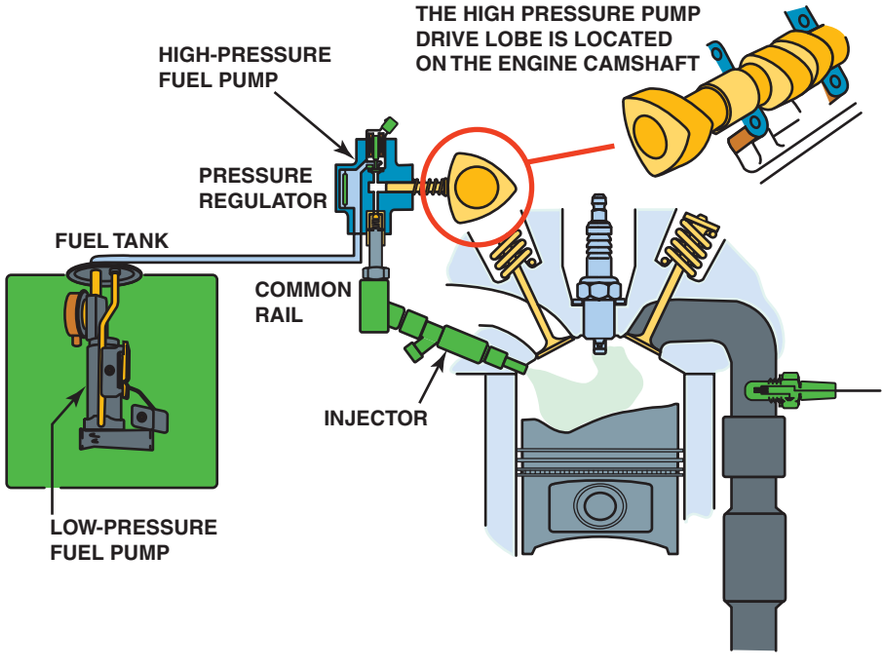


FIGURE 79–3 A typical direct-injection system uses two pumps—one low-pressure electric pump in the fuel tank and the other a high-pressure pump driven by the camshaft. The high pressure fuel system operates at a pressure as low as 500 PSI during light load conditions and as high as 2,900 PSI under heavy loads.

HIGH-PRESSURE PUMP In a General Motors system, the engine control module (ECM) controls the output of the high-pressure pump, which has a range between 500 PSI (3,440 kPa) and 2,900 PSI (15,200 kPa) during engine operation. The high-pressure fuel pump connects to the pump in the fuel tank through the low-pressure fuel line. The pump consists of a single-barrel piston pump, which is driven by the engine camshaft. The pump plunger rides on a three-lobed cam on the camshaft. The high-pressure pump is cooled and lubricated by the fuel itself. ● **SEE FIGURE 79–4.**

FUEL RAIL The fuel rail stores the fuel from the high-pressure pump and stores high pressure fuel for use to each injector. All injectors get the same pressure fuel from the fuel rail.

FUEL PRESSURE REGULATOR An electric pressure-control valve is installed between the pump inlet and outlet valves. The fuel rail pressure sensor connects to the PCM with three wires:

- 5-volt reference
- ground
- signal

The sensor signal provides an analog signal to the PCM that varies in voltage as fuel rail pressure changes. Low pressure results in a low-voltage signal and high pressure results in a high-voltage signal.

The PCM uses internal drivers to control the power feed and ground for the pressure control valve. When both PCM drivers are deactivated, the inlet valve is held open by spring pressure. This

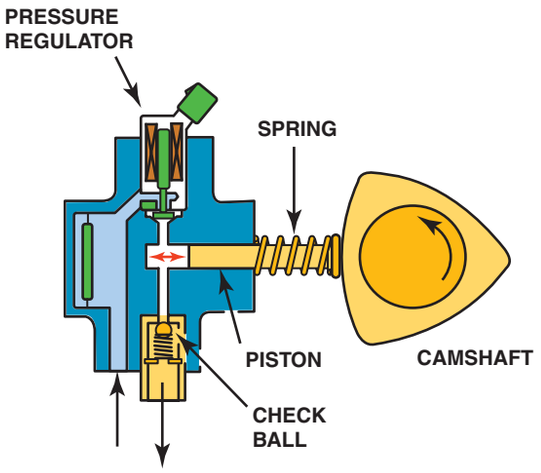


FIGURE 79–4 A typical camshaft-driven high-pressure pump used to increase fuel pressure to 2,000 PSI or higher.

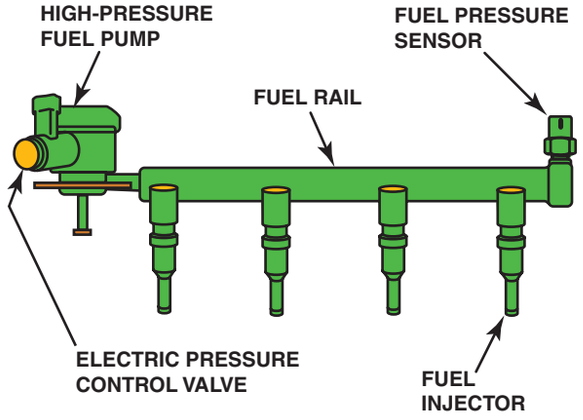


FIGURE 79–5 A gasoline direct-injection (GDI) fuel rail and pump assembly with the electric pressure control valve.

causes the high pressure fuel pump to default to low-pressure mode. The fuel from the high-pressure fuel pump flows through a line to the fuel rail and injectors. The actual operating pressure can vary from as low as 900 PSI (6,200 kPa) at idle to over 2,000 PSI (13,800 kPa) during high speed or heavy load conditions. ● **SEE FIGURE 79–5.**

GASOLINE DIRECT-INJECTION FUEL INJECTORS

Each high-pressure fuel injector assembly is an electrically magnetic injector mounted in the cylinder head. In the GDI system, the PCM controls each fuel injector with 50 to 90 volts (usually 60–70 volts), depending on the system, which is created by a boost capacitor in the PCM. During the high-voltage boost phase, the capacitor is discharged through an injector, allowing for initial injector opening. The injector is then held open with 12 volts. The high-pressure fuel injector has a small slit or six precision-machined holes that generate the desired spray pattern. The injector also has an extended tip to allow for cooling from a water jacket in the cylinder head.

● **SEE CHART 79–1** for an overview of the differences between a port fuel-injection system and a gasoline direct-injection system.

PORT FUEL-INJECTION SYSTEM COMPARED WITH GDI SYSTEM

	PORT FUEL-INJECTION	GASOLINE DIRECT INJECTION
Fuel pressure	35 to 60 PSI	Lift pump—50 to 60 PSI High-pressure pump—500 to 2,900 PSI
Injection pulse width at idle	1.5 to 3.5 ms	About 0.4 ms (400 µs)
Injector resistance	12 to 16 ohms	1 to 3 ohms
Injector voltage	6 V for low-resistance injectors, 12 V for most injectors	50 to 90 V
Number of injections per event	One	1 to 3
Engine compression ratio	8:1 to 11:1	11:1 to 13:1

CHART 79–1

A comparison chart showing the major differences between a port fuel-injection system and a gasoline direct-injection system.

MODES OF OPERATION

The two basic modes of operation include:

1. **Stratified mode.** In this mode of operation, the air–fuel mixture is richer around the spark plug than it is in the rest of the cylinder.
2. **Homogeneous mode.** In this mode of operation, the air–fuel mixture is the same throughout the cylinder.

There are variations of these modes that can be used to fine-tune the air–fuel mixture inside the cylinder. For example, Bosch, a supplier to many vehicle manufacturers, uses six modes of operation including:

- **Homogeneous mode.** In this mode, the injector is pulsed one time to create an even air–fuel mixture in the cylinder. The injection occurs during the intake stroke. This mode is used during high-speed and/or high-torque conditions.
- **Homogeneous lean mode.** Similar to the homogeneous mode except that the overall air–fuel mixture is slightly lean for better fuel economy. The injection occurs during the intake stroke. This mode is used under steady, light-load conditions.
- **Stratified mode.** In this mode of operation, the injection occurs just before the spark occurs resulting in lean combustion, reducing fuel consumption.
- **Homogeneous stratified mode.** In this mode, there are two injections of fuel:
  - The first injection is during the intake stroke.
  - The second injection is during the compression stroke.

  As a result of these double injections, the rich air–fuel mixture around the spark plug is ignited first. Then, the rich mixture

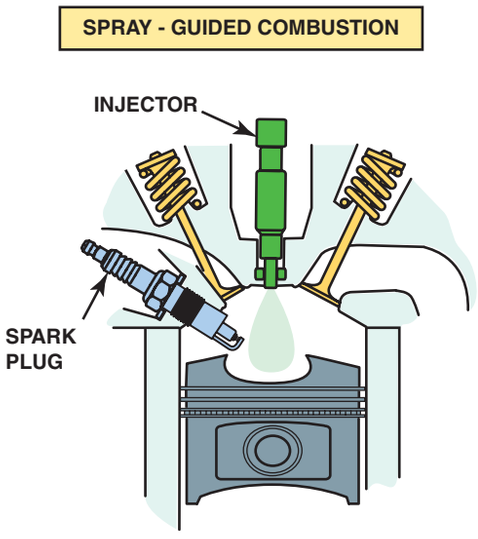


FIGURE 79–6 In this design, the fuel injector is at the top of the cylinder and sprays fuel into the cavity of the piston.

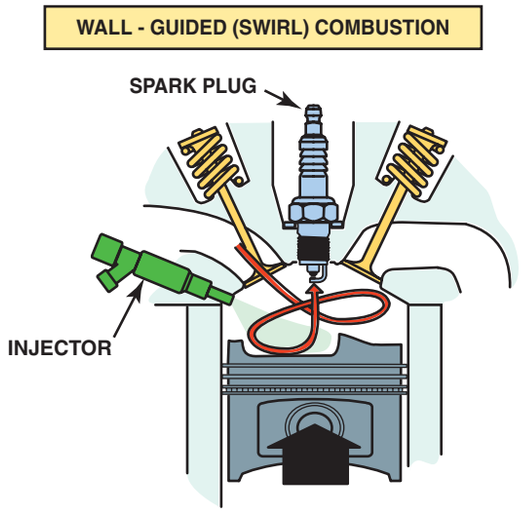


FIGURE 79–7 The side injector combines with the shape of the piston to create a swirl as the piston moves up on the compression stroke.

ignites the leaner mixture. The advantages of this mode include lower exhaust emissions than the stratified mode and less fuel consumption than the homogeneous lean mode.

- **Homogeneous knock protection mode.** The purpose of this mode is to reduce the possibility of spark knock from occurring under heavy loads at low engine speeds. There are two injections of fuel:
  - The first injection occurs on the intake stroke.
  - The second injection occurs during the compression stroke with the overall mixture being stoichiometric.

  As a result of this mode, the PCM does not need to retard ignition timing as much to operate knock-free.
- **Stratified catalyst heating mode.** In this mode, there are two injections:
  - The first injection is on the compression stroke just before combustion.
  - The second injection occurs after combustion occurs to heat the exhaust. This mode is used to quickly warm the catalytic converter and to burn the sulfur from the NO_x catalyst.

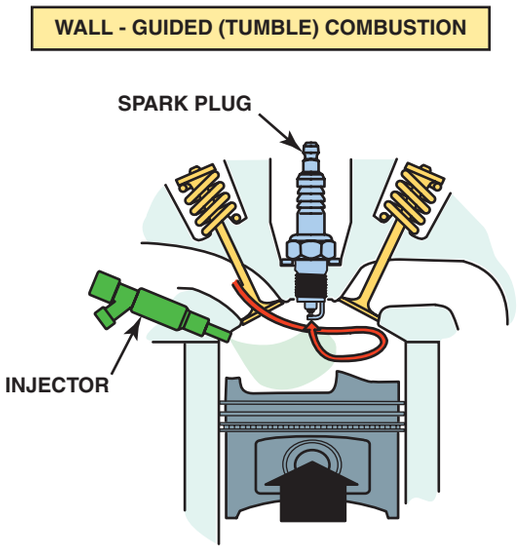


FIGURE 79–8 The piston creates a tumbling force as the piston moves upward.

PISTON TOP DESIGNS

Gasoline direct injection (GDI) systems use a variety of shapes of piston and injector locations depending on make and model of engine. Three of the most commonly used designs include:

- **Spray-guided combustion.** In this design, the injector is placed in the center of the combustion chamber and injects fuel into the dished out portion of the piston. The shape of the piston helps guide and direct the mist of fuel in the combustion chamber. ● **SEE FIGURE 79–6.**
- **Swirl combustion.** This design uses the shape of the piston and the position of the injector at the side of the combustion chamber to create turbulence and swirl of the air–fuel mixture. ● **SEE FIGURE 79–7.**
- **Tumble combustion.** Depending on when the fuel is injected into the combustion chamber, helps determine how the air–fuel is moved or tumbled. ● **SEE FIGURE 79–8.**

LEXUS PORT- AND DIRECT-INJECTION SYSTEMS

OVERVIEW Many Lexus vehicles use gasoline direct injection (GDI) and in some engines, they also use a conventional port fuel-injection system. The Lexus D-4S system combines direct-injection injectors located in the combustion chamber with port fuel-injectors in the intake manifold near the intake valve. The two injection systems work together to supply the fuel needed by the engine. ● **SEE FIGURE 79–9** for how the two systems are used throughout the various stages of engine operation.

COLD-START WARM-UP To help reduce exhaust emissions after a cold start, the fuel system uses a stratified change mode. This results in a richer air–fuel mixture near the spark plug and allows for the

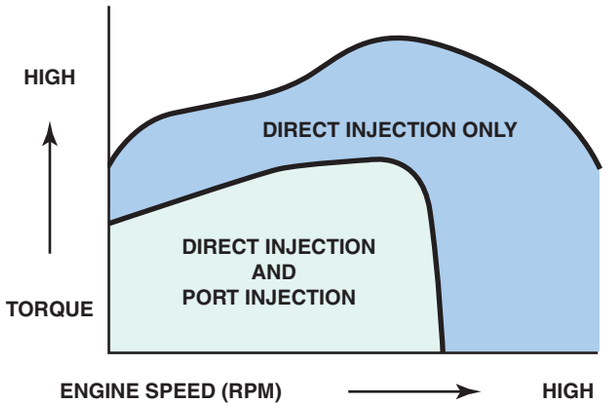


FIGURE 79–9 Notice that there are conditions when the port fuel-injector located in the intake manifold, and the gasoline direct injector, located in the cylinder both operate to provide the proper air–fuel mixture.

spark to be retarded to increase the temperature of the exhaust. As a result of the increased exhaust temperature, the catalytic converter rapidly reaches operating temperature, which reduces exhaust emissions.

ENGINE START SYSTEM

An engine equipped with gasoline direct injection could use the system to start the engine. This is most useful during idle stop mode when the engine is stopped while the vehicle is at a traffic light to save fuel. The steps used in the Mitsubishi start-stop system, called the *smart idle stop system (SISS)*, allow the engine to be started without a starter motor and include the following steps:

STEP 1 The engine is stopped. The normal stopping position of an engine when it stops is 70 degrees before top dead center, plus or minus 20 degrees. This is because the engine stops with one cylinder on the compression stroke and the PCM can determine the cylinder position, using the crankshaft and camshaft position sensors.

STEP 2 When a command is made to start the engine by the PCM, fuel is injected into the cylinder that is on the compression stroke and ignited by the spark plug.

STEP 3 The piston on the compression stroke is forced downward forcing the crankshaft to rotate counterclockwise or in the opposite direction to normal operation.

STEP 4 The rotation of the crankshaft then forces the companion cylinder toward the top of the cylinder.

STEP 5 Fuel is injected and the spark plug is fired, forcing the piston down, causing the crankshaft to rotate in the normal (clockwise) direction. Normal combustion events continue allowing the engine to keep running.

GASOLINE DIRECT-INJECTION SERVICE

NOISE ISSUES Gasoline direct injection (GDI) systems operate at high pressure and the injectors can often be heard with the engine running and the hood open. This noise can be a customer concern because the clicking sound is similar to noisy valves. If a noise issue is the customer concern, check the following:

- Check a similar vehicle to determine if the sound is louder or more noticeable than normal.
- Check that nothing under the hood is touching the fuel rail. If another line or hose is in contact with the fuel rail, the sound of the injectors clicking can be transmitted throughout the engine, making the sound more noticeable.
- Check for any technical service bulletins (TSBs) that may include new clips or sound insulators to help reduce the noise.

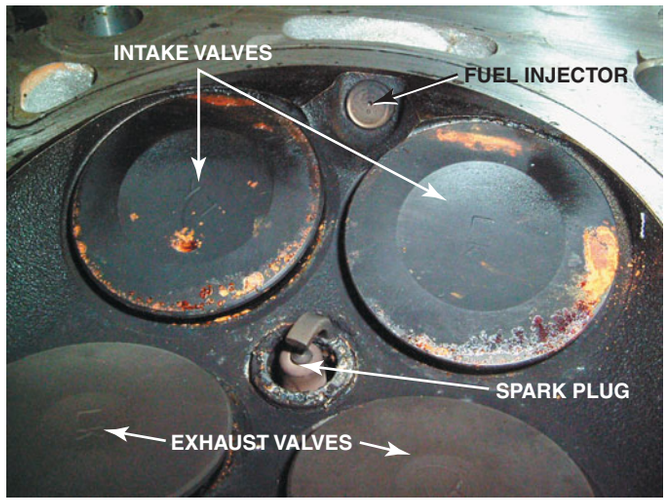


FIGURE 79–10 There may become a driveability issue because the gasoline direct-injection injector is exposed to combustion carbon and fuel residue.

CARBON ISSUES Carbon is often an issue in engines equipped with gasoline direct-injection systems. Carbon can affect engine operation by accumulating in two places:

- **On the injector itself.** Because the injector tip is in the combustion chamber, fuel residue can accumulate on the injector, reducing its ability to provide the proper spray pattern and amount of fuel. Some injector designs are more likely to be affected by carbon than others. For example, if the injector uses small holes, these tend to become clogged more often than an injector that uses a single slit opening where the fuel being sprayed out tends to blast away any carbon. ● **SEE FIGURE 79–10.**
- **The backside of the intake valve.** This is a common place for fuel residue and carbon to accumulate on engines equipped with gasoline direct injection. The accumulation of carbon on the intake valve can become so severe that the engine will start and idle, but lack power to accelerate the vehicle. The carbon deposits restrict the airflow into the cylinder enough to decrease engine power.

NOTE: Lexus engines that use both port and gasoline direct-injection injectors do not show intake valve deposits. It is thought that the fuel being sprayed onto the intake valve from the port injector helps keep the intake valve clean.

CARBON CLEANING. Most experts recommend the use of Techron®, a fuel system dispersant, to help keep carbon from accumulating. The use of a dispersant every six months or every 6,000 miles has proven to help prevent injector and intake valve deposits.

If the lack of power is discovered and there are no stored diagnostic trouble codes, a conventional carbon cleaning procedure will likely restore power if the intake valves are coated.

REVIEW QUESTIONS

1. What are two advantages of gasoline direct injection compared with port fuel-injection?
2. What are two disadvantages of gasoline direct injection compared with port fuel-injection?
3. How is the fuel delivery system different from a port fuel-injection system?
4. What are the basic modes of operation of a GDI system?

CHAPTER QUIZ

1. Where is the fuel injected in an engine equipped with gasoline direct injection?
   a. Into the intake manifold near the intake valve
   b. Directly into the combustion chamber
   c. Above the intake port
   d. In the exhaust port
2. The fuel pump inside the fuel tank on a vehicle equipped with gasoline direct injection produces about what fuel pressure?
   a. 5 to 10 PSI **c.** 20 to 40 PSI
   b. 10 to 20 PSI **d.** 50 to 60 PSI
3. The high-pressure fuel pumps used in gasoline direct injection (GDI) systems are powered by _____.
   a. Electricity (DC motor) **c.** The camshaft
   b. Electricity (AC motor) **d.** The crankshaft
4. The high-pressure fuel pressure is regulated by using _____.
   a. An electric pressure-control valve
   b. A vacuum-biased regulator
   c. A mechanical regulator at the inlet to the fuel rail
   d. A non-vacuum biased regulator
5. The fuel injectors operate under a fuel pressure of about _____.
   a. 35 to 45 PSI **c.** 500 to 2,900 PSI
   b. 90 to 150 PSI **d.** 2,000 to 5,000 PSI
6. The fuel injectors used on a gasoline direct-injection system are pulsed on using what voltage?
   a. 12 to 14 V **c.** 100 to 110 V
   b. 50 to 90 V **d.** 200 to 220 V
7. Which mode of operation results in a richer air–fuel mixture near the spark plug?
   a. Stoichiometric **c.** Stratified
   b. Homogeneous **d.** Knock protection
8. Some engines that use a gasoline direct-injection system also have port injection.
   a. True
   b. False
9. A gasoline direct-injection system can be used to start an engine without the need for a starter.
   a. True
   b. False
10. A lack of power from an engine equipped with gasoline direct injection could be due to _____.
    a. Noisy injectors
    b. Carbon on the injectors
    c. Carbon on the intake valves
    d. Both b and c

chapter 80

ELECTRONIC THROTTLE CONTROL SYSTEM

OBJECTIVES: After studying Chapter 80, the reader will be able to: • Prepare for ASE test content area "E" (Computerized Engine Controls Diagnosis and Repair). • Describe the purpose and function of an electronic throttle control (ETC) system. • Explain how an electronic throttle control system works. • List the parts of a typical electronic throttle control system. • Describe how to diagnose faults in an electronic throttle control system.

KEY TERMS: Accelerator pedal position (APP) sensor 893 • Coast-down stall 898 • Default position 894 • Drive-by-wire 893 • Electronic throttle control (ETC) 893 • Fail safe position 894 • Neutral position 894 • Servomotor 894 • Throttle position (TP) sensor 893

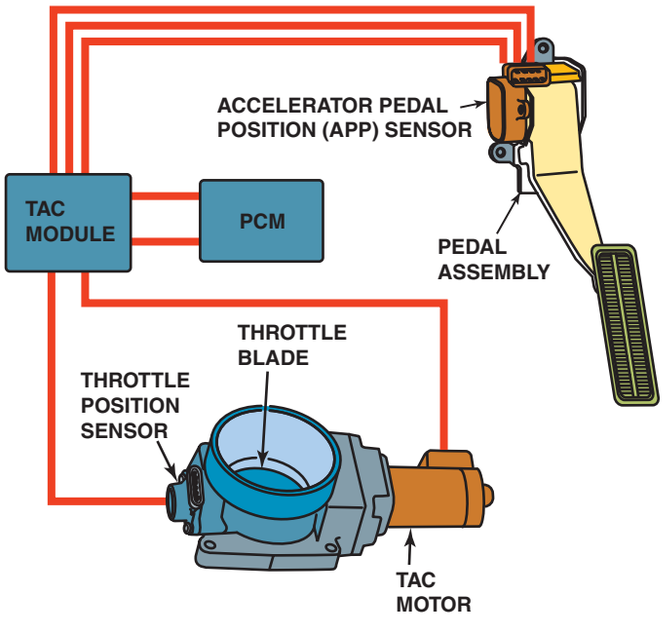


FIGURE 80–1 The throttle pedal is connected to the accelerator pedal position (APP) sensor. The electronic throttle body includes a throttle position sensor to provide throttle angle feedback to the vehicle computer. Some systems use a Throttle Actuator Control (TAC) module to operate the throttle blade (plate).

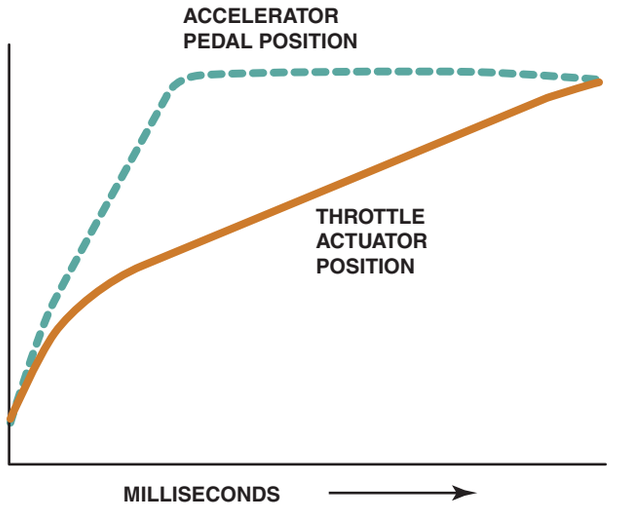


FIGURE 80–2 The opening of the throttle plate can be delayed as long as 30 milliseconds (0.030 sec.) to allow time for the amount of fuel needed to catch up to the opening of the throttle plate.

ELECTRONIC THROTTLE CONTROL (ETC) SYSTEM

ADVANTAGES OF ETC The absence of any mechanical linkage between the throttle pedal and the throttle body requires the use of an electric actuator motor. The electronic throttle system has the following advantages over the conventional cable:

- Eliminates the mechanical throttle cable, thereby reducing the number of moving parts.
- Eliminates the need for cruise control actuators and controllers.
- Helps reduce engine power for traction control (TC) and electronic stability control (ESC) systems.
- Used to delay rapid applications of torque to the transmission/transaxle to help improve driveability and to smooth shifts.
- Helps reduce pumping losses by using the electronic throttle to open at highway speeds with greater fuel economy. The electronic throttle control (ETC) opens the throttle to maintain engine and vehicle speed as the powertrain control module (PCM) leans the air–fuel ratio, retards ignition timing, and introduces additional exhaust gas recirculation (EGR) to reducing pumping losses.
- Used to provide smooth engine operation, especially during rapid acceleration.
- Eliminates the need for an idle air control valve.

The electronic throttle can be called **drive-by-wire,** but most vehicle manufacturers use the term **electronic throttle control (ETC)** to describe the system that opens the throttle valve electrically.

PARTS INVOLVED The typical ETC system includes the following components:

1. **Accelerator pedal position (APP)** sensor, also called accelerator pedal sensor (APS)
2. The electronic throttle actuator (servomotor), which is part of the electronic throttle body
3. A **throttle position (TP) sensor**
4. An electronic control unit, which is usually the powertrain control module (PCM)

● **SEE FIGURE 80–1.**

NORMAL OPERATION OF THE ETC SYSTEM

Driving a vehicle equipped with an electronic throttle control (ETC) system is about the same as driving a vehicle with a conventional mechanical throttle cable and throttle valve. However, the driver may notice some differences, which are to be considered normal. These normal conditions include:

- The engine may not increase above idle speed when depressing the accelerator pedal when the gear selector is in PARK.
- If the engine speed does increase when the accelerator is depressed with the transmission in PARK or NEUTRAL, the engine speed will likely be limited to less than 2000 RPM.
- While accelerating rapidly, there is often a slight delay before the engine responds. ● **SEE FIGURE 80–2.**
- While at cruise speed, the accelerator pedal may or may not cause the engine speed to increase if the accelerator pedal is moved slightly.

ACCELERATOR PEDAL POSITION SENSOR

CABLE-OPERATED SYSTEM Honda Accords until 2008 model year used a cable attached to the accelerator pedal to operate the APP sensor located under the hood. A similar arrangement

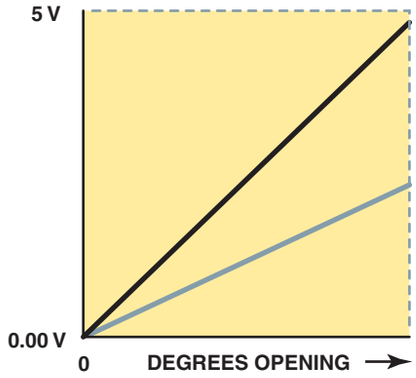


FIGURE 80–3 A typical accelerator pedal position (APP) sensor, showing two different output voltage signals that are used by the PCM to determine accelerator pedal position. Two (or three in some applications) are used as a double check because this is a safety-related sensor.

was used in Dodge RAM trucks in 2003. In both of these applications, the throttle cable was simply moving the APP sensor and not moving the throttle plate. The throttle plate is controlled by the PCM and moved by the electronic throttle control motor.

TWO SENSORS The accelerator pedal position sensor uses two and sometimes three separate sensors, which act together to give accurate accelerator pedal position information to the controller, but also are used to check that the sensor is working properly. They function just like a throttle position sensor, and two are needed for proper system function. One APP sensor output signal increases as the pedal is depressed and the other signal decreases. The controller compares the signals with a look-up table to determine the pedal position. Using two or three signals improves redundancy should one sensor fail, and allows the PCM to quickly detect a malfunction. When three sensors are used, the third signal can either decrease or increase with pedal position, but its voltage range will still be different from the other two. ● **SEE FIGURE 80–3.**

? FREQUENTLY ASKED QUESTION

What Is the "Spring Test"?

The spring test is a self-test performed by the PCM whenever the engine is started. The PCM operates the throttle to check if it can react to the command and return to the default (home) position. This self-test is used by the PCM to determine that the spring and motor are working correctly and may be noticed by some vehicle owners by the following factors:

- A slight delay in the operation of the starter motor. The PCM performs this test when the ignition switch is turned to the "on" position. While it takes just a short time to perform the test, it can be sensed by the driver that there could be a fault in the ignition switch or starter motor circuits.
- A slight "clicking" sound may also be heard coming from under the hood when the ignition is turned on. This is normal and is related to the self-test on the throttle as it opens and closes.

? FREQUENTLY ASKED QUESTION

Why Not Use a Stepper Motor for ETC?

A stepper motor is a type of motor that has multiple windings and is pulsed by a computer to rotate a certain number of degrees when pulsed. The disadvantage is that a stepper motor is too slow to react compared with a conventional DC electric motor and is the reason a stepper motor is not used in electronic throttle control systems.

THROTTLE BODY ASSEMBLY

The throttle body assembly contains the following components:

- Throttle plate
- Electric actuator DC motor
- Dual throttle position (TP) sensors
- Gears used to multiply the torque of the DC motor
- Springs used to hold the throttle plate in the default location

THROTTLE PLATE AND SPRING The throttle plate is held slightly open by a concentric clock spring. The spring applies a force that will close the throttle plate if power is lost to the actuator motor. The spring is also used to open the throttle plate slightly from the fully closed position.

ELECTRONIC THROTTLE BODY MOTOR The actuator is a DC electric motor and is often called a **servomotor.** The throttle plate is held in a **default position** by a spring inside the throttle body assembly. This partially open position, also called the **neutral position** or the **fail safe position,** is about 16% to 20% open. This default position varies depending on the vehicle and usually results in an engine speed of 1200 to 1500 RPM.

- The throttle plate is driven closed to achieve speeds lower than the default position, such as idle speed.
- The throttle plate is driven open to achieve speeds higher than the default position, such as during acceleration. ● **SEE FIGURE 80–4.**

The throttle plate motor is driven by a bidirectional pulse-width modulated (PWM) signal from the PCM or electronic throttle control module using an H-bridge circuit. ● **SEE FIGURE 80–5a, b.**

The H-bridge circuit is controlled by the powertrain control module (PCM) by:

- Reversing the polarity of power and ground brushes to the DC motor
- Pulse-width modulating (PWM) the current through the motor

The PCM monitors the position of the throttle from the two throttle position (TP) sensors. The PCM then commands the throttle plate to the desired position. ● **SEE FIGURE 80–6.**

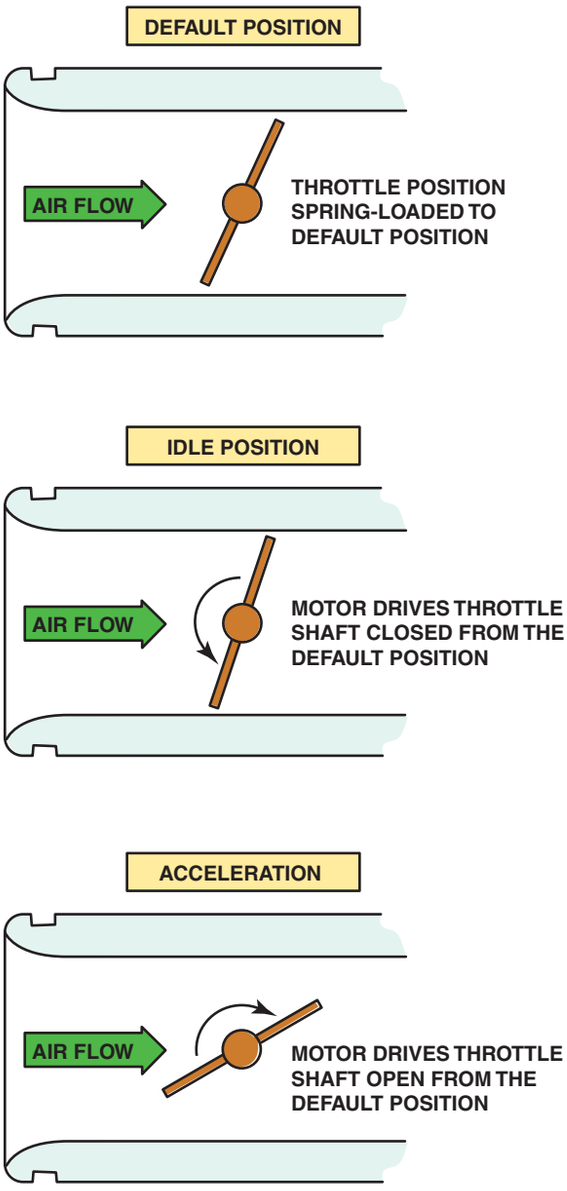


FIGURE 80–4 The default position for the throttle plate is in slightly open position. The servomotor then is used to close it for idle and open it during acceleration.

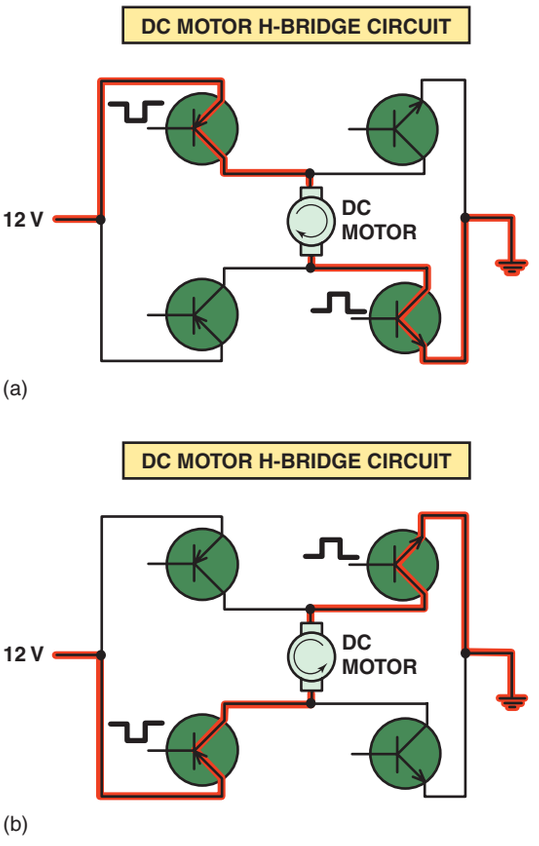


FIGURE 80–5 (a) An H-bridge circuit is used to control the direction of the DC electric motor of the electronic throttle control unit. (b) To reverse the direction of operation, the polarity of the current through the motor is reversed.

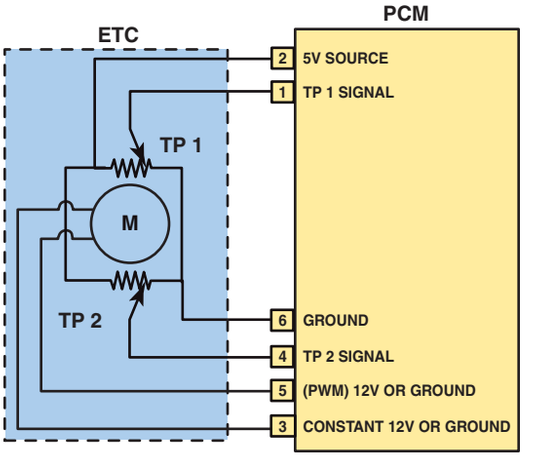


FIGURE 80–6 Schematic of a typical electronic throttle control (ETC) system. Note that terminal #5 is always pulse-width modulated and that terminal #3 is always constant, but both power and ground are switched to change the direction of the motor.

THROTTLE POSITION (TP) SENSOR

Two throttle position (TP) sensors are used in the throttle body assembly to provide throttle position signals to the PCM. Two sensors are used as a fail-safe measure and for diagnosis. There are two types of TP sensors used in electronic throttle control (ETC) systems: potentiometers and Hall-effect.

THREE-WIRE POTENTIOMETER SENSORS These sensors use a 5-volt reference from the PCM and produce an analog (variable) voltage signal that is proportional to the throttle plate position. The two sensors produce opposite signals as the throttle plate opens:

- One sensor starts at low voltage (about 0.5 V) and increases as the throttle plate is opened.
- The second sensor starts at a higher voltage (about 4.5 V) and produces a lower voltage as the throttle plate is opened. ● **SEE FIGURE 80–7.**

HALL-EFFECT TP SENSORS Some vehicle manufacturers, Honda for example, use a non-contact Hall-effect throttle position sensor. Because there is not physical contact, this type of sensor is less likely to fail due to wear.

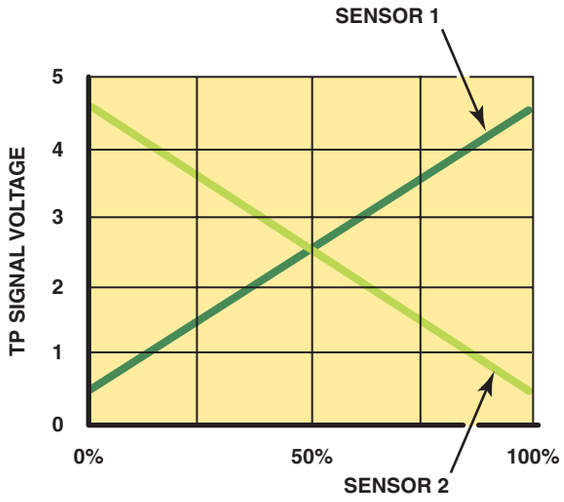
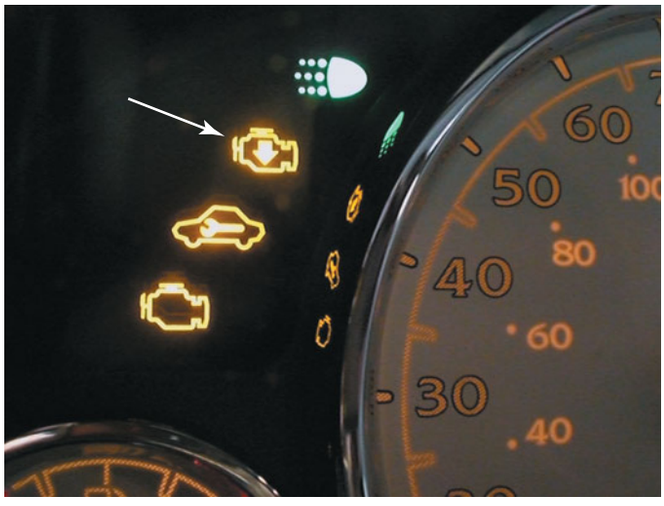


FIGURE 80–7 The two TP sensors used on the throttle body of an electronic throttle body assembly produce opposite voltage signals as the throttle is opened. The total voltage of both combined at any throttle plate position is 5 volts.



(a)



(b)

FIGURE 80–8 (a) A "reduced power" warning light indicates a fault with the electronic throttle control system on some General Motors vehicles. (b) A symbol showing an engine with an arrow pointing down is used on some General Motors vehicles to indicate a fault with the electronic throttle control system.

? FREQUENTLY ASKED QUESTION

How Do You Calibrate a New APP Sensor?

Whenever an accelerator pedal position (APP) sensor is replaced, it should be calibrated before it will work correctly. Always check service information for the exact procedure to follow after APP sensor replacement. Here is a typical example of the procedure:

STEP 1 Make sure accelerator pedal is fully released.
STEP 2 Turn the ignition switch on (engine off) and wait at least 2 seconds.
STEP 3 Turn the ignition switch off and wait at least 10 seconds.
STEP 4 Turn the ignition switch on (engine on) and wait at least 2 seconds.
STEP 5 Turn the ignition switch off and wait at least 10 seconds.

DIAGNOSIS OF ELECTRONIC THROTTLE CONTROL SYSTEMS

FAULT MODE Electronic throttle control (ETC) systems can have faults like any other automatic system. Due to the redundant sensors in accelerator pedal position (APP) sensors and throttle position (TP) sensor, many faults result in a *"limp home"* situation instead of a total failure. The limp home mode is also called the *"fail-safe mode"* and indicates the following actions performed by the powertrain control module (PCM).

- Engine speed is limited to the default speed (about 1200 to 1600 RPM).
- There is slow or no response when the accelerator pedal is depressed.
- The cruise control system is disabled.
- A diagnostic trouble code (DTC) is set.
- An ETC warning lamp on the dash will light. The warning lamp may be labeled differently, depending on the vehicle manufacturer. For example:
  - General Motors vehicle–Reduced power lamp (● **SEE FIGURE 80–8**)
  - Ford–Wrench symbol (amber or green) (● **SEE FIGURE 80–9**)
  - Chrysler–Red lightning bolt symbol (● **SEE FIGURE 80–10**)
- The engine will run and can be driven slowly. This limp-in mode operation allows the vehicle to be driven off of the road and to a safe location.

The ETC may enter the limp-in mode if any of the following has occurred:

- Low battery voltage has been detected
- PCM failure
- One TP and the MAP sensor have failed
- Both TP sensors have failed
- The ETC actuator motor has failed
- The ETC throttle spring has failed



FIGURE 80–9 A wrench symbol warning lamp on a Ford vehicle. The symbol can also be green.



FIGURE 80–10 A symbol used on a Chrysler vehicle indicating a fault with the electronic throttle control.



FIGURE 80–11 The throttle plate stayed where it was moved, which indicates that there is a problem with the electronic throttle body control assembly.



FIGURE 80–12 A corroded electronic throttle control assembly shown with the cover removed.

REAL WORLD FIX

The High Idle Toyota

The owner of a Toyota Camry complained that the engine would idle at over 1200 RPM compared with a normal 600 to 700 RPM. The vehicle would also not accelerate. Using a scan tool, a check for diagnostic trouble codes showed one code: P2101–"TAC motor circuit low."

Checking service information led to the inspection of the electronic throttle control throttle body assembly. With the ignition key out of the ignition and the inlet air duct off the throttle body, the technician used a screwdriver to push gently to see if the throttle plate worked.

Normal operation–The throttle plate should move and then spring back quickly to the default position.

Abnormal operation–If the throttle plate stays where it is moved or does not return to the default position, there is a fault with the throttle body assembly.

● **SEE FIGURE 80–11.**

Solution: The technician replaced the throttle body assembly with an updated version and proper engine operation was restored. The technician disassembled the old throttle body and found it was corroded inside due to moisture entering the unit through the vent hose.

● **SEE FIGURE 80–12.**

VACUUM LEAKS The electronic throttle control (ETC) system is able to compensate for many vacuum leaks. A vacuum leak at the intake manifold for example will allow air into the engine that is not measured by the mass airflow sensor. The ETC system will simply move the throttle as needed to achieve the proper idle speed to compensate for the leak.

DIAGNOSTIC PROCEDURE If a fault occurs in the ETC system, check service information for the specified procedure to follow for the vehicle being checked. Most vehicle service information includes the following steps:

STEP 1 Verify the customer concern.

STEP 2 Use a factory scan tool or an aftermarket scan tool with original equipment capability and check for diagnostic trouble codes (DTCs).

STEP 3 If there are stored diagnostic trouble codes, follow service information instructions for diagnosing the system.

STEP 4 If there are no stored diagnostic trouble codes, check scan tool data for possible fault areas in the system.

SCAN TOOL DATA Scan data related to the electronic throttle control system can be confusing. Typical data and the meaning include:

- **APP indicated angle.** The scan tool will display a percentage ranging from 0% to 100%. When the throttle is released, the indicated angle should be 0%. When the throttle is depressed to wide open, the reading should indicate 100%.
- **TP desired angle.** The scan tool will display a percentage ranging from 0% to 100%. This represents the desired throttle angle as commanded by the driver of the vehicle.
- **TP indicated angle.** The TP indicated angle is the angle of the measured throttle opening and it should agree with the TP desired angle.
- **TP sensors 1 and 2.** The scan tool will display "agree" or "disagree." If the PCM or throttle actuator control (TAC) module receives a voltage signal from one of the TP sensors that is not in the proper relationship to the other TP sensor, the scan tool will display disagree.

ETC THROTTLE FOLLOWER TEST

On some vehicles, such as many Chrysler vehicles, the operation of the electronic throttle control can be tested using a factory or factory-level scan tool. To perform this test, use the "throttle follower test" procedure as shown on the scan tool. An assistant is needed to check that the throttle plate is moving as the accelerator pedal is depressed. This test cannot be done normally because the PCM does not normally allow the throttle plate to be moved unless the engine is running.

SERVICING ELECTRONIC THROTTLE SYSTEMS

ETC-RELATED PERFORMANCE ISSUES The only service that an electronic throttle control system may require is a cleaning of the throttle body. Throttle body cleaning is a routine service procedure on port fuel-injected engines and is still needed when the throttle is being opened by an electric motor rather than a throttle cable tied to a mechanical accelerator pedal. The throttle body may need cleaning if one or more of the following symptoms are present:

- Lower than normal idle speed
- Rough idle
- Engine stalls when coming to a stop (called a **coast-down stall**)

If any of the above conditions exists, a throttle body cleaning will often correct these faults.

CAUTION: Some vehicle manufacturers add a nonstick coating to the throttle assembly and warn that cleaning could remove this protective coating. Always follow the vehicle manufacturer's recommended procedures.

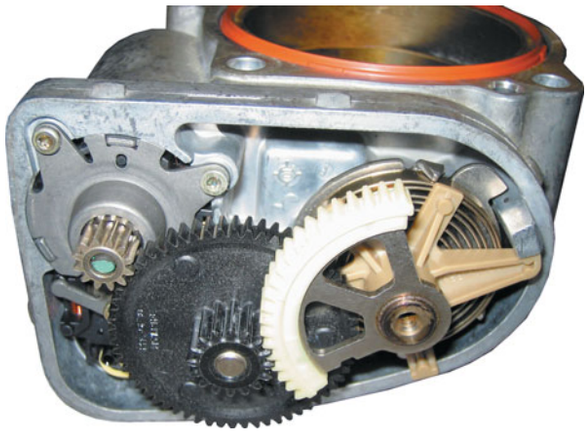


FIGURE 80–13 Notice the small motor gear on the left drives a larger plastic gear (black), which then drives the small gear in mesh with the section of a gear attached to the throttle plate. This results in a huge torque increase from the small motor and helps explain why it could be dangerous to insert a finger into the throttle body assembly.

THROTTLE BODY CLEANING PROCEDURE Before attempting to clean a throttle body on an engine equipped with an electronic throttle control system, be sure that the ignition key is out of the vehicle and the ready light is off if working on a Toyota/Lexus hybrid electric vehicle to avoid the possibility of personal injury.

WARNING

The electric motor that operates the throttle plate is strong enough to cut off a finger. ● **SEE FIGURE 80–13.**

To clean the throttle, perform the following steps:

STEP 1 With the ignition off and the key removed from the ignition, remove the air inlet hose from the throttle body.

STEP 2 Spray throttle body cleaner onto a shop cloth.

STEP 3 Open the throttle body and use the shop cloth to remove the varnish and carbon deposits from the throttle body housing and throttle plate.

CAUTION: Do not spray cleaner into the throttle body assembly. The liquid cleaner could flow into and damage the throttle position (TP) sensors.

STEP 4 Reinstall the inlet hose being sure that there are no air leaks between the hose and the throttle body assembly.

STEP 5 Start the engine and allow the PCM to learn the correct idle. If the idle is not correct, check service information for the specified procedures to follow to perform a throttle relearn.

THROTTLE BODY RELEARN PROCEDURE When installing a new throttle body or powertrain control module (PCM) or sometimes after cleaning the throttle body, the throttle position has to be learned by the PCM. After the following conditions have been met, a typical throttle body relearn procedure for a General Motors vehicle includes:

- Accelerator pedal released
- Battery voltage higher than 8 volts

- Vehicle speed must be zero
- Engine coolant temperature (ECT) higher than 40°F (5°C) and lower than 212°F (100°C)
- Intake air temperature (IAT) higher than 40°F (5°C)
- No throttle diagnostic trouble codes set

If all of the above conditions are met, perform the following steps:

STEP 1 Turn the ignition on (engine off) for 30 seconds.

STEP 2 Turn the ignition off and wait 30 seconds.

Start the engine and the idle learn procedure should cause the engine to idle at the correct speed.

REVIEW QUESTIONS

1. What parts can be deleted if an engine uses an electronic throttle control (ETC) system instead of a conventional accelerator pedal and cable to operate the throttle valve?
2. How can the use of an electronic throttle control (ETC) system improve fuel economy?
3. How is the operation of the throttle different on a system that uses an electronic throttle control system compared with a conventional mechanical system?
4. What component parts are included in an electronic throttle control system?
5. What is the default or limp-in position of the throttle plate?
6. What dash warning light indicates a fault with the ETC system?

CHAPTER QUIZ

1. The use of an electronic throttle control (ETC) system allows the elimination of all except _____.
   a. Accelerator pedal
   b. Mechanical throttle cable (most systems)
   c. Cruise control actuator
   d. Idle air control
2. The throttle plate is spring loaded to hold the throttle slightly open how far?
   a. 3% to 5%
   b. 8% to 10%
   c. 16% to 20%
   d. 22% to 28%
3. The throttle plate actuator motor is what type of electric motor?
   a. Stepper motor
   b. DC motor
   c. AC motor
   d. Brushless motor
4. The actuator motor is controlled by the PCM through what type of circuit?
   a. Series
   b. Parallel
   c. H-bridge
   d. Series-parallel
5. When does the PCM perform a self-test of the ETC system?
   a. During cruise speed when the throttle is steady
   b. During deceleration
   c. During acceleration
   d. When the ignition switch is first rotated to the on position before the engine starts
6. The throttle position sensor used in the throttle body assembly of an electronic throttle control (ETC) system is what type?
   a. A single potentiometer
   b. Two potentiometers that read in the opposite direction
   c. A Hall-effect sensor
   d. Either b or c
7. A green wrench symbol is displayed on the dash. What does this mean?
   a. A fault in the ETC in a Ford has been detected
   b. A fault in the ETC in a Honda has been detected
   c. A fault in the ETC in a Chrysler has been detected
   d. A fault in the ETC in a General Motors vehicle has been detected
8. A technician is checking the operation of the electronic throttle control system by depressing the accelerator pedal with the ignition in the on (run) position (engine off). What is the most likely result if the system is functioning correctly?
   a. The throttle goes to wide open when the accelerator pedal is depressed all the way
   b. No throttle movement
   c. The throttle will open partially but not all of the way
   d. The throttle will perform a self-test by closing and then opening to the default position
9. With the ignition off and the key out of the ignition, what should happen if a technician uses a screwdriver and gently pushes on the throttle plate in an attempt to open the valve?
   a. Nothing. The throttle should be kept from moving by the motor, which is not energized with the key off.
   b. The throttle should move and stay where it is moved and not go back unless moved back.
   c. The throttle should move, and then spring back to the home position when released.
   d. The throttle should move closed, but not open farther than the default position.
10. The throttle body may be cleaned (if recommended by the vehicle manufacturer) if what conditions are occurring?
    a. Coast-down stall
    b. Rough idle
    c. Lower-than-normal idle speed
    d. Any of the above

chapter 81

FUEL-INJECTION SYSTEM DIAGNOSIS AND SERVICE

OBJECTIVES: **After studying Chapter 81, the reader will be able to:** • Prepare for ASE Engine Performance (A8) certification test content area "C" (Fuel, Air Induction, and Exhaust Systems Diagnosis and Repair). • Explain how to test the fuel injection system using a scan tool. • Explain how to check a fuel-pressure regulator. • Describe how to test fuel injectors. • Explain how to diagnose electronic fuel-injection problems. • Describe how to service the fuel-injection system.

KEY TERMS: Graphing multimeter (GMM) 900 • IAC counts 902 • Idle air control (IAC) 908 • Noid light 903 • Peak-and-hold injector 908 • Pressure transducer 900 • Saturation 907

PORT FUEL-INJECTION PRESSURE REGULATOR DIAGNOSIS

Most port-fuel-injected engines use a vacuum hose connected to the fuel-pressure regulator. At idle, the pressure inside the intake manifold is low (high vacuum). Manifold vacuum is applied above the diaphragm inside the fuel-pressure regulator. This reduces the pressure exerted on the diaphragm and results in a lower, about 10 PSI (69 kPa), fuel pressure applied to the injectors. To test a vacuum-controlled fuel-pressure regulator, follow these steps:

1. Connect a fuel-pressure gauge to monitor the fuel pressure.
2. Locate the fuel-pressure regulator and disconnect the vacuum hose from the regulator.

   NOTE: If gasoline drips out of the vacuum hose when removed from the fuel-pressure regulator, the regulator is defective and will require replacement.

3. With the engine running at idle speed, reconnect the vacuum hose to the fuel-pressure regulator while watching the fuel-pressure gauge. The fuel pressure should drop (about 10 PSI or 69 kPa) when the hose is reattached to the regulator.
4. Using a hand-operated vacuum pump, apply vacuum (20 in. Hg) to the regulator. The regulator should hold vacuum. If the vacuum drops, replace the fuel-pressure regulator. ● **SEE FIGURE 81–1.**

NOTE: Some vehicles do not use a vacuum-regulated fuel-pressure regulator. Many of these vehicles use a regulator located inside the fuel tank that supplies a constant fuel pressure to the fuel injectors.

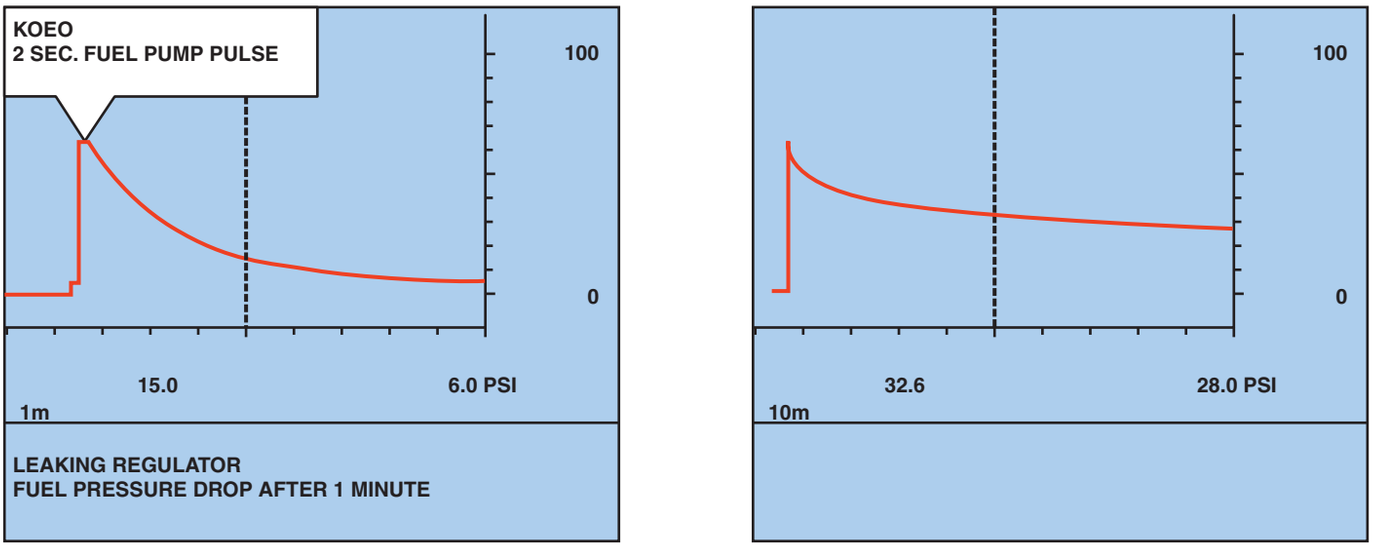


FIGURE 81–1 If the vacuum hose is removed from the fuel-pressure regulator when the engine is running, the fuel pressure should increase. If it does not increase, then the fuel pump is not capable of supplying adequate pressure or the fuel-pressure regulator is defective. If gasoline is visible in the vacuum hose, the regulator is leaking and should be replaced.

TECH TIP

Pressure Transducer Fuel Pressure Test

Using a **pressure transducer** and a **graphing multimeter (GMM)** or digital storage oscilloscope (DSO) allows the service technician to view the fuel pressure over time. ● **SEE FIGURE 81–2(a).** Note that the fuel pressure dropped from 15 PSI down to 6 PSI on a TBI-equipped vehicle after just one minute. A normal pressure holding capability is shown in ● **FIGURE 81–2(b)** when the pressure dropped only about 10% after 10 minutes on a port-fuel injection system.



(a) (b)

FIGURE 81–2 (a) A fuel-pressure graph after key on, engine off (KOEO) on a TBI system. (b) Pressure drop after 10 minutes on a normal port fuel-injection system.



FIGURE 81–3 A clogged PCV system caused the engine oil fumes to be drawn into the air cleaner assembly. This is what the technician discovered during a visual inspection on this TBI system.

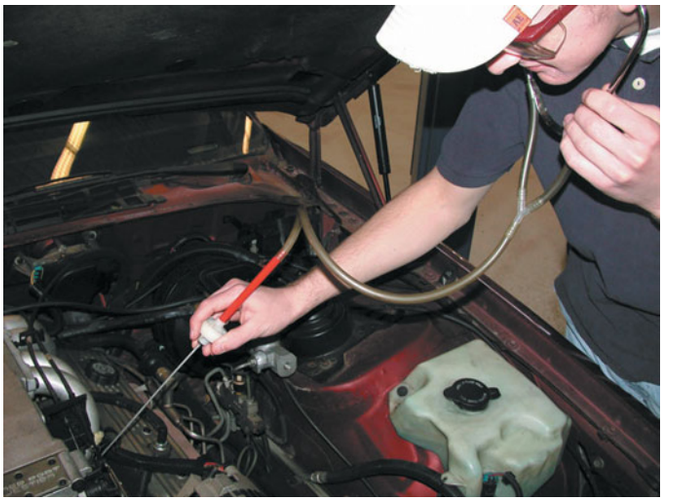


FIGURE 81–4 All fuel injectors should make the same sound with the engine running at idle speed. A lack of sound indicates a possible electrically open injector or a break in the wiring. A defective computer could also be the cause of a lack of clicking (pulsing) of the injectors.

DIAGNOSING ELECTRONIC FUEL-INJECTION PROBLEMS USING VISUAL INSPECTION

All fuel-injection systems require the proper amount of clean fuel delivered to the system at the proper pressure and the correct amount of filtered air. The following items should be carefully inspected before proceeding to more detailed tests.

- Check the air filter and replace as needed.
- Check the air induction system for obstructions.
- Check the conditions of all vacuum hoses. Replace any hose that is split, soft (mushy), or brittle.
- Check the positive crankcase ventilation (PCV) valve for proper operation or replacement as needed. ● **SEE FIGURE 81–3.**

NOTE: The use of an incorrect PCV valve can cause a rough idle or stalling.

TECH TIP

Stethoscope Fuel-Injection Test

A commonly used test for injector operation is to listen to the injector using a stethoscope with the engine operating at idle speed. ● **SEE FIGURE 81–4.** All injectors should produce the same clicking sound. If any injector makes a clunking or rattling sound, it should be tested further or replaced. With the engine still running, place the end of the stethoscope probe to the return line from the fuel-pressure regulator. ● **SEE FIGURE 81–5.** Fuel should be heard flowing back to the fuel tank if the fuel-pump pressure is higher than the fuel-regulator pressure. If no sound of fuel is heard, then either the fuel pump or the fuel-pressure regulator is at fault.

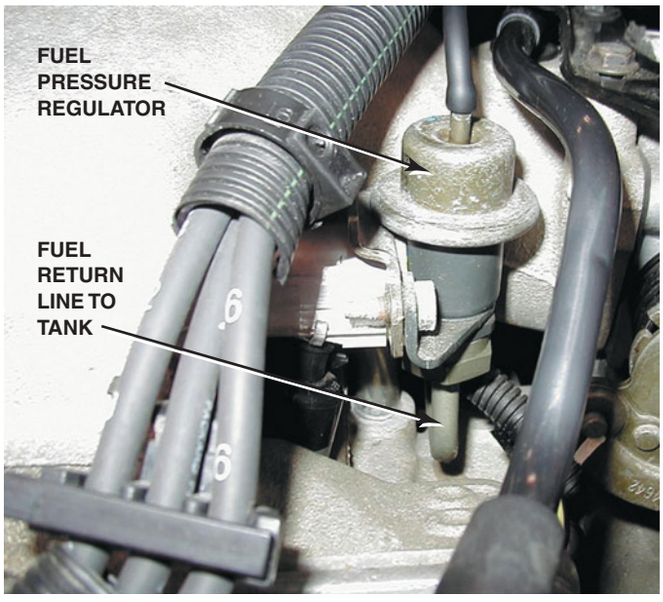


FIGURE 81–5 Fuel should be heard returning to the fuel tank at the fuel return line if the fuel-pump and fuel-pressure regulator are functioning correctly.



FIGURE 81–6 Using a scan tool to check for IAC counts or percentage as part of a diagnostic routine.

TECH TIP

Quick and Easy Leaking Injector Test

Leaking injectors may be found by disabling the ignition, unhooking all injectors, and checking exhaust for hydrocarbons (HC) using a gas analyzer while cranking the engine (maximum HC = 300 PPM). This test does not identity which injector is leaking but it does confirm that one or more injector is leaking.

TECH TIP

No Spark, No Squirt

Most electronic fuel-injection computer systems use the ignition primary (pickup coil or crank sensor) pulse as the trigger for when to inject (squirt) fuel from the injectors (nozzles). If this signal were not present, no fuel would be injected. Because this pulse is also necessary to trigger the module to create a spark from the coil, it can be said that "no spark" could also mean "no squirt." Therefore, if the cause of a no-start condition is observed to be a lack of fuel injection, do not start testing or replacing fuel-system components until the ignition system is checked for proper operation.

- Check all fuel-injection electrical connections for corrosion or damage.
- Check for gasoline at the vacuum port of the fuel-pressure regulator if the vehicle is so equipped. Gasoline in the vacuum hose at the fuel-pressure regulator indicates that the regulator is defective and requires replacement.

SCAN TOOL VACUUM LEAK DIAGNOSIS

If a vacuum (air) leak occurs on an engine equipped with a speed-density-type of fuel injection, the extra air would cause the following to occur:

- The idle speed increases due to the extra air just as if the throttle pedal was depressed.
- The MAP sensor reacts to the increased air from the vacuum leak as an additional load on the engine.
- The computer increases the injector pulse width slightly longer due to the signal from the MAP sensor.
- The air–fuel mixture remains unchanged.
- The idle air control (IAC) counts will decrease, thereby attempting to reduce the engine speed to the target idle speed stored in the computer memory. ● **SEE FIGURE 81–6.**

Therefore, one of the best indicators of a vacuum leak on a speed-density fuel-injection system is to look at the IAC counts or percentage. Normal **IAC counts** or percentage is usually 15 to 25. A reading of less than 5 indicates a vacuum leak.

If a vacuum leak occurs on an engine equipped with a mass airflow-type fuel-injection system, the extra air causes the following to occur:

- The engine will operate leaner-than-normal because the extra air has not been measured by the MAF sensor.
- The idle speed will likely be lower due to the leaner-than-normal air–fuel mixture.
- The idle air control (IAC) counts or percentage will often increase in an attempt to return the engine speed to the target speed stored in the computer.

PORT FUEL-INJECTION SYSTEM DIAGNOSIS

To determine if a port fuel-injection system—including the fuel pump, injectors, and fuel-pressure regulator–is operating correctly, take the following steps.

1. Attach a fuel-pressure gauge to the Schrader valve on the fuel rail. ● **SEE FIGURE 81–7.**



FIGURE 81–7 Checking the fuel pressure using a fuel-pressure gauge connected to the Schrader valve.

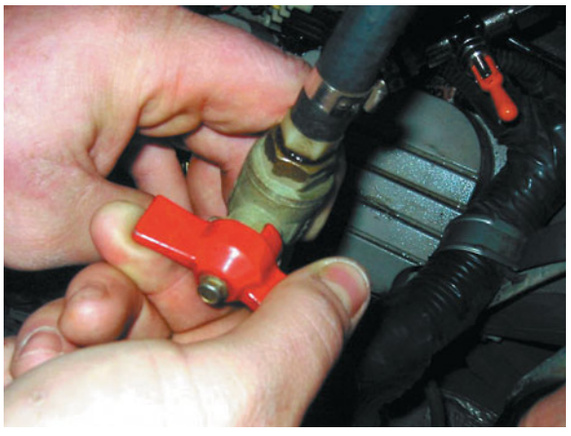


FIGURE 81–8 Shutoff valves must be used on vehicles equipped with plastic fuel lines to isolate the cause of a pressure drop in the fuel system.

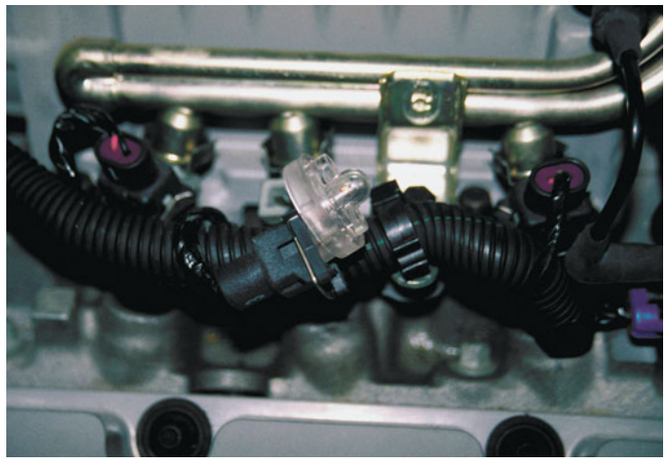
2. Turn the ignition key on or start the engine to build up the fuel-pump pressure (often about 35 to 45 PSI. Always check service information for the specified fuel pressure).
3. Wait 20 minutes and observe the fuel pressure retained in the fuel rail and note the PSI reading. The fuel pressure should not drop more than 20 PSI (140 kPa) in 20 minutes. If the drop is less than 20 PSI in 20 minutes, everything is okay; if the drop is *greater,* then there is a possible problem with:
   - The check valve in the fuel pump
   - Leaking injectors, lines, or fittings
   - A defective (leaking) fuel-pressure regulator

   To determine which unit is defective, perform the following:

- Reenergize the electric fuel pump.
- Clamp the fuel *supply* line, and wait 10 minutes (see Caution box). If the pressure drop does not occur, replace the fuel pump. If the pressure drop still occurs, continue with the next step.
- Repeat the pressure buildup of the electric pump and clamp the fuel return line. If the pressure drop time is now okay, replace the fuel-pressure regulator.
- If the pressure drop still occurs, one or more of the injectors is leaking. Remove the injectors with the fuel rail and hold over paper. Replace those injectors that drip one or more drops after 10 minutes with pressurized fuel.



(a)



(b)

FIGURE 81–9 (a) Noid lights are usually purchased as an assortment so that one is available for any type or size of injector wiring connector. (b) The connector is unplugged from the injector and a noid light is plugged into the harness side of the connector. The noid light should flash when the engine is being cranked if the power circuit and the pulsing to ground by the computer are functioning normally.

CAUTION: Do not clamp plastic fuel lines. Connect shutoff valves to the fuel system to shut off supply and return lines. ● **SEE FIGURE 81–8.**

TESTING FOR AN INJECTOR PULSE

One of the first checks that should be performed when diagnosing a no-start condition is whether the fuel injectors are being pulsed by the computer. Checking for proper pulsing of the injector is also important in diagnosing a weak or dead cylinder.

A **noid light** is designed to electrically replace the injector in the circuit and to flash if the injector circuit is working correctly. ● **SEE FIGURE 81–9.** To use a noid light, disconnect the electrical connector at the fuel injector and plug the noid light into the injector harness connections. Crank or start the engine. The noid light should flash regularly.

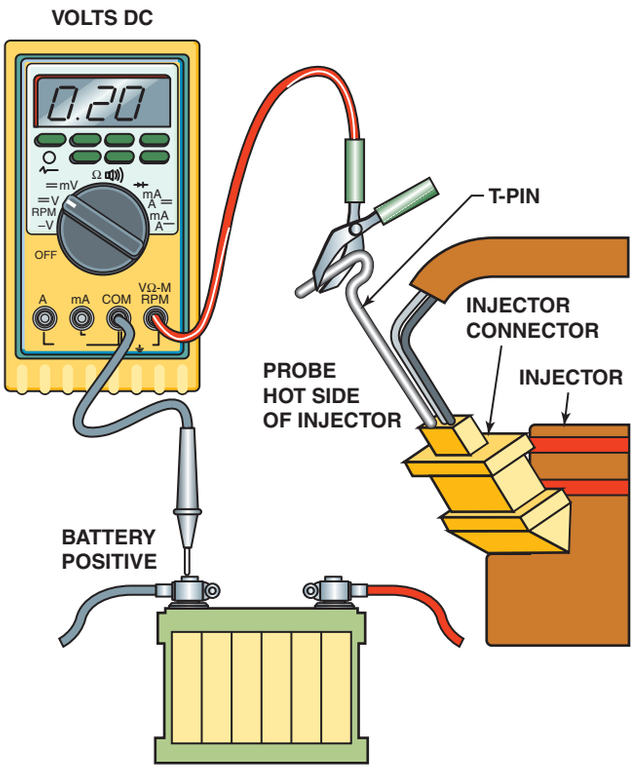


FIGURE 81–10 Use a DMM set to read DC volts to check the voltage drop of the positive circuit to the fuel injector. A reading of 0.5 volt or less is generally considered to be acceptable.

NOTE: The term *noid* is simply an abbreviation of the word *solenoid.* Injectors use a movable iron core and are therefore solenoids. Therefore, a noid light is a replacement for the solenoid (injector).

Possible noid light problems and causes include the following:

1. **The light is off and does not flash.** The problem is an open in either the power side or ground side (or both) of the injector circuit.
2. **The noid light flashes dimly.** A dim noid light indicates excessive resistance or low voltage available to the injector. Both the power and ground side must be checked.
3. **The noid light is on and does not flash.** If the noid light is on, then both a power and a ground are present. Because the light does not flash (blink) when the engine is being cranked or started, then a short-to-ground fault exists either in the computer itself or in the wiring between the injector and the computer.

CAUTION: A noid lamp must be used with caution. The computer may show a good noid light operation and have low supply voltage. ● **SEE FIGURE 81–10.**

CHECKING FUEL-INJECTOR RESISTANCE

Each port fuel injector must deliver an equal amount of fuel or the engine will idle roughly or perform poorly.

The electrical balance test involves measuring the injector coil-winding resistance. For best engine operation, all injectors should have the same electrical resistance. To measure the resistance, carefully release the locking feature of the connector and remove the connector from the injector.

Injector Resistance Table

Manufacturer	Injector Application	Resistance Values
General Motors		
	Quad 4	1.95–2.15 Ω
	CPI Vortec 4.3L	1.48–1.52 Ω
	MFI Bosch Style Injector (1985–1989) 2.8L	15.95–16.35 Ω
	MFI Black Multec Injector 2.8L, 3.1L, 3.3L, 3.4L	11.8–12.6 Ω
	MFI 3800	14.3–14.7 Ω
	MFI 3.8L, 5.0L, 5.7L	15.8–16.6 Ω
	MFI 5.7 LT5-ZR1	11.8–12.6 Ω
	TBI 220 Series 2.8L, 3.1L, 4.3L, 5.0L, 5.7L, 7.4L	1.16–1.36 Ω
	TBI 295 Series 4.3L, 6.0L, 7.0L	1.42–1.62 Ω
	TBI 700 Series 2.0L, 2.2L, 2.5L	1.42–1.62 Ω
Chrysler		
	MFI Early Years through 1992 (majority of)	2.4 Ω
	MFI Later Years after 1992 (majority of)	14.5 Ω
	TBI Low-Pressure Systems (majority of)	1.3 Ω
	TBI High-Pressure Systems (majority of)	0.7 Ω
Ford		
	MFI (majority of)	15.0–18.0 Ω
	TBI Low-Pressure 1.9L (1987–1990)	1.0–2.0 Ω
	TBI Low-Pressure 2.3L (1985–1987)	1.0–2.0 Ω
	TBI Low-Pressure 2.5L (1986–1990)	1.0–2.0 Ω
	TBI High-Pressure 3.8L (1984–1987)	1.5–2.5 Ω
	TBI High-Pressure 5.0L (1981–1985)	1.5–3.5 Ω

NOTE: Some engines require specific procedures to gain access to the injectors. Always follow the manufacturers' recommended procedures.

With an ohmmeter, measure the resistance across the injector terminals. Be sure to use the low-ohms feature of the digital ohmmeter to read in tenths (0.1) of an ohm. ● **SEE FIGURES 81–11 AND 81–12.** Check service information for the resistance specification of the injectors. Measure the resistance of all of the injectors. Replace any injector that does not fall within the resistance range of the specification. The resistance of the injectors should be measured twice—once when the engine (and injectors) are cold and once after the engine has reached normal operating temperature. If any injector resistance is not equal to specifications, make certain that the terminals of the injector are electrically sound, and perform other tests to confirm an injector problem before replacement.

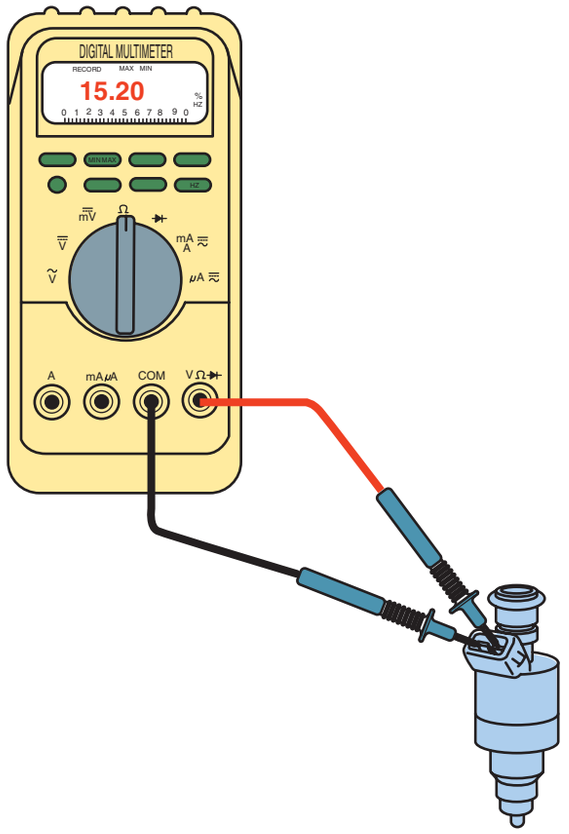


FIGURE 81–11 An ohmmeter is connected to the injector electrical terminals to read injector coil resistance.



FIGURE 81–12 To measure fuel-injector resistance, a technician constructed a short wiring harness with a double banana plug that fits into the V and COM terminals of the meter and an injector connector at the other end. This setup makes checking resistance of fuel injectors quick and easy.

MEASURING RESISTANCE OF GROUPED INJECTORS

Many vehicles are equipped with a port fuel-injection system that "fires" two or more injectors at a time. For example, a V-6 may group all three injectors on one bank to pulse on at the same time. Then the other three injectors will be pulsed on. This sequence alternates. To measure the resistance of these injectors, it is often easiest to measure each group of three that is wired in parallel. The resistance of three injectors wired in parallel is one-third of the resistance of each individual injector. For example,

Injector resistance = 12 ohms (Ω)

Three injectors in parallel = 4 ohms (Ω)

A V-6 has two groups of three injectors. Therefore, both groups should measure the same resistance. If both groups measure 4 ohms, then it is likely that all six injectors are okay. However, if one group measures only 2.9 ohms and the other group measures 4 ohms, then it is likely that one or more fuel injectors are defective (shorted). This means that the technician now has reasonable cause to remove the intake manifold to get access to each injector for further testing. ● **SEE FIGURE 81–13.**

TECH TIP

Equal Resistance Test

All fuel injectors should measure the specified resistance. However the specification often indicates the temperature of the injectors be at room temperature and of course will vary according to the temperature. Rather than waiting for all of the injectors to achieve room temperature, measure the resistance and check that they are all within 0.4 ohm of each other. To determine the difference, record the resistance of each injector and then subtract the lowest resistance reading from the highest resistance reading to get the difference. If more than 0.4 ohm then further testing will be needed to verify defective injector(s).

MEASURING RESISTANCE OF INDIVIDUAL INJECTORS

While there are many ways to check injectors, the first test is to measure the resistance of the coil inside and compare it to factory specifications. ● **SEE FIGURE 81–14.** If the injectors are not accessible, check service information for the location of the electrical connector for the injectors. Unplug the connector and measure the resistance of each injector at the injector side of the connector. Use service information to determine the wire colors for the power side and the pulse side of each injector.

PRESSURE-DROP BALANCE TEST

The pressure balance test involves using an electrical timing device to pulse the fuel injectors on for a given amount of time, usually 500 ms or 0.5 second, and observing the drop in pressure that accompanies the pulse. If the *fuel flow* through each injector is equal, the drop in pressure in the system will be equal. Most manufacturers



(a)



(b)

FIGURE 81–13 (a) The meter is connected to read one group of three 12-ohm injectors. The result should be 4 ohms and this reading is a little low indicating that at least one injector is shorted (low resistance). (b) This meter is connected to the other group of three injectors and indicates that most, if not all three, injectors are shorted. The technician replaced all six injectors and the engine ran great.

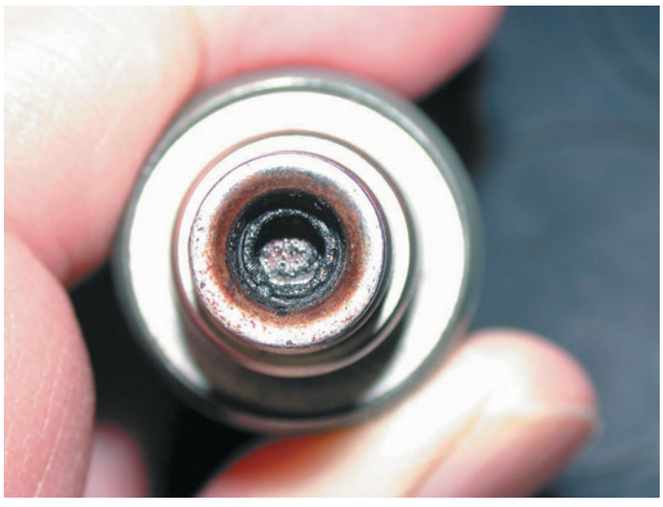


FIGURE 81–14 If an injector has the specified resistance, this does not mean that it is okay. This injector had the specified resistance yet it did not deliver the correct amount of fuel because it was clogged.

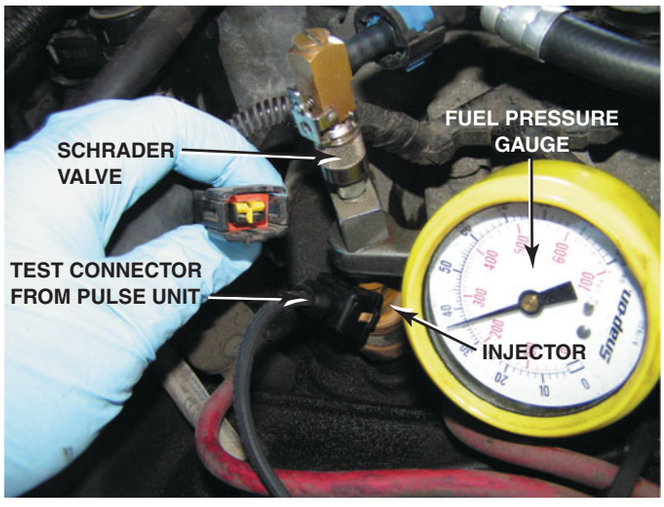


FIGURE 81–15 After connecting a pressure gauge, unplug the electrical connector from an injector and attach the test lead from the pulse unit to the injector.

recommend that the pressures be within about 1.5 PSI (10 kPa) of each other for satisfactory engine performance. This test method not only tests the electrical functioning of the injector (for definite time and current pulse), but also tests for mechanical defects that could affect fuel flow amounts.

The purpose of running this injector balance test is to determine which injector is restricted, inoperative, or delivering fuel differently than the other injectors. Replacing a complete set of injectors can be expensive. The basic tools needed are:

- Accurate pressure gauge with pressure relief
- Injector pulser with time control
- Necessary injector connection adapters
- Safe receptacle for catching and disposing of any fuel released

STEP 1 Attach the pressure gauge to the fuel delivery rail on the supply side. Make sure the connections are safe and leakproof.

STEP 2 Attach the injector pulser to the first injector to be tested.

STEP 3 Turn the ignition key to the on position to prime the fuel rail. Note the static fuel-pressure reading.

STEP 4 Activate the pulser for the timed firing pulses.

STEP 5 Note and record the new static rail pressure after the injector has been pulsed. ● **SEE FIGURE 81–15.**

STEP 6 Reenergize the fuel pump and repeat this procedure for all of the engine injectors.

STEP 7 Compare the two pressure readings and compute the pressure drop for each injector. Compare the pressure drops of the injectors to each other. Any variation in pressure drops will indicate an uneven fuel delivery rate between the injectors.

For example:

Injector	1	2	3	4	5	6
Initial pressure	40	40	40	40	40	40
Second pressure	30	30	35	30	20	30
Pressure drop	10	10	5	10	20	10
Possible problem	OK	OK	Restriction	OK	Leak	OK



FIGURE 81–16 An injector tester being used to check the voltage drop through the injector while the tester is sending current through the injectors. This test is used to check the coil inside the injector. This same tester can be used to check for equal pressure drop of each injector by pulsing the injector on for 500 ms.

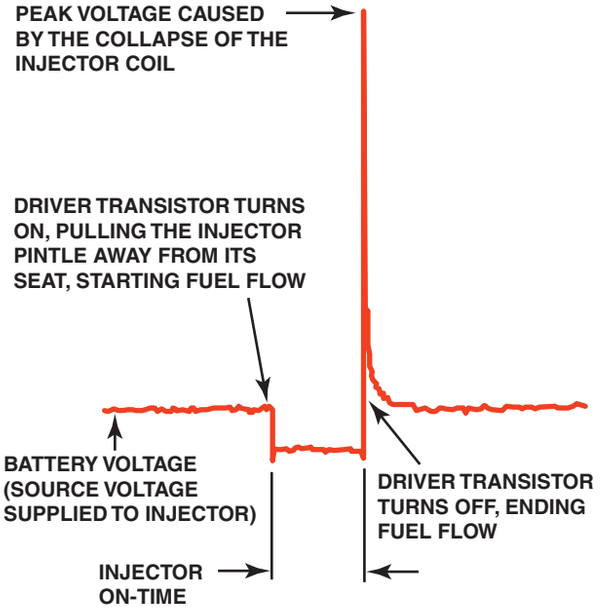


FIGURE 81–18 The injector on-time is called the pulse width. (*Courtesy of Fluke Corporation*)

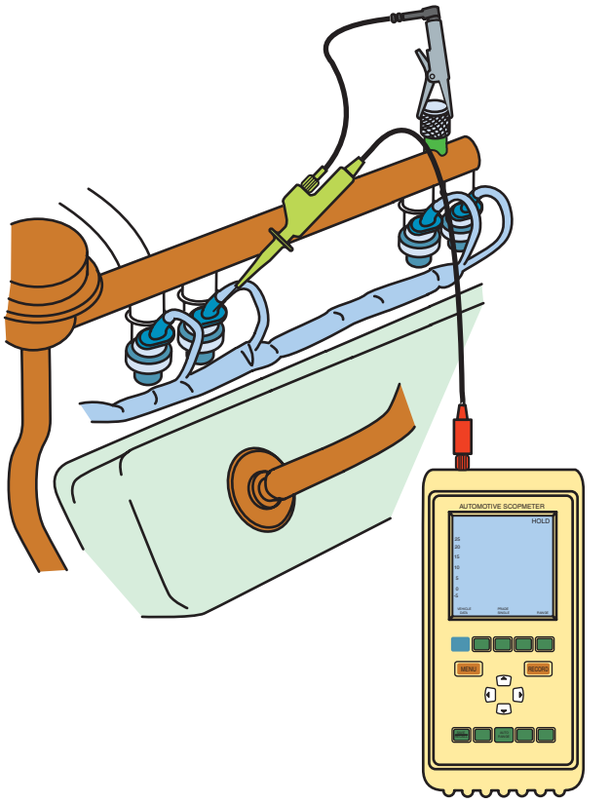


FIGURE 81–17 A digital storage oscilloscope can be easily connected to an injector by carefully back probing the electrical connector.

INJECTOR VOLTAGE-DROP TESTS

Another test of injectors involves pulsing the injector and measuring the voltage drop across the windings as current is flowing. A typical voltage-drop tester is shown in ● **FIGURE 81–16.** The tester, which is recommended for use by General Motors Corporation, pulses the injector while a digital multimeter is connected to the unit, which will display the voltage drop as the current flows through the winding.

CAUTION: Do not test an injector using a pulse-type tester more than one time without starting the engine to help avoid a hydrostatic lock caused by the flow of fuel into the cylinder during the pulse test.

Record the highest voltage drop observed on the meter display during the test. Repeat the voltage-drop test for all of the injectors. The voltage drop across each injector should be within 0.1 volt of each other. If an injector has a higher-than-normal voltage drop, the injector windings have higher-than-normal resistance.

SCOPE-TESTING FUEL INJECTORS

A scope (analog or digital storage) can be connected into each injector circuit. There are three types of injector drive circuits and each type of circuit has its own characteristic pattern. ● **SEE FIGURE 81–17** for an example of how to connect a scope to read a fuel-injector waveform.

SATURATED SWITCH TYPE In a saturated switch-type injector-driven circuit, voltage (usually a full 12 volts) is applied to the injector. The ground for the injector is provided by the vehicle computer. When the ground connection is completed, current flows through the injector windings. Due to the resistance and inductive reactance of the coil itself, it requires a fraction of a second (about 3 milliseconds or 0.003 seconds) for the coil to reach **saturation** or maximum current flow. Most saturated switch-type fuel injectors have 12 to 16 ohms of resistance. This resistance, as well as the computer switching circuit, control and limit the current flow through the injector. A voltage spike occurs when the computer shuts off (opens the injector ground-side circuit) the injectors. ● **SEE FIGURE 81–18.**

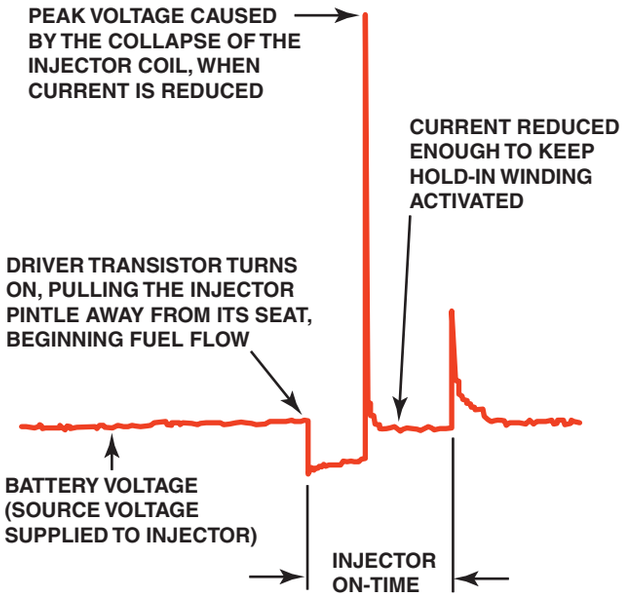


FIGURE 81–19 A typical peak-and-hold fuel-injector waveform. Most fuel injectors that measure less than 6 ohms will usually display a similar waveform.

PEAK-AND-HOLD TYPE A **peak-and-hold** type is typically used for TBI and some port low-resistance injectors. Full battery voltage is applied to the injector and the ground side is controlled through the computer. The computer provides a high initial current flow (about 4 amperes) to flow through the injector windings to open the injector core. Then the computer reduces the current to a lower level (about 1 ampere). The hold current is enough to keep the injector open, yet conserves energy and reduces the heat buildup that would occur if the full current flow remains on as long as the injector is commanded on. Typical peak-and-hold-type injector resistance ranges from 2 to 4 ohms.

The scope pattern of a typical peak-and-hold-type injector shows the initial closing of the ground circuit, then a voltage spike as the current flow is reduced. Another voltage spike occurs when the lower level current is turned off (opened) by the computer. ● **SEE FIGURE 81–19.**

PULSE-WIDTH MODULATED TYPE A pulse-width modulated type of injector drive circuit uses lower-resistance coil injectors. Battery voltage is available at the positive terminal of the injector and the computer provides a variable-duration connection to ground on the negative side of the injector. The computer can vary the time intervals that the injector is grounded for very precise fuel control.

Each time the injector circuit is turned off (ground circuit opened), a small voltage spike occurs. It is normal to see multiple voltage spikes on a scope connected to a pulse-width modulated type of fuel injector.

IDLE AIR SPEED CONTROL DIAGNOSIS

On an engine equipped with fuel injection (TBI or port injection), the idle speed is controlled by increasing or decreasing the amount of air bypassing the throttle plate. Again, an electronic stepper motor or pulse-width modulated solenoid is used to maintain the correct idle speed. This control is often called the **idle air control (IAC).** ● **SEE FIGURES 81–21 THROUGH 81–23.**

When the engine stops, most IAC units will retract outward to get ready for the next engine start. When the engine starts, the engine speed is high to provide for proper operation when the engine is cold. Then, as the engine gets warmer, the computer reduces engine idle speed gradually by reducing the number of counts or steps commanded by the IAC.

When the engine is warm and restarted, the idle speed should momentarily increase, then decrease to normal idle speed. This increase and then decrease in engine speed is often called an engine-flare. If the engine speed does not flare, then the IAC may not be working (it may be stuck in one position).



FIGURE 81–20 A set of six reconditioned injectors. The sixth injector is barely visible at the far right.

FREQUENTLY ASKED QUESTION

If Three of Six Injectors Are Defective, Should I Also Replace the Other Three?

This is a good question. Many service technicians "recommend" that the three good injectors also be replaced along with the other three that tested as being defective. The reasons given by these technicians include:

- All six injectors have been operating under the same fuel, engine, and weather conditions.
- The labor required to replace all six is just about the same as replacing only the three defective injectors.
- Replacing all six at the same time helps ensure that all of the injectors are flowing the same amount of fuel so that the engine is operating most efficiently.

With these ideas in mind, the customer should be informed and offered the choice. Complete sets of injectors such as those in ● **FIGURE 81–20** can be purchased at a reasonable cost.

FUEL-INJECTION SERVICE

After many years of fuel-injection service, some service technicians still misunderstand the process of proper fuel-system handling. Much has been said over the years with regard to when and how

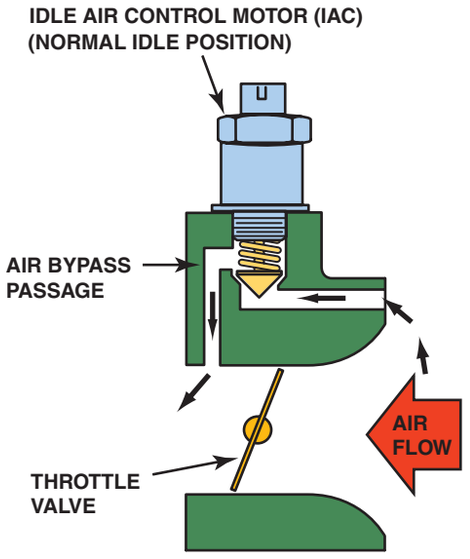


FIGURE 81–21 An IAC controls idle speed by controlling the amount of air that passes around the throttle plate. More airflow results in a higher idle speed.

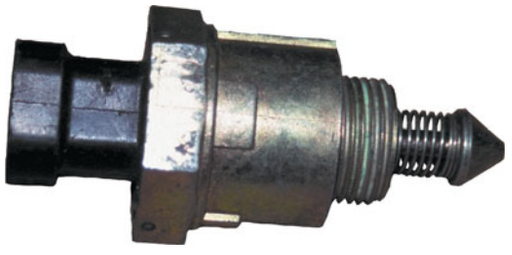


FIGURE 81–22 A typical IAC.

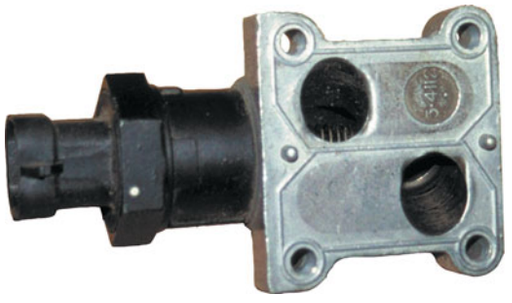


FIGURE 81–23 Some IAC units are purchased with the housing as shown. Carbon buildup in these passages can cause a rough or unstable idling or stalling.



(a)



(b)

FIGURE 81–24 (a) Nothing looks unusual when the hood is first opened. (b) When the cover is removed from the top of the engine, a mouse or some other animal nest is visible. The animal had already eaten through a couple of injector wires. At least the cause of the intermittent misfire was discovered.

REAL WORLD FIX

There Is No Substitute for a Thorough Visual Inspection

An intermittent "check engine" light and a random-misfire diagnostic trouble code (DTC) P0300 was being diagnosed. A scan tool did not provide any help because all systems seemed to be functioning normally. Finally, the technician removed the engine cover and discovered a mouse nest. ● **SEE FIGURE 81–24.**

to perform injector cleaning. Some manufacturers have suggested methods of cleaning while others have issued bulletins to prohibit any cleaning at all.

All engines using fuel injection do require some type of fuel-system maintenance. Normal wear and tear with underhood temperatures and changes in gasoline quality contribute to the buildup of olefin wax, dirt, water, and many other additives. Unique to each engine is an idle air-control design that also may contribute different levels of carbon deposits.

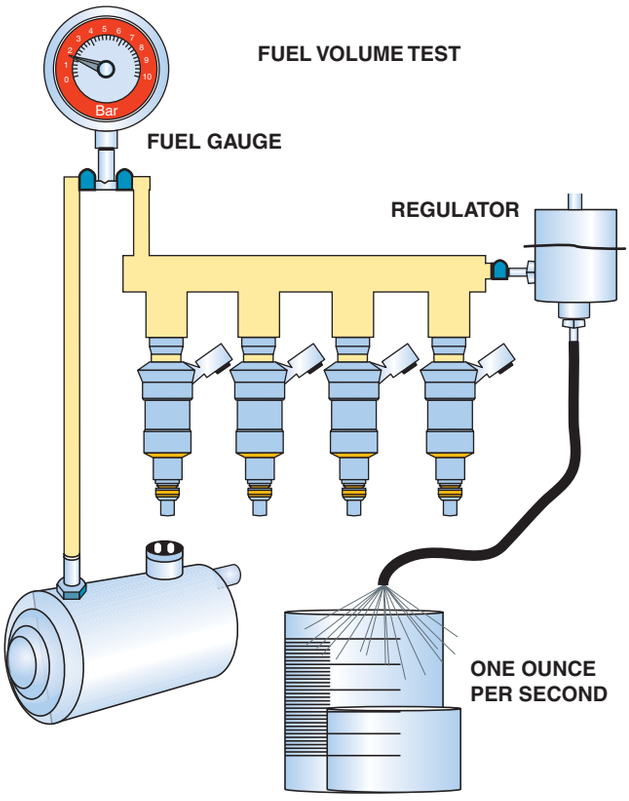


FIGURE 81–25 Checking fuel-pump volume using a hose from the outlet of the fuel-pressure regulator into a calibrated container.

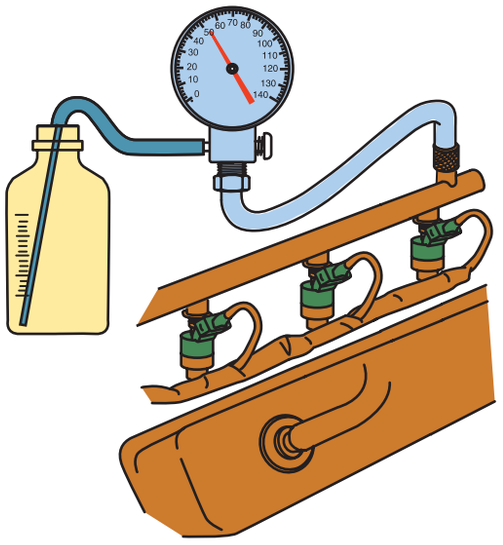


FIGURE 81–26 Testing fuel-pump volume using a fuel-pressure gauge with a bleed hose inserted into a suitable container. The engine is running during this test.

Fuel-injection system service should include the following operations:

1. **Check fuel-pump operating pressure and volume.** The missing link here is volume. Most working technicians assume that if the pressure is correct, the volume is also okay. Hook up a fuel-pressure tester to the fuel rail inlet to quickly test the fuel pressure with the engine running. At the same time, test the volume of the pump by sending fuel into the holding tank. (One ounce per second is the usual specification.) ● **SEE FIGURE 81–25.** A two-line system tester is the recommended procedure to use and is attached to the fuel inlet and the return on the fuel rail. The vehicle onboard system is looped and returns fuel to the tank.
2. **Test the fuel-pressure regulator for operation and leakage.** At this time, the fuel-pressure regulator would be tested for operational pressure and proper regulation, including leakage. Below are some points to consider:
   - Good pressure does not mean proper volume. For example, a clogged filter may test okay on pressure but the restriction may not allow proper volume under load. ● **SEE FIGURE 81–26.**
   - It is a good idea to use the vehicle's own gasoline to service the system versus a can of shop gasoline that has been sitting around for some time.
   - Pressure regulators do fail and a lot more do not properly shut off fuel, causing higher-than-normal pump wear and shorter service life.
3. **Flush the entire fuel rail and upper fuel-injector screens including the fuel-pressure regulator.** Raise the input pressure to a point above regulator setting to allow a constant flow of fuel through the inlet pressure side of the system, through the fuel rail, and out the open fuel-pressure regulator. In most cases the applied pressure is 75 to 90 PSI (517 to 620 kPa), but will be maintained by the presence of a regulator. At this point, cleaning chemical is added to the fuel at a 5:1 mixture and allowed to flow through the system for 15 to 30 minutes. ● **SEE FIGURE 81–27.** Results are best on a hot engine with the fuel supply looped and the engine not running. Below are some points to consider:
   - This flush is the fix most vehicles need first. The difference is that the deposits are removed to a remote tank and filter versus attempting to soften the deposits and blow them through the upper screens.
   - Most injectors use a 10-micron final filter screen. A 25% restriction in the upper screen would increase the injector on-time approximately 25%.
   - **Clean the fuel injectors.** Start the engine and adjust the output pressure closer to regulator pressure or lower than in the previous steps. Lower pressure will cause the pulse width to open up somewhat longer and allow the injectors to be cleaned. Slow speed (idle) position will take a longer time frame and operating temperature will be reached. Clean injectors are the objective, but the chemical should also decarbon the engine valves, pistons, and oxygen sensor.
4. **Decarbon the engine assembly.** On most vehicles, the injector spray will help the decarboning process. On others, you may need to enhance the operation with external addition of a mixture through the PCV hose, throttle plates, or idle air controls.
5. **Clean the throttle plate and idle air control passages.** Doing this service alone on most late-model engines will show a manifold vacuum increase of up to 2 in. Hg. Stop the engine and clean the areas as needed, then use a handheld fuel injector connected in parallel with the pressure hose, along with a pulser to allow cleaning of the throttle plates with the same chemical as injectors are running on. ● **SEE FIGURE 81–28.** This works well as air is drawn into IAC passages on a running engine and will clean the passages without IAC removal.
6. **Relearn the onboard computer.** Some vehicles may have been running in such a poor state of operation that the onboard computer may need to be relearned. Consult service information for the suggested relearn procedures for each particular vehicle.

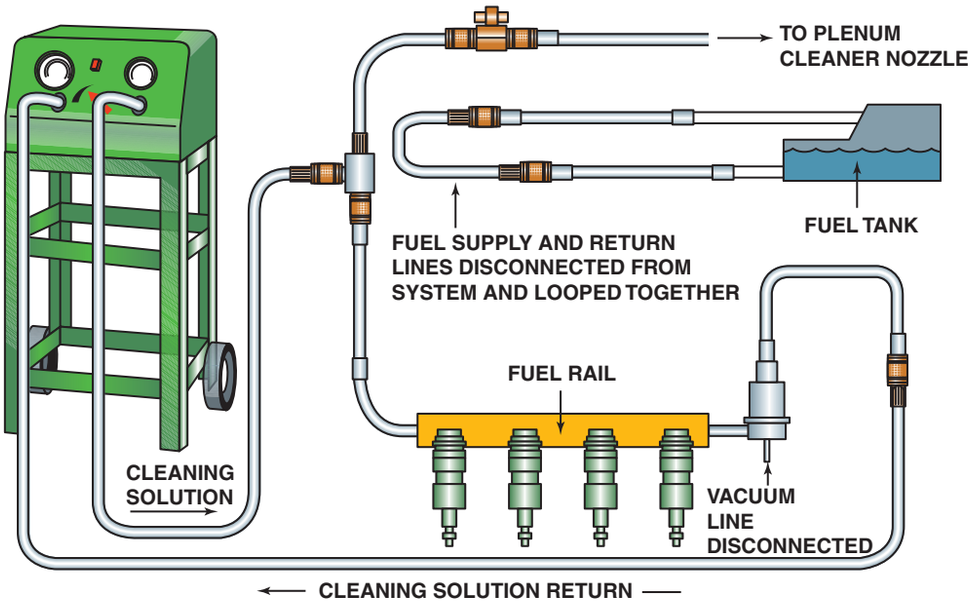


FIGURE 81–27 A typical two-line cleaning machine hookup, showing an extension hose that can be used to squirt a cleaning solution into the throttle body while the engine is running on the cleaning solution and gasoline mixture. Typical two-line cleaning machines include Carbon Clean, Auto Care, Injector Test, DeCarbon, or Motor-Vac.

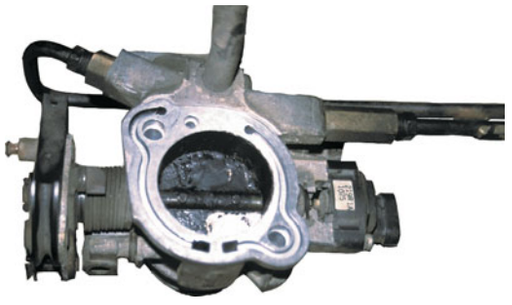


FIGURE 81–28 To thoroughly clean a throttle body, it is sometimes best to remove it from the vehicle.

TECH TIP

Check the Injectors at the "Bends and the Ends"

Injectors that are most likely to become restricted due to clogging of the filter basket screen are the injectors at the ends of the rail especially on returnless systems where dirt can accumulate. Also the injectors that are located at the bends of the fuel rail are also subject to possible clogging due to the dirt being deposited where the fuel makes a turn in the rail.

This service usually takes approximately one hour for the vehicle to run out of fuel and the entire service to be performed. The good thing is that the technician may do other services while this is being performed. Some technicians may install a set of plugs or change the fuel filter while the engine is flushing. This service should restore the fuel system to original operations.

TECH TIP

Be Sure to Clean the Fuel Rail

Whenever you service the fuel injectors, or if you suspect that there may be a fuel-injector problem, remove the entire fuel rail assembly and check the passages for contamination. Always thoroughly clean the rail when replacing fuel injectors.

Fuel-Injection Symptom Chart

Symptom	Possible Causes
Hard cold starts	• Low fuel pressure • Leaking fuel injectors • Contaminated fuel • Low-volatility fuel • Dirty throttle plate
Garage stalls	• Low fuel pressure • Insufficient fuel volume • Restricted fuel injector • Contaminated fuel • Low-volatility fuel
Poor cold performance	• Low fuel pressure • Insufficient fuel volume • Contaminated fuel • Low-volatility fuel
Tip-in hesitation (hesitation just as the accelerator pedal is depressed)	• Low fuel pressure • Insufficient fuel volume • Intake valve deposits • Contaminated fuel • Low-volatility fuel

FUEL-SYSTEM SCAN TOOL DIAGNOSTICS

FUEL TRIM VALUES Diagnosing a faulty fuel system can be a difficult task. However, it can be made easier by utilizing the information available via the serial data stream. By observing the long-term fuel trim and the short-term fuel trim, we can determine how the fuel system is performing. Short-term fuel trim and long-term fuel trim can help us to zero in on specific areas of trouble. Readings should be taken at idle and at 3000 RPM. Use the following chart as a guide.

Condition	Long-Term Fuel Trim at Idle	Long-Term Fuel Trim at 3000 RPM
System normal	0% ± 10%	0% ± 10%
Vacuum leak	HIGH	OK
Fuel flow problem	OK	HIGH
Low fuel pressure	HIGH	HIGH
High fuel pressure	*OK or LOW	*OK or LOW

*High fuel pressure will affect trim at idle, at 3000 RPM, or both.

IAC COUNTS A scan tool can be used to check the counts or steps needed to control the idle speed. With the engine at normal operating temperature, the following IAC position as displayed on a scan tool will help with fuel system diagnosis.

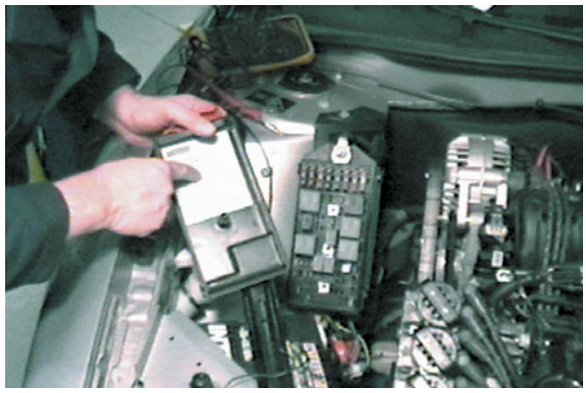
Normal—Normal idle air control counts should be 25–35 counts or percentage.

Lower-than-normal—If the IAC counts or percentage is less than 5 then there could be a vacuum leak (speed density system) or false air on some mass air flow engines.

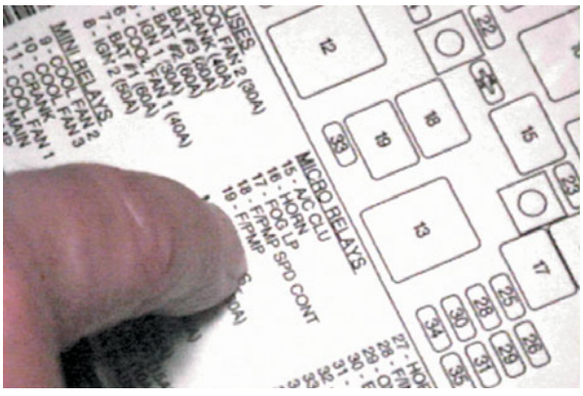
Higher-than-normal—If the counts or percentage is higher than 50, then this could be due to an excessive drag on the engine or a dirty throttle body or throttle plate.



1 The tools needed to diagnose a circuit containing a relay include a digital multimeter (DMM), a fused jumper wire, and an assortment of wiring terminals.



2 Start the diagnosis by locating the relay center. It is under the hood on this General Motors vehicle, so access is easy. Not all vehicles are this easy.



3 The chart under the cover for the relay center indicates the location of the relay that controls the electric fuel pump.



4 Locate the fuel-pump relay and remove by using a puller if necessary. Try to avoid rocking or twisting the relay to prevent causing damage to the relay terminals or the relay itself.



5 Terminals 85 and 86 represent the coil inside the relay. Terminal 30 is the power terminal, 87a is the normally closed contact, and 87 is the normally open contact.

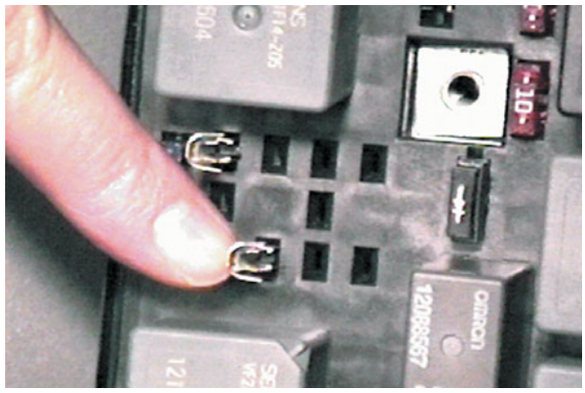


6 The terminals are also labeled on most relays.

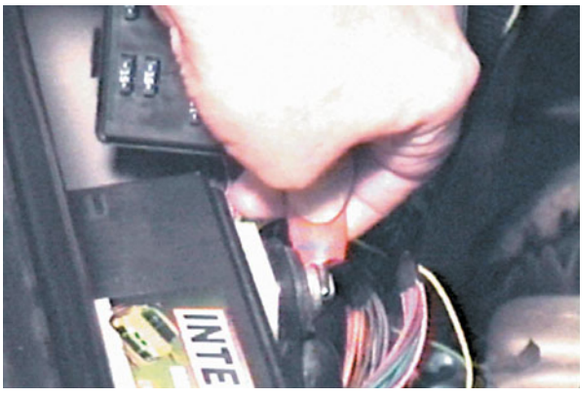
CONTINUED ▶



7 To help make good electrical contact with the terminals without doing any harm, select the proper-size terminal from the terminal assortment.



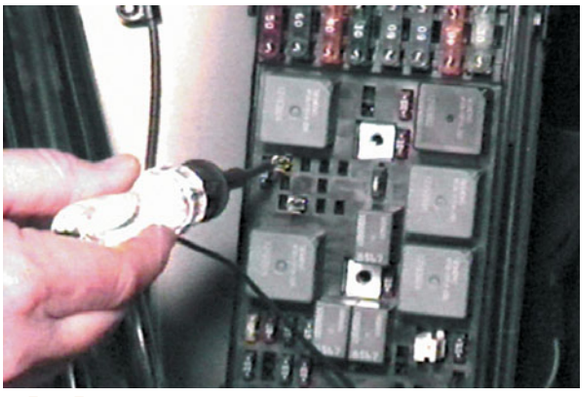
8 Insert the terminals into the relay socket in 30 and 87.



9 To check for voltage at terminal 30, use a test light or a voltmeter. Start by connecting the alligator clip of the test light to the positive (+) terminal of the battery.



10 Touch the test light to the negative (−) terminal of the battery or a good engine ground to check the test light.



11 Connect the ground lead of the test light to a good ground and check for voltage at terminal 30 of the relay. The ignition may have to be in the on (run) position.



12 To check to see if the electric fuel pump can be operated from the relay contacts, use a fused jumper wire and touch the relay contacts that correspond to terminals 30 and 87 of the relay.



13 Connect the leads of the meter to contacts 30 and 87 of the relay socket. The reading of 4.7 amperes is okay because the specification is 4 to 8 amperes.



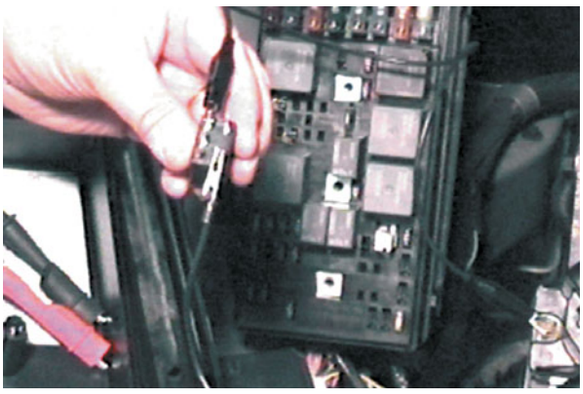
14 Set the meter to read ohms (Ω) and measure the resistance of the relay coil. The usual reading for most relays is between 60 and 100 ohms.



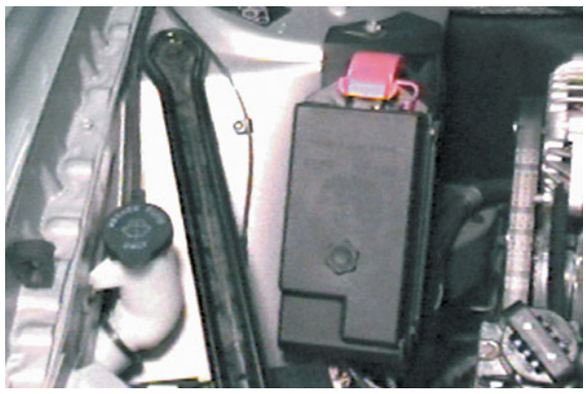
15 Measure between terminal 30 and 87a. Terminal 87a is the normally closed contact, and there should be little, if any, resistance between these two terminals, as shown.



16 To test the normally open contacts, connect one meter lead to terminal 30 and the other lead to terminal 87. The ohmmeter should show an open circuit by displaying OL.

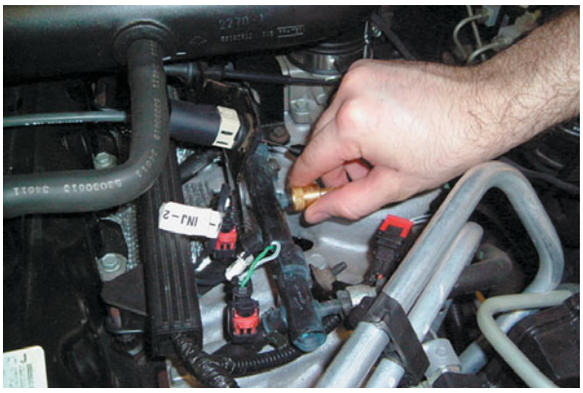


17 Connect a fused jumper wire to supply 12 volts to terminal 86 and a ground to terminal 85 of the relay. If the relay clicks, then the relay coil is able to move the armature (movable arm) of the relay.

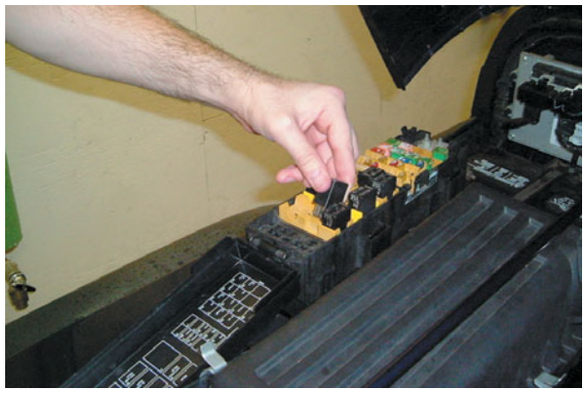


18 After testing, be sure to reinstall the relay and the relay cover.

FUEL INJECTOR CLEANING



1 Start the fuel injector cleaning process by bringing the vehicle's engine up to operating temperature. Shut off the engine, remove the cap from the fuel rail test port, and install the appropriate adapter.



2 The vehicle's fuel pump is disabled by removing its relay or fuse. In some cases, it may be necessary to disconnect the fuel pump at the tank if the relay or fuse powers more than just the pump.



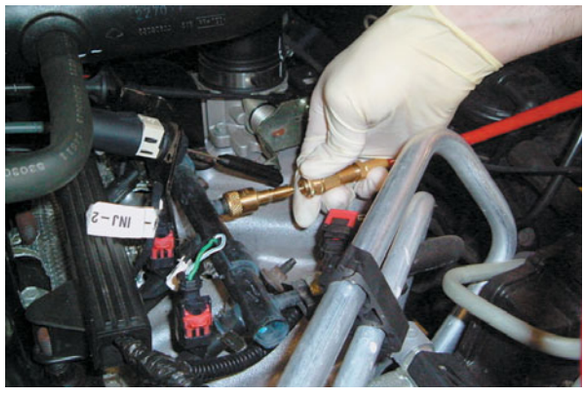
3 Turn the outlet valve of the canister to the OFF or CLOSED position.



4 Remove the fuel injector cleaning canister's top and regulator assembly. Note that there is an O-ring seal located here that must be in place for the canister's top to seal properly.



5 Pour the injection system cleaning fluid into the open canister. Rubber gloves are highly recommended for this step as the fluid is toxic.



6 Replace the canister's top (making sure it is tight) and connect its hose to the fuel rail adapter. Be sure that the hose is routed away from exhaust manifolds and other hazards.



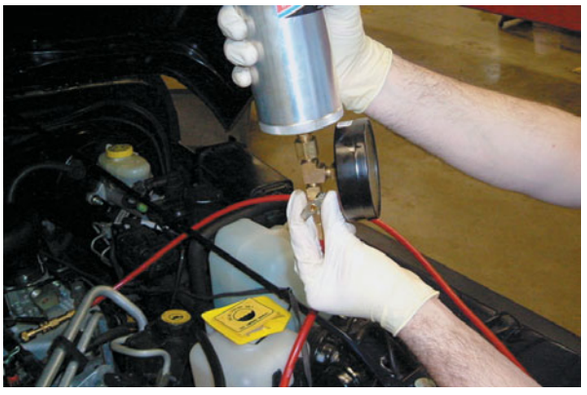
7 Hang the canister from the vehicle's hood and adjust the air pressure regulator to full OPEN position (CCW).



8 Connect shop air to the canister and adjust the air pressure regulator to the desired setting. Canister pressure can be read directly from the gauge.



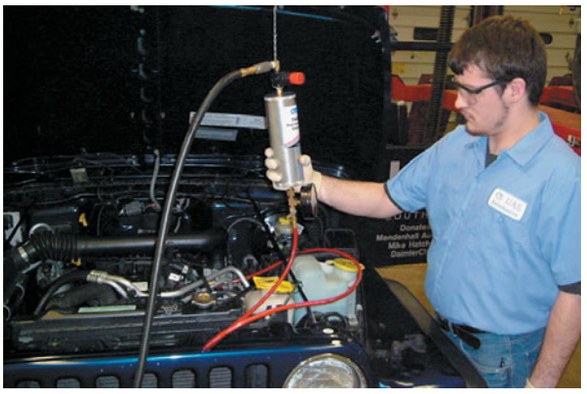
9 Canister pressure should be adjusted to 5 PSI below system fuel pressure. An alternative for return-type systems is to block the fuel return line to the tank.



10 Open the outlet valve on the canister.



11 Start the vehicle's engine and let run at 1000–1500 RPM. The engine is now running on fuel injector cleaning fluid provided by the canister.



12 Continue the process until the canister is empty and the engine stalls. Remove the cleaning equipment, enable the vehicle's fuel pump, and run the engine to check for leaks.

REVIEW QUESTIONS

1. List the ways fuel injectors can be tested.
2. List the steps necessary to test a fuel-pressure regulator.
3. Describe why it may be necessary to clean the throttle plate of a port fuel-injected engine.

CHAPTER QUIZ

1. Most port fuel-injected engines operate on how much fuel pressure?
   a. 3 to 5 PSI (21 to 35 kPa)
   b. 9 to 13 PSI (62 to 90 kPa)
   c. 35 to 45 PSI (240 to 310 kPa)
   d. 55 to 65 PSI (380 to 450 kPa)
2. Fuel injectors can be tested using _____.
   a. An ohmmeter **c.** A scope
   b. A stethoscope **d.** All of the above
3. Throttle-body fuel-injection systems use what type of injector driver?
   a. Peak and hold **c.** Pulse-width modulated
   b. Saturated switch **d.** Pulsed
4. Port fuel-injection systems generally use what type of injector driver?
   a. Peak and hold **c.** Pulse-width modulated
   b. Saturated switch **d.** Pulsed
5. The vacuum hose from the fuel-pressure regulator was removed from the regulator and gasoline dripped out of the hose. Technician A says that is normal and that everything is okay. Technician B says that one or more of the injectors may be defective, causing the fuel to get into the hose. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. The fuel pressure drops rapidly when the engine is turned off. Technician A says that one or more injectors could be leaking. Technician B says that a defective check valve in the fuel pump could be the cause. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
7. In a typical port fuel-injection system, which injectors are most subject to becoming restricted?
   a. Any of them equally
   b. The injectors at the end of the rail on a returnless system
   c. The injectors at the bends in the rail
   d. Either b or c
8. What component pulses the fuel injector on most vehicles?
   a. Powertrain control module (PCM)
   b. Ignition module
   c. Crankshaft sensor
   d. Both b and c
9. Fuel-injection service is being discussed. Technician A says that the throttle plate(s) should be cleaned. Technician B says that the fuel rail should be cleaned. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
10. If the throttle plate needs to be cleaned, what symptoms will be present regarding the operation of the engine?
    a. Stalls **c.** Hesitation on acceleration
    b. Rough idle **d.** All of the above

chapter 82

VEHICLE EMISSION STANDARDS AND TESTING

OBJECTIVES: After studying Chapter 82, the reader will be able to: • Prepare for ASE A8 certification test content area "D" (Emissions Control Systems Diagnosis and Repair) and ASE L1 certification test content area "F" (I/M Failure Diagnosis). • Discuss emission standards. • Identify the reasons why excessive amounts of HC, CO, and NO_X exhaust emissions are created. • Describe how to baseline a vehicle after an exhaust emission failure. • List acceptable levels of HC, CO, CO_2, and O_2 with and without a catalytic converter. • List four possible causes for high readings for HC, CO, and NO_X.

KEY TERMS: Acceleration simulation mode (ASM) 922 • ASM 25/25 test 922 • ASM 50/15 test 922 • Clean Air Act Amendments (CAAA) 919 • Federal Test Procedure (FTP) 921 • I/M 240 test 922 • Lean indicator 925 • Non-methane hydrocarbon (NMHC) 923 • Ozone 925 • Rich indicator 924 • Sealed Housing for Evaporative Determination (SHED) test 921 • Smog 925 • State Implementation Plan (SIP) 920

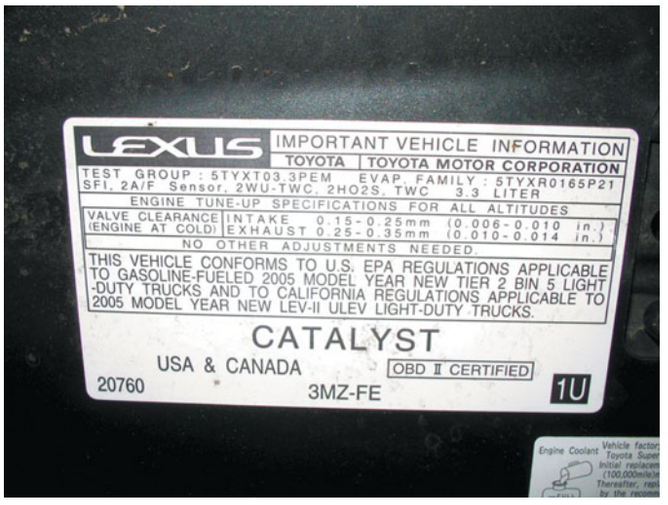


FIGURE 82–1 The underhood decal showing that this Lexus RX-330 meets both national (Tier 2; BIN 5) and California LEV-II (ULEV) regulation standards.

EMISSION STANDARDS IN THE UNITED STATES

In the United States, emissions standards are managed by the Environmental Protection Agency (EPA) as well as some U.S. state governments. Some of the strictest standards in the world are formulated in California by the California Air Resources Board (CARB).

TIER 1 AND TIER 2

Federal emission standards are set by the **Clean Air Act Amendments (CAAA)** of 1990 grouped by tier. All vehicles sold in the United States must meet Tier 1 standards that went into effect in 1994 and are the least stringent. Additional Tier 2 standards have been optional since 2001, and was fully phased in by 2009. The current Tier 1 standards are different between automobiles and light trucks (SUVs, pickup trucks, and minivans), but Tier 2 standards will be the same for both types of vehicles.

There are several ratings that can be given to vehicles, and a certain percentage of a manufacturer's vehicles must meet different levels in order for the company to sell its products in affected regions. Beyond Tier 1, and in order by stringency, are the following levels:

- **TLEV Transitional Low-Emission Vehicle.** More stringent for HC than Tier 1.
- **LEV** (also known as **LEV I): Low-Emission Vehicle.** An intermediate California standard about twice as stringent as Tier 1 for HC and NO_x.
- **ULEV** (also known as **ULEV I): Ultra-Low-Emission Vehicle.** A stronger California standard emphasizing very low HC emissions.
- **ULEV II: Ultra-Low-Emission Vehicle.** A cleaner-than-average vehicle certified under the Phase II LEV standard. Hydrocarbon and carbon monoxide emissions levels are nearly 50% lower than those of a LEV II-certified vehicle. ● **SEE FIGURE 82–1.**
- **SULEV: Super-Ultra-Low-Emission Vehicle.** A California standard even tighter than ULEV, including much lower HC and NO_x emissions; roughly equivalent to Tier 2 Bin 2 vehicles.
- **ZEV: Zero-Emission Vehicle.** A California standard prohibiting any tailpipe emissions. The ZEV category is largely restricted to electric vehicles and hydrogen-fueled vehicles. In these cases, any emissions that are created are produced at another site, such as a power plant or hydrogen reforming center, unless such sites run on renewable energy.

NOTE: A battery-powered electric vehicle charged from the power grid will still be up to 10 times cleaner than even the cleanest gasoline vehicles over their respective lifetimes.

- **PZEV: Partial Zero-Emission Vehicle.** Compliant with the SULEV standard; additionally has near-zero evaporative emissions and a 15-year/150,000-mile warranty on its emission control equipment.

Tier 2 standards are even more stringent. Tier 2 variations are appended with "II," such as LEV II or SULEV II. Other categories have also been created:

- **ILEV: Inherently Low-Emission Vehicle.** A vehicle certified to meet the transitional low-emission vehicle standards established by the California Air Resources Board (CARB)
- **AT-PZEV: Advanced Technology Partial Zero-Emission Vehicle.** If a vehicle meets the PZEV standards and is using high-technology features, such as an electric motor or high-pressure gaseous fuel tanks for compressed natural gas, it qualifies as an AT-PZEV. Hybrid electric vehicles such as the Toyota Prius can qualify, as can internal combustion engine vehicles that run on natural gas (CNG), such as the Honda Civic GX. These vehicles are classified as "partial" ZEV because they receive partial credit for the number of ZEV vehicles that automakers would otherwise be required to sell in California.
- **NLEV: National Low-Emission Vehicle.** All vehicles nationwide must meet this standard, which started in 2001.

FEDERAL EPA BIN NUMBER

The higher the tier number, the newer the regulation; the lower the bin number, the cleaner the vehicle. The Toyota Prius is a very clean Bin 3, while the Hummer H2 is a dirty Bin 11. ● **SEE CHARTS 82–1, 82–2, AND 82–3.**

SMOG EMISSION INFORMATION

New vehicles are equipped with a sticker that shows the relative level of smog-causing emissions created by the vehicle compared to others on the market. Smog-causing emissions include unburned hydrocarbons (HC) and oxides of nitrogen (NO_x). ● **SEE FIGURE 82–2.**

CALIFORNIA STANDARDS

The pre-2004 California Air Resources Board (CARB) standards as a whole were known as LEV I. Within that, there were four possible ratings: Tier 1, TLEV, LEV, and ULEV. The newest CARB rating system (since January 1, 2004) is known as LEV II. Within that rating system there are three primary ratings: LEV, ULEV, and SULEV. States other than California are given the option to use the federal EPA standards, or they can adopt California's standards.

EUROPEAN STANDARDS

Europe has its own set of standards that vehicles must meet, which includes the following tiers:

- Euro I (1992–1995)
- Euro II (1995–1999)

CERTIFICATION LEVEL	NMOG (G/MI)	CO (G/MI)	NO_x (G/MI)
Bin 1	0.0	0.0	0.0
Bin 2	0.010	2.1	0.02
Bin 3	0.055	2.1	0.03
Bin 4	0.070	2.1	0.04
Bin 5	0.090	4.2	0.07
Bin 6	0.090	4.2	0.10
Bin 7	0.090	4.2	0.15
Bin 8a	0.125	4.2	0.20
Bin 8b	0.156	4.2	0.20
Bin 9a	0.090	4.2	0.30
Bin 9b	0.130	4.2	0.30
Bin 9c	0.180	4.2	0.30
Bin 10a	0.156	4.2	0.60
Bin 10b	0.230	6.4	0.60
Bin 10c	0.230	6.4	0.60
Bin 11	0.230	7.3	0.90

CHART 82–1

EPA Tier 2—120,000-Mile Tailpipe Emission Limits. NMOG stands for non-methane organic gases which is a measure of all gases except those often created naturally by animals. After January 2007, the highest allowable Bin is 7.
Source: Data compiled from the Environmental Protection Agency (EPA).
NOTE: The bin number is determined by the type and weight of the vehicle.

U.S. EPA VEHICLE INFORMATION PROGRAM (THE HIGHER THE SCORE, THE LOWER THE EMISSIONS)	
SELECTED EMISSIONS STANDARDS	SCORE
Bin 1 and ZEV	10
PZEV	9.5
Bin 2	9
Bin 3	8
Bin 4	7
Bin 5 and LEV II cars	6
Bin 6	5
Bin 7	4
Bin 8	3
Bin 9a and LEV I cars	2
Bin 9b	2
Bin 10a	1
Bin 10b and Tier 1 cars	1
Bin 11	0

CHART 82–2

Air Pollution Score
Source: Courtesy of the Environmental Protection Agency (EPA).

- Euro III (1999–2005)
- Euro IV (2005–2008)
- Euro V (2008+)

Vehicle emission standards and technological advancements have successfully reduced pollution from cars and trucks by about 90% since the 1970s. Unfortunately, there currently are more vehicles on the road and they are being driven more miles each year, partially offsetting the environmental benefits of individual vehicle emissions reductions.

SCORE	MINIMUM FUEL ECONOMY (MPG) COMBINED CITY-HIGHWAY LABEL VALUE				
	GASOLINE	DIESEL	E-85	LPG	CNG*
10	44	50	31	28	33
9	36	41	26	23	27
8	30	35	22	20	23
7	26	30	19	17	20
6	23	27	17	15	18
5	21	24	15	14	16
4	19	22	14	12	14
3	17	20	12	11	13
2	16	18	—	—	12
1	15	17	11	10	11
0	14	16	10	9	10

CHART 82–3

Greenhouse Gas Score
Source: Courtesy of the Environmental Protection Agency (EPA).
*CNG assumes a gallon equivalent of 121.5 cubic feet.

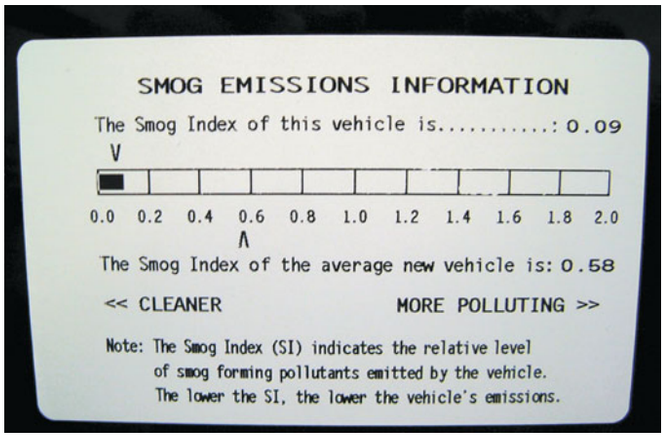


FIGURE 82–2 This label on a Toyota Camry hybrid shows the relative smog-producing emissions, but this does not include carbon dioxide (CO_2), which may increase global warming.

EXHAUST ANALYSIS TESTING

The Clean Air Act Amendments require enhanced Inspection and Maintenance (I/M) programs in areas of the country that have the worst air quality and the Northeast Ozone Transport region. The states must submit to the EPA a **State Implementation Plan (SIP)** for their programs. Each enhanced I/M program is required to include as a minimum the following items:

- Computerized emission analyzers
- Visual inspection of emission control items
- Minimum waiver limit (to be increased based on the inflation index)



FIGURE 82–3 Photo of a sign taken at an emissions test facility.

- Remote on-road testing of one-half of 1% of the vehicle population
- Registration denial for vehicles not passing an I/M test
- Denial of waiver for vehicles that are under warranty or that have been tampered with
- Annual inspections
- OBD-II systems check for 1996 and newer vehicles

FEDERAL TEST PROCEDURE (FTP) The **Federal Test Procedure (FTP)** is the test used to certify all new vehicles before they can be sold. Once a vehicle meets these standards, it is certified by the EPA for sale in the United States. The FTP test procedure is a loaded-mode test lasting for a total duration of 505 seconds and is designed to simulate an urban driving trip. A cold start-up representing a morning start and a hot start after a soak period is part of the test. In addition to this drive cycle, a vehicle must undergo evaporative testing. Evaporative emissions are determined using the **Sealed Housing for Evaporative Determination (SHED)** test, which measures the evaporative emissions from the vehicle after a heat-up period representing a vehicle sitting in the sun. In addition, the vehicle is driven and then tested during the hot soak period.

NOTE: A SHED is constructed entirely of stainless steel. The walls, floors, and ceiling, plus the door, are all constructed of stainless steel because it does not absorb hydrocarbons, which could offset test results.

The FTP is a much more stringent test of vehicle emissions than is any test type that uses equipment that measures percentages of exhaust gases. The federal emission standards for each model year vehicle are the same for that model regardless of what size engine the vehicle is equipped with. This is why larger V-8 engines often are equipped with more emission control devices than smaller four- and six-cylinder engines.

I/M TEST PROGRAMS There are a variety of I/M testing programs that have been implemented by the various states. These programs may be centralized testing programs or decentralized testing programs. Each state is free to develop a testing program suitable to their needs as long as they can demonstrate to the EPA that their plan will achieve the attainment levels set by the EPA. This approach has led to a variety of different testing programs. ● **SEE FIGURE 82–3.**



FIGURE 82–4 A vehicle being tested during an enhanced emission test.

VISUAL TAMPERING CHECKS Visual tampering checks may be part of an I/M testing program and usually include checking for the following items:

- Catalytic converter
- Fuel tank inlet restrictor
- Exhaust gas recirculation (EGR)
- Evaporative emission system
- Air-injection reaction system (AIR)
- Positive crankcase ventilation (PCV)

If any of these systems are missing, not connected, or tampered with, the vehicle will fail the emissions test and will have to be repaired/replaced by the vehicle owner before the vehicle can pass the emission test. Any cost associated with repairing or replacing these components may not be used toward the waiver amount required for the vehicle to receive a waiver.

ONE-SPEED AND TWO-SPEED IDLE TEST The one-speed and two-speed idle test measures the exhaust emissions from the tailpipe of the vehicle at idle and/or at 2500 RPM. This uses stand-alone exhaust gas sampling equipment that measures the emissions in percentages. Each state chooses the standards that the vehicle has to meet in order to pass the test. The advantage to using this type of testing is that the equipment is relatively cheap and allows states to have decentralized testing programs because many facilities can afford the necessary equipment required to perform this test.

LOADED MODE TEST The loaded mode test uses a dynamometer that places a "single weight" load on the vehicle. The load applied to the vehicle varies with the speed of the vehicle. Typically, a four-cylinder vehicle speed would be 24 mph, a six-cylinder vehicle speed would be 30 mph, and an eight-cylinder vehicle speed would be 34 mph. Conventional stand-alone sampling equipment is used to measure HC and CO emissions. This type of test is classified as a Basic I/M test by the EPA. ● **SEE FIGURE 82–4.**

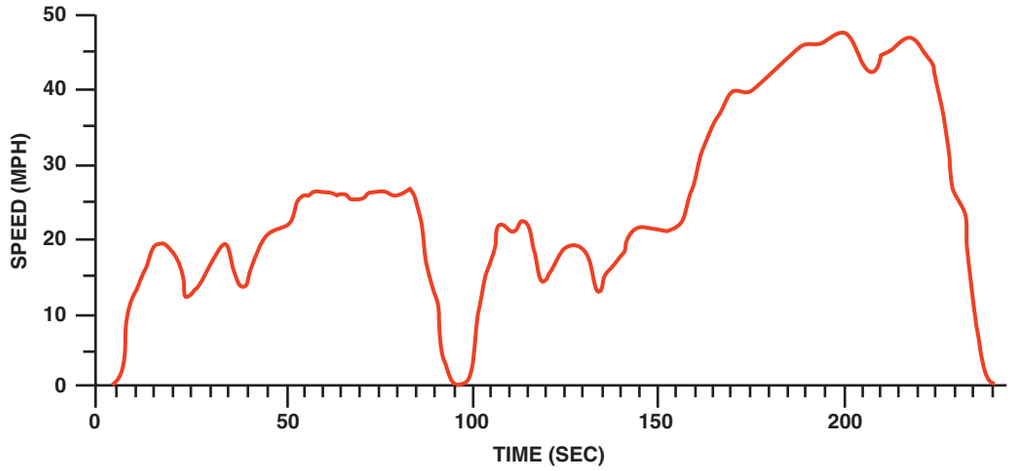


FIGURE 82–5 Trace showing the Inspection/Maintenance 240 test. The test duplicates an urban test loop around Los Angeles, California. The first "hump" in the curve represents the vehicle being accelerated to about 20 mph, then driving up a small hill to about 30 mph and coming to a stop at 94 seconds. Then, the vehicle accelerates while climbing a hill and speeding up to about 50 mph during this second phase of the test.

ACCELERATION SIMULATION MODE (ASM) The **ASM-type** of test uses a dynamometer that applies a heavy load on the vehicle at a steady-state speed. The load applied to the vehicle is based on the acceleration rate on the second simulated hill of the FTP. This acceleration rate is 3.3 mph/sec/sec (read as 3.3 mph per second per second, which is the unit of acceleration). There are different ASM tests used by different states.

The **ASM 50/15** test places a load of 50% on the vehicle at a steady 15 mph. This load represents 50% of the horsepower required to simulate the FTP acceleration rate of 3.3 mph/sec. This type of test produces relatively high levels of NO_x emissions; therefore, it is useful in detecting vehicles that are emitting excessive NO_x.

The **ASM 25/25** test places a 25% load on the vehicle while it is driven at a steady 25 mph. This represents 25% of the load required to simulate the FTP acceleration rate of 3.3 mph/sec. Because this applies a smaller load on the vehicle at a higher speed, it will produce a higher level of HC and CO emissions than the ASM 50/15. NO_x emissions will tend to be lower with this type of test.

I/M 240 TEST The **I/M 240** test is the EPA's enhanced test. It is actually a portion of the 505-second FTP test used by the manufacturers to certify their new vehicles. The "240" stands for 240 seconds of drive time on a dynamometer. This is a loaded-mode transient test that uses constant volume sampling equipment to measure the exhaust emissions in mass just as is done during the FTP. The I/M 240 test simulates the first two hills of the FTP drive cycle. ● **FIGURE 82–5** shows the I/M 240 drive trace.

OBD-II TESTING In 1999, the EPA requested that states adopt OBD-II systems testing for 1996 and newer vehicles. The OBD-II system is designed to illuminate the MIL light and store trouble codes any time a malfunction exists that would cause the vehicle emissions to exceed 1 1/2 times the FTP limits. If the OBD-II system is working correctly, the system should be able to detect a vehicle failure that would cause emissions to increase to an unacceptable level. The EPA has determined that the OBD-II system should detect emission failures of a vehicle even before that vehicle would fail an emissions test of the type that most states are employing. Furthermore, the EPA has determined that, as the population of OBD-II-equipped vehicles increases and the population of older non-OBD-II-equipped vehicles decreases, tailpipe testing will no longer be necessary.

The OBD-II testing program consists of a computer that can scan the vehicle OBD-II system using the DLC connector. The technician first performs a visual check of the vehicle MIL light to determine if it is working correctly. Next, the computer is connected to the vehicle's DLC connector. The computer will scan the vehicle OBD-II system and determine if there are any codes stored that are commanding the MIL light on. In addition, it will scan the status of the readiness monitors and determine if they have all run and passed. If the readiness monitors have all run and passed, it indicates that the OBD-II system has tested all the components of the emission control system. An OBD-II vehicle would fail this OBD-II test if:

- The MIL light does not come on with the key on, engine off
- The MIL is commanded on
- A number (varies by state) of the readiness monitors have not been run

If none of these conditions are present, the vehicle will pass the emissions test.

REMOTE SENSING The EPA requires that, in high-enhanced areas, states perform on-the-road testing of vehicle emissions. The state must sample 0.5% of the vehicle population base in high-enhanced areas. This may be accomplished by using a remote sensing device. This type of sensing may be done through equipment that projects an infrared light through the exhaust stream of a passing vehicle. The reflected beam can then be analyzed to determine the pollutant levels coming from the vehicle. If a vehicle fails this type of test, the vehicle owner will receive notification in the mail that he or she must take the vehicle to a test facility to have the emissions tested.

RANDOM ROADSIDE TESTING Some states may implement random roadside testing that would usually involve visual checks of the emission control devices to detect tampering. Obviously, this method is not very popular as it can lead to traffic tie-ups and delays on the part of commuters.

Exhaust analysis is an excellent tool to use for the diagnosis of engine performance concerns. In areas of the country that require



FIGURE 82–6 A partial stream sampling exhaust probe being used to measure exhaust gases in parts per million (PPM) or percent (%).

exhaust testing to be able to get license plates, exhaust analysis must be able to:

- Establish a baseline for failure diagnosis and service.
- Identify areas of engine performance that are and are not functioning correctly.
- Determine that the service and repair of the vehicle have been accomplished and are complete.

EXHAUST ANALYSIS AND COMBUSTION EFFICIENCY

A popular method of engine analysis, as well as emission testing, involves the use of five-gas exhaust analysis equipment. ● **SEE FIGURE 82–6.** The five gases analyzed and their significance include:

HYDROCARBONS Hydrocarbons (HC) are unburned gasoline and are measured in parts per million (ppm). A correctly operating engine should burn (oxidize) almost all the gasoline; therefore, very little unburned gasoline should be present in the exhaust. Acceptable levels of HC are 50 PPM or less. High levels of HC could be due to excessive oil consumption caused by weak piston rings or worn valve guides. The most common cause of excessive HC emissions is a fault in the ignition system. Items that should be checked include:

- Spark plugs
- Spark plug wires
- Distributor cap and rotor (if the vehicle is so equipped)
- Ignition timing (if possible)
- Ignition coil

CARBON MONOXIDE Carbon monoxide (CO) is unstable and will easily combine with any oxygen to form stable carbon dioxide (CO_2). The fact that CO combines with oxygen is the reason that CO is a poisonous gas (in the lungs, it combines with oxygen to form CO_2 and deprives the brain of oxygen). CO levels of a properly operating engine should be less than 0.5%. High levels of CO can be caused by clogged or restricted crankcase ventilation devices such as the PCV valve, hose(s), and tubes. Other items that might cause excessive CO include:

- Clogged air filter
- Incorrect idle speed
- Too-high fuel-pump pressure
- Any other items that can cause a rich condition

CARBON DIOXIDE (CO_2) Carbon dioxide (CO_2) is the result of oxygen in the engine combining with the carbon of the gasoline. An acceptable level of CO_2 is between 12% and 15%. A high reading indicates an efficiently operating engine. If the CO_2 level is low, the mixture may be either too rich or too lean.

OXYGEN The next gas is oxygen (O_2). There is about 21% oxygen in the atmosphere, and most of this oxygen should be "used up" during the combustion process to oxidize all the hydrogen and carbon (hydrocarbons) in the gasoline. Levels of O_2 should be very low (about 0.5%). High levels of O_2, especially at idle, could be due to an exhaust system leak.

NOTE: Adding 10% alcohol to gasoline provides additional oxygen to the fuel and will result in lower levels of CO and higher levels of O_2 in the exhaust.

OXIDES OF NITROGEN (NO_X) An oxide of nitrogen (NO) is a colorless, tasteless, and odorless gas when it leaves the engine, but as soon as it reaches the atmosphere and mixes with more oxygen,

? FREQUENTLY ASKED QUESTION

What Does NMHC Mean?

NMHC means **non-methane hydrocarbon** and it is the standard by which exhaust emission testing for hydrocarbons is evaluated. Methane is natural gas and can come from animals, animal waste, and other natural sources. By not measuring methane gas, all background sources are eliminated, giving better results as to the true amount of unburned hydrocarbons that are present in the exhaust stream.

? FREQUENTLY ASKED QUESTION

How Can My Worn-Out, Old, High-Mileage Vehicle Pass an Exhaust Emission Test?

Age and mileage of a vehicle are generally not factors when it comes to passing an exhaust emission test. Regular maintenance is the most important factor for passing an enhanced Inspection and Maintenance (I/M) exhaust analysis test. Failure of the vehicle owner to replace broken accessory drive belts, leaking air pump tubes, defective spark plug wires, or a cracked exhaust manifold can lead to failure of other components such as the catalytic converter. Tests have shown that if the vehicle is properly cared for, even an engine that has 300,000 miles (483,000 km) can pass an exhaust emission test.

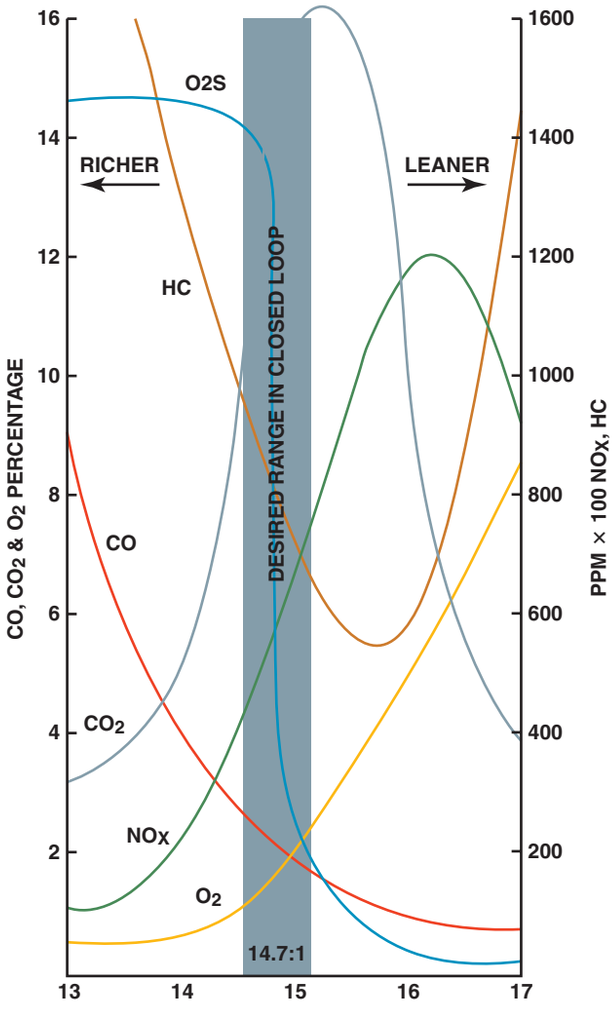


FIGURE 82–7 Exhaust emissions are very complex. When the air–fuel mixture becomes richer, some exhaust emissions are reduced, while others increase.

nitrogen oxides (NO_2) are formed. NO_2 is reddish-brown and has an acid and pungent smell. NO and NO_2 are grouped together and referred to as NO_X, where *x* represents any number of oxygen atoms. NO_X, the symbol used to represent all oxides of nitrogen, is the fifth gas commonly tested using a five-gas analyzer. The exhaust gas recirculation (EGR) system is the major controlling device limiting the formation of NO_X.

Acceptable exhaust emissions include:

	Without Catalytic Converter	With Catalytic Converter
HC	300 PPM or less	30 to 50 PPM or less
CO	3% or less	0.3% to 0.5% or less
O_2	0% to 2%	0% to 2%
CO_2	12% to 15% or higher	12% to 15% or higher
NO_X	Less than 100 PPM at idle and less than 1,000 PPM at WOT	Less than 100 PPM at idle and less than 1,000 PPM at WOT

SEE FIGURE 82–7.

TECH TIP

CO Equals O_2

If the exhaust is rich, CO emissions will be higher than normal. If the exhaust is lean, O_2 emissions will be higher than normal. Therefore, if the CO reading is the same as the O_2 reading, then the engine is operating correctly. For example, if both CO and O_2 are 0.5% and the engine develops a vacuum leak, the O_2 will rise. If a fuel-pressure regulator were to malfunction, the resulting richer air–fuel mixture would increase CO emissions. Therefore, if both the rich indicator (CO) and the lean indicator (O_2) are equal, the engine is operating correctly.

HC TOO HIGH

High hydrocarbon exhaust emissions are usually caused by an engine misfire. What burns the fuel in an engine? The ignition system ignites a spark at the spark plug to ignite the proper mixture inside the combustion chamber. If a spark plug does not ignite the mixture, the resulting unburned fuel is pushed out of the cylinder on the exhaust stroke by the piston through the exhaust valves and into the exhaust system. Therefore, if any of the following ignition components or adjustments are not correct, excessive HC emission is likely.

1. Defective or worn spark plugs
2. Defective or loose spark plug wires
3. Defective distributor cap and/or rotor
4. Incorrect ignition timing (either too far advanced or too far retarded)
5. A lean air–fuel mixture can also cause a misfire. This condition is referred to as a lean misfire. A lean air-fuel mixture can be caused by low fuel pump pressure, a clogged fuel filter or a restricted fuel injector.

NOTE: To make discussion easier in future reference to these items, this list of ignition components and check can be referred to as simply as "spark stuff."

CO TOO HIGH

Excessive carbon monoxide is an indication of too rich an air–fuel mixture. CO is the **rich indicator.** The higher the CO reading, the richer the air–fuel mixture. High concentrations of CO indicate that not enough oxygen was available for the amount of fuel. Common causes of high CO include:

- Too-high fuel-pump pressure
- Defective fuel-pressure regulator
- Clogged air filter or PCV valve

NOTE: One technician remembers "CO" as meaning "clogged oxygen" and always looks for restricted airflow into the engine whenever high CO levels are detected.

- Defective injectors

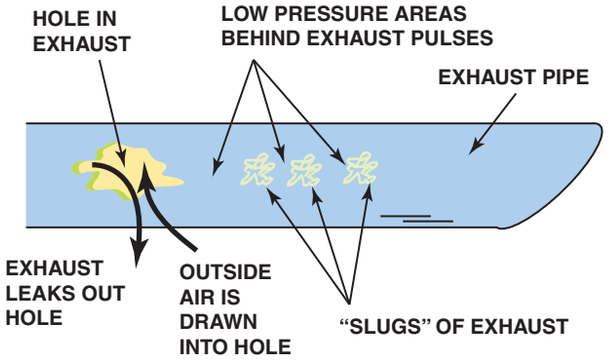


FIGURE 82–8 A hole in the exhaust system can cause outside air (containing oxygen) to be drawn into the exhaust system. This extra oxygen can be confusing to a service technician because the extra O_2 in the exhaust stream could be misinterpreted as a too-lean air–fuel mixture.

TECH TIP

How to Find a Leak in the Exhaust System

A hole in the exhaust system can dilute the exhaust gases with additional oxygen (O_2). ● **SEE FIGURE 82–8.**

This additional O_2 in the exhaust can lead the service technician to believe that the air–fuel mixture is too lean. To help identify an exhaust leak, perform an exhaust analysis at idle and at 2500 RPM (fast idle) and compare with the following:

- If the O_2 is high at idle and at 2500 RPM, the mixture is lean at both idle and at 2500 RPM.
- If the O_2 is low at idle and high at 2500 RPM, this usually means that the vehicle is equipped with a working AIR pump.
- If the O_2 is high at idle, but okay at 2500 RPM, a hole in the exhaust or a small vacuum leak that is "covered up" at higher speed is indicated.

MEASURING OXYGEN (O_2) AND CARBON DIOXIDE (CO_2)

Two gas exhaust analyzers (HC and CO) work well, but both HC and CO are consumed (converted) inside the catalytic converter. The amount of leftover oxygen coming out of the tailpipe is an indication of leanness. The higher the O_2 level, the leaner the exhaust. Oxygen therefore is the **lean indicator.** Acceptable levels of O_2 are 0% to 2%.

NOTE: A hole in the exhaust system can draw outside air (oxygen) into the exhaust system. Therefore, to be assured of an accurate reading, carefully check the exhaust system for leaks. Using a smoke machine is an easy method to locate leaks in the exhaust system.

Carbon dioxide (CO_2) is a measure of efficiency. The higher the level of CO_2 in the exhaust stream, the more efficiently the engine is operating. Levels of 12% to 15% are considered to be acceptable.

TECH TIP

Your Nose Knows

Using the nose, a technician can often identify a major problem without having to connect the vehicle to an exhaust analyzer. For example,

- The strong smell of exhaust is due to excessive unburned hydrocarbon (HC) emissions. Look for an ignition system fault that could prevent the proper burning of the fuel. A vacuum leak could also cause a lean misfire and cause excessive HC exhaust emissions.
- If your eyes start to burn or water, suspect excessive oxides of nitrogen (NO_x) emissions. The oxides of nitrogen combine with the moisture in the eyes to form a mild solution of nitric acid. The acid formation causes the eyes to burn and water. Excessive NO_x exhaust emissions can be caused by:
  - A vacuum leak causing higher-than-normal combustion chamber temperatures
  - Overadvanced ignition timing causing higher-than-normal combustion chamber temperatures
  - Lack of proper amount of exhaust gas recirculation (EGR) (This is usually noticed above idle on most vehicles.)
- Dizzy feeling or headache. This is commonly caused by excessive carbon monoxide (CO) exhaust emissions. Get into fresh air as soon as possible. A probable cause of high levels of CO is an excessively rich air–fuel mixture.

Because CO_2 levels peak at an air–fuel mixture of 14.7:1, a lower level of CO_2 indicates either a too-rich or a too-lean condition. The CO_2 measurement by itself does not indicate which condition is present. For example:

CO_2 = 8% (This means efficiency is low and the air–fuel mixture is not correct.)

Look at O_2 and CO levels.

A high O_2 indicates lean and a high CO indicates rich.

PHOTOCHEMICAL SMOG FORMATION

Oxides of nitrogen are formed by high temperature—over 2500°F (1370°C)—and/or pressures inside the combustion chamber. Oxides of nitrogen contribute to the formation of photochemical **smog** when sunlight reacts chemically with NO_x and unburned hydrocarbons (HC). Smog is a term derived by combining the words *smoke* and *fog*. Ground-level ozone is a constituent of smog. **Ozone** is an enriched oxygen molecule with three atoms of oxygen (O_3) instead of the normal two atoms of oxygen (O_2).

Ozone in the upper atmosphere is beneficial because it blocks out harmful ultraviolet rays that contribute to skin cancer. However, at ground level, this ozone (smog) is an irritant to the respiratory system.

TECH TIP

Check for Dog Food?

A commonly experienced problem in many parts of the country involves squirrels or other animals placing dog food into the air intake ducts of vehicles. Dog food is often found packed tight in the ducts against the air filter. An air intake restriction reduces engine power and vehicle performance.

REAL WORLD FIX

The Case of the Retarded Exhaust Camshaft

A Toyota equipped with a double overhead camshaft (DOHC) inline six-cylinder engine failed the state-mandated enhanced exhaust emission test for NO_x. The engine ran perfectly without spark knocking (ping), which is usually a major reason for excessive NO_x emissions. The technician checked the following:

- The ignition timing, which was found to be set to specifications (if too far advanced, can cause excessive NO_x)
- The cylinders, which were decarbonized using top engine cleaner
- The EGR valve, which was inspected and the EGR passages cleaned

After all the items were completed, the vehicle was returned to the inspection station where the vehicle again failed for excessive NO_x emissions (better, but still over the maximum allowable limit).

After additional hours of troubleshooting, the technician decided to go back to basics and start over again. A check of the vehicle history with the owner indicated that the only previous work performed on the engine was a replacement timing belt over a year before. The technician discovered that the exhaust cam timing was retarded two teeth, resulting in late closing of the exhaust valve. The proper exhaust valve timing resulted in a slight amount of exhaust being retained in the cylinder. This extra exhaust was added to the amount supplied by the EGR valve and helped reduce NO_x emissions. After repositioning the timing belt, the vehicle passed the emissions test well within the limits.

REAL WORLD FIX

O2S Shows Rich, but Pulse Width Is Low

A service technician was attempting to solve a driveability problem. The computer did not indicate any diagnostic trouble codes (DTCs). A check of the oxygen sensor voltage indicated a higher-than-normal reading almost all the time. The pulse width to the port injectors was lower than normal. The lower-than-normal pulse width indicates that the computer is attempting to reduce fuel flow into the engine by decreasing the amount of on-time for all the injectors.

What could cause a rich mixture if the injectors were being commanded to deliver a lean mixture? Finally the technician shut off the engine and took a careful look at the entire fuel-injection system. Although the vacuum hose was removed from the fuel-pressure regulator, fuel was found dripping from the vacuum hose. The problem was a defective fuel-pressure regulator that allowed an uncontrolled amount of fuel to be drawn by the intake manifold vacuum into the cylinders. While the computer tried to reduce fuel by reducing the pulse width signal to the injectors, the extra fuel being drawn directly from the fuel rail caused the engine to operate with too rich an air–fuel mixture.

TESTING FOR OXIDES OF NITROGEN

Because the formation of NO_x occurs mostly under load, the most efficient method to test for NO_x is to use a portable exhaust analyzer that can be carried in the vehicle while the vehicle is being driven under a variety of conditions.

SPECIFICATIONS FOR NO_x From experience, a maximum reading of 1,000 parts per million (PPM) of NO_x under loaded driving conditions will generally mean that the vehicle will pass an enhanced I/M roller test. A reading of over 100 PPM at idle should be considered excessive.

Exhaust Gas Summary Chart

Gas	Cause and Correction
High HC	Engine misfire or incomplete burning of fuel caused by: 1. Ignition system fault 2. Lean misfire 3. Too low an engine temperature (thermostat)
High CO	**Rich** condition caused by: 1. Leaking fuel injectors or fuel-pressure regulator 2. Clogged air filter or PCV system 3. Excessive fuel pressure
High HC and CO	Excessively rich condition caused by: 1. All items included under high CO 2. Fouled spark plugs causing a misfire to occur 3. Possible nonoperating catalytic converter
High NO_x	Excessive combustion chamber temperature: 1. Nonoperating EGR valve 2. Clogged EGR passages 3. Engine operating temperature too high due to cooling system restriction, worn water pump impeller, or other faults in the cooling system 4. Lean air–fuel mixture 5. High compression caused by excessive carbon buildup in the cylinders

REVIEW QUESTIONS

1. List the five exhaust gases and their maximum allowable readings for a fuel-injected vehicle equipped with a catalytic converter.
2. List two causes of a rich exhaust.
3. List two causes of a lean exhaust.
4. List those items that should be checked if a vehicle fails an exhaust test for excessive NO_x emissions.

CHAPTER QUIZ

1. Technician A says that high HC emission levels are often caused by a fault in the ignition system. Technician B says that high CO_2 emissions are usually caused by a richer-than-normal air–fuel mixture. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. HC and CO are high and CO_2 and O_2 are low. This could be caused by a _____.
   a. Rich mixture
   b. Lean mixture
   c. Defective ignition component
   d. Clogged EGR passage
3. Which gas is generally considered to be the rich indicator? (The higher the level of this gas, the richer the air–fuel mixture.)
   a. HC **c.** CO_2
   b. CO **d.** O_2
4. Which gas is generally considered to be the lean indicator? (The higher the level of this gas, the leaner the air–fuel mixture.)
   a. HC **c.** CO_2
   b. CO **d.** O_2
5. Which exhaust gas indicates efficiency? (The higher the level of this gas, the more efficient the engine operates.)
   a. HC **c.** CO_2
   b. CO **d.** O_2
6. All of the gases are measured in percentages *except* _____.
   a. HC **c.** CO_2
   b. CO **d.** O_2
7. After the following exhaust emissions were measured, how was the engine operating?
   HC = 766 PPM CO_2 = 8.2% CO = 4.6% O_2 = 0.1%
   a. Too rich
   b. Too lean
8. Technician A says that carbon inside the engine can cause excessive NO_x to form. Technician B says that excessive NO_x could be caused by a cooling system fault causing the engine to operate too hot. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. A clogged EGR passage could cause excessive _____ exhaust emissions.
   a. HC **c.** NO_x
   b. CO **d.** CO_2
10. An ignition fault could cause excessive _____ exhaust emissions.
    a. HC **c.** NO_x
    b. CO **d.** CO2

chapter 83

EVAPORATIVE EMISSION CONTROL SYSTEMS

OBJECTIVES: After studying Chapter 83, the reader should be able to: • Prepare for the ASE Engine Performance (A8) certification test content area "D" (Emission Control Systems). • Describe the purpose and function of the evaporative emission control system. • Discuss how the evaporative emission control system is tested under OBD-II regulations. • Explain methods for diagnosing and testing faults in the evaporative emission control system.

KEY TERMS: Adsorption 928 • Evaporative control (EVAP) system 928 • Fuel tank pressure (FTP) 933 • Leak detection pump (LDP) 931 • Onboard refueling vapor recovery (ORVR) 931 • Purge valve 930 • Vent valve 930 • Volatile organic compounds (VOC) 928



FIGURE 83–1 A capless system from a Ford Flex does not use a replaceable cap; instead, it is spring-loaded closed.

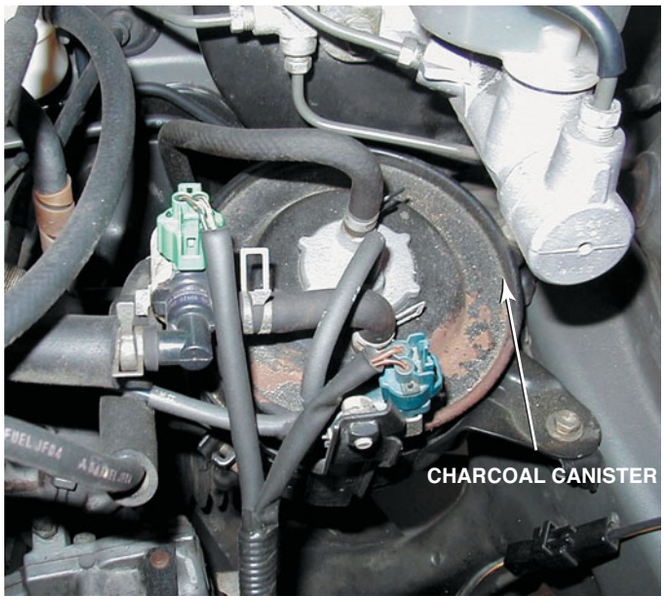


FIGURE 83–2 A charcoal canister can be located under the hood or underneath the vehicle.

? FREQUENTLY ASKED QUESTION

When Filling My Fuel Tank, Why Should I Stop When the Pump Clicks Off?

Every fuel tank has an upper volume chamber that allows for expansion of the fuel when hot. The volume of the chamber is between 10% and 20% of the volume of the tank. For example, if a fuel tank had a capacity of 20 gallons, the expansion chamber volume would be from 2 to 4 gallons. A hose is attached at the top of the chamber and vented to the charcoal canister. If extra fuel is forced into this expansion volume, liquid gasoline can be drawn into the charcoal canister. This liquid fuel can saturate the canister and create an overly rich air-fuel mixture when the canister purge valve is opened during normal vehicle operation. This extra-rich air-fuel mixture can cause the vehicle to fail an exhaust emissions test, reduce fuel economy, and possibly damage the catalytic converter. To avoid problems, simply add fuel to the next dime's worth after the nozzle clicks off. This will ensure that the tank is full yet not overfilled.

EVAPORATIVE EMISSION CONTROL SYSTEM

PURPOSE AND FUNCTION The purpose of the evaporative emission control system is to trap and hold gasoline vapors, also called **volatile organic compounds (VOCs).** The **evaporative control (EVAP) system** includes the charcoal canister, hoses, and valves. These vapors are routed into a charcoal canister, then into the intake airflow, where they are burned in the engine instead of being released into the atmosphere.

COMMON COMPONENTS The fuel tank filler caps used on vehicles with modern EVAP systems are a special design. Most EVAP fuel tank filler caps have a built-in pressure-vacuum relief valve. When pressure or vacuum exceeds a calibrated value, the valve opens. Once the pressure or vacuum has been relieved, the valve closes. If a sealed cap is used on an EVAP system that requires a pressure-vacuum relief design, a vacuum may develop in the fuel system, or the fuel tank may be damaged by fuel expansion or contraction. ● **SEE FIGURE 83–1.**

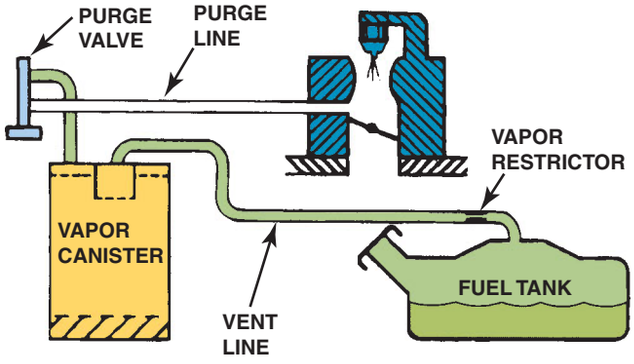


FIGURE 83–3 The EVAP system includes all of the lines, hoses, and valves, plus the charcoal canister.

EVAP SYSTEM OPERATION The canister is located under the hood or underneath the vehicle and is filled with activated charcoal granules that can hold up to one-third of their own weight in fuel vapors. ● **SEE FIGURE 83–2.**

NOTE: Some vehicles with large or dual fuel tanks may have dual canisters.

Activated charcoal is an effective vapor trap because of its great surface area. Each gram of activated charcoal has a surface area of 1,100 square meters, or more than 1/4 acre. Typical canisters hold either 300 or 625 grams of charcoal *with a surface area equivalent to 80 or 165 football fields.* By a process called **adsorption,** the fuel vapor molecules adhere to the carbon surface. This attaching force is not strong, so the system purges the vapor molecules quite simply by sending a fresh airflow through the charcoal:

- **Vapor purging.** During engine operation, stored vapors are drawn from the canister into the engine through a hose connected to the throttle body or the air cleaner. This "purging" process mixes unburned gasoline (hydrocarbons, abbreviated HCs) vapors from the canister with the existing air-fuel charge. ● **SEE FIGURES 83–3 AND 83–4.**

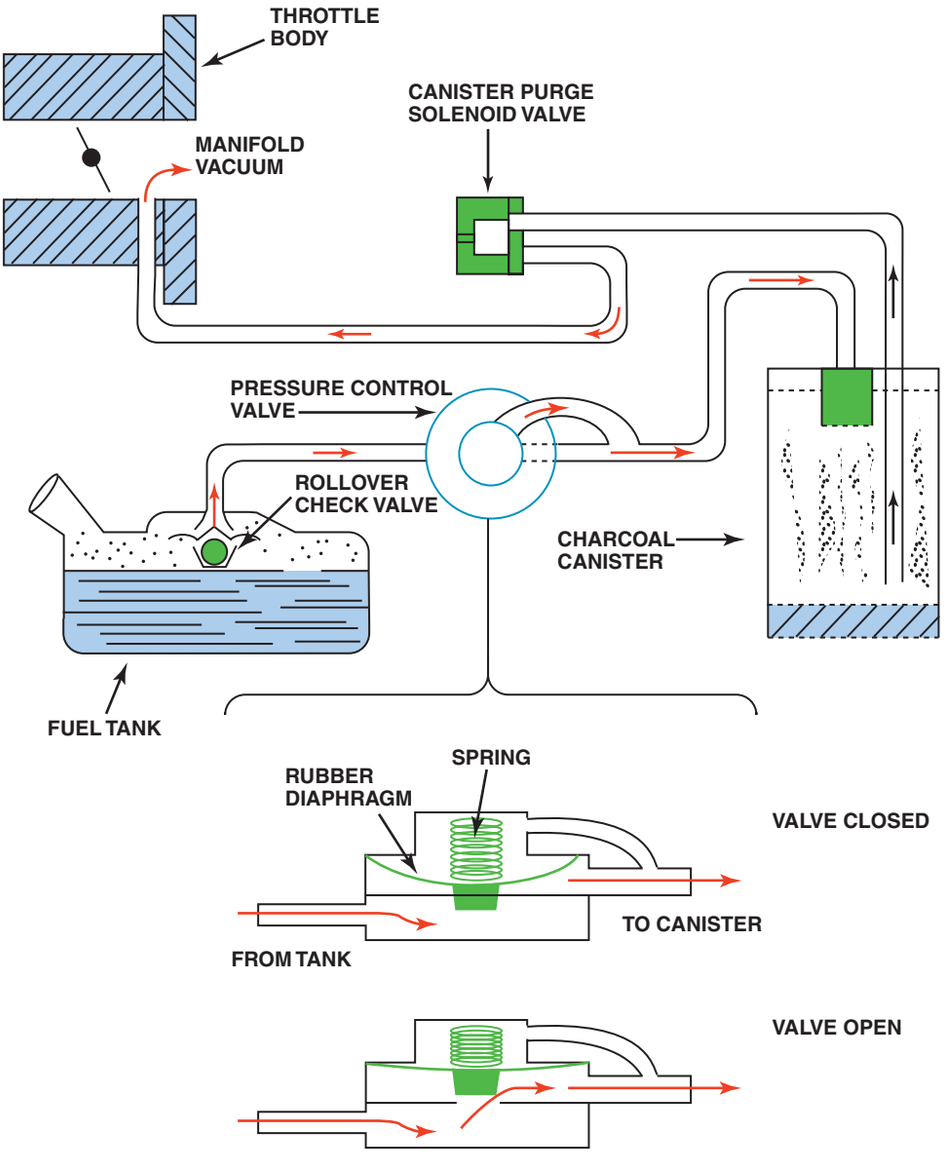


FIGURE 83–4 A typical EVAP system. Note that when the computer turns on the canister purge solenoid valve, manifold vacuum draws any stored vapors from the canister into the engine. Manifold vacuum also is applied to the pressure control valve. When this valve opens, fumes from the fuel tank are drawn into the charcoal canister and eventually into the engine. When the solenoid valve is turned off (or the engine stops and there is no manifold vacuum), the pressure control valve is spring-loaded shut to keep vapors inside the fuel tank from escaping to the atmosphere.

- **Computer-controlled purge.** The PCM controls when the canister purges on most engines. This is done by an electric vacuum solenoid and one or more purge valves. Under normal conditions, most engine control systems permit purging only during closed-loop operation at cruising speeds. During other engine operation conditions, such as open-loop mode, idle, deceleration, or wide-open throttle, the PCM prevents canister purging.

EVAPORATIVE PRESSURES

Pressures can build inside the fuel system and are usually measured in units of inches of water, abbreviated "in. H_2O" (28 in. H_2O equals 1 pound per square inch, or 1 PSI). Pressure buildup can be caused by the following:

- Fuel evaporation rates (volatility)
- Gas tank size (fuel surface area and volume)
- Fuel level (liquid versus vapor)
- Fuel slosh (driving conditions)
- Temperature (ambient, in-tank, close to the tank)
- Returned fuel from the rail

Some scan tools display other units of measure for the EVAP system that makes understanding the system difficult. ● **SEE CHART 83–1** for pressure conversions between pounds per square inch (PSI), inches of mercury (in. Hg), and inches of water (in. H_2O).

NONENHANCED EVAPORATIVE CONTROL SYSTEMS

Prior to 1996, evaporative systems were referred to as nonenhanced evaporative control (EVAP) systems. This term refers to evaporative systems that had limited diagnostic capabilities. While they are often PCM controlled, their diagnostic capability is usually limited to their ability to detect if purge has occurred. Many of these older systems

have a diagnostic switch that could sense if purge is occurring and set a code if no purge is detected. This system does not check for leaks. On some vehicles, the PCM also has the capability of monitoring the integrity of the purge solenoid and circuit. These systems' limitations are their ability to check the integrity of the evaporative system on the vehicle. They could not detect leaks or missing or loose gas caps that could lead to excessive evaporative emissions from the vehicle. Nonenhanced evaporative systems use either a canister purge solenoid or a vapor management valve to control purge vapor.

PSI	INCHES HG	INCHES H_2O
14.7	29.93	407.19
1.0	2.036	27.7
0.9	1.8	24.93
0.8	1.63	22.16
0.7	1.43	19.39
0.6	1.22	16.62
0.5	1.018	13.85
0.4	0.814	11.08
0.3	0.611	8.31
0.2	0.407	5.54
0.1	0.204	2.77
0.09	0.183	2.49
0.08	0.163	2.22
0.07	0.143	1.94
0.06	0.122	1.66
0.05	0.102	1.385

CHART 83–1

Pressure conversions.
NOTE: 1 PSI = 28 in. H_2O
0.25 PSI = 7 in. H_2O

ENHANCED EVAPORATIVE CONTROL SYSTEM

BACKGROUND Beginning in 1996 with OBD-II vehicles, manufacturers were required to install systems that are able to detect both purge flow and evaporative system leakage:

- The systems on models produced between 1996 and 2000 must be able to detect a leak as small as 0.040 inches in diameter.
- Beginning in the model year 2000, the enhanced systems started a phase-in of 0.020-inch diameter leak detection.
- All vehicles built after 1995 have enhanced evaporative systems with the ability to detect purge flow and system leakage. If either of these two functions fails, the system is required to set a diagnostic trouble code (DTC) and turn on the malfunction indicator lamp (MIL) to warn the driver of the failure.
  ● **SEE FIGURE 83–5.**

VENT VALVE The canister **vent valve** is a *normally open* valve and is closed only when commanded by the PCM during testing of the system. The vent valve is closed only during testing by the PCM as part of the mandated OBD-II standards. The vent solenoid is located under the vehicle in most cases and is exposed to the environment, making this valve subject to rust and corrosion.

PURGE VALVE The canister **purge valve,** also called the *canister purge (CANP) solenoid,* is normally closed and is pulsed open by the PCM during purging. The purge valve is connected to intake manifold vacuum using a rubber hose to draw gasoline vapors from the charcoal canister into the engine when the purge valve is commanded open. Most purge valves are pulsed on and off to better control the amount of fumes being drawn into the intake manifold.

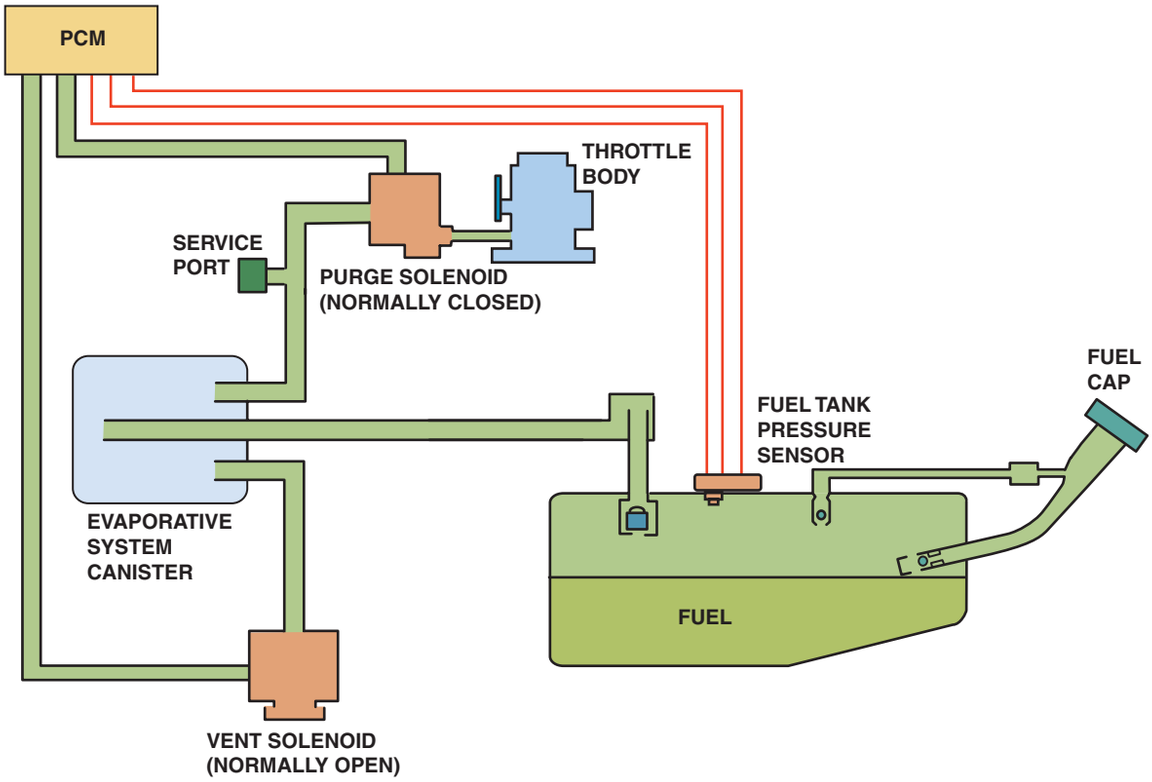


FIGURE 83–5 An enhanced EVAP system is able to perform system and leak detection diagnosis.

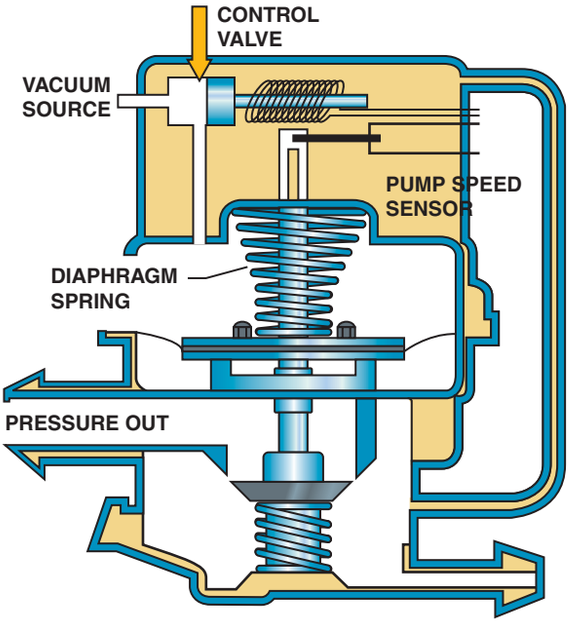


FIGURE 83–6 A leak detection pump (LDP) used on some Chrysler and other vehicles to pressurize (slightly) the fuel system to check for leaks.

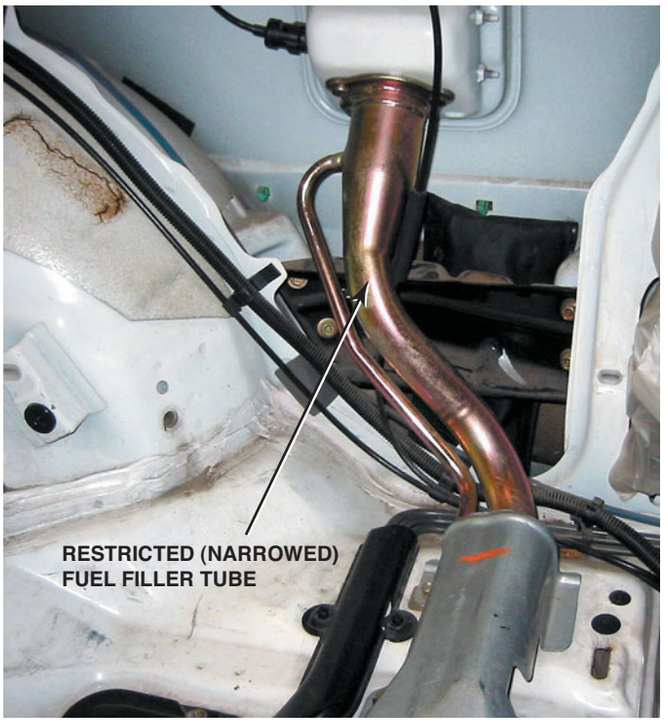


FIGURE 83–7 A restricted fuel fill pipe shown on vehicle with the interior removed.

TECH TIP

Problems after Refueling? Check the Purge Valve

The purge valve is normally closed and open only when the PCM is commanding the system to purge. If the purge solenoid were to become stuck in the open position, gasoline fumes would be allowed to flow directly from the gas tank to the intake manifold. When refueling, this would result in a lot of fumes being forced into the intake manifold and as a result cause a hard-to-start condition after refueling. This would also result in a rich exhaust and likely black exhaust when first starting the engine after refueling. While the purge solenoid is usually located under the hood of most vehicles and is less subject to rust and corrosion as with the vent valve, it can still fail.

LEAK DETECTION PUMP SYSTEM

PURPOSE AND FUNCTION Many vehicles use a vacuum operated **leak detection pump (LDP)** as part of the evaporative control system diagnosis equipment. ● **SEE FIGURE 83–6.**

OPERATION The system works to test for leaks as follows:

- The purge solenoid is normally closed.
- The vent valve in the LDP is normally open. Filtered fresh air is drawn through the LDP to the canister.
- The LDP uses a spring attached to a diaphragm to apply pressure (7.5 in. H_2O) to the fuel tank.
- The PCM monitors the LDP switch that is triggered if the pressure drops in the fuel tank.
- The time between LDP solenoid off and LDP switch close is called the pump period. This time period is inversely proportional to the size of the leak. The shorter the pump period, the larger the leak. The longer the pump period, the smaller the leak.

  EVAP large leak (greater than 0.080 in.): less than 0.9 second

  EVAP medium leak (0.040 to 0.080 in.): 0.9 to 1.2 seconds

  EVAP small leak (0.020 to 0.040 in.): 1.2 to 6 seconds

ONBOARD REFUELING VAPOR RECOVERY

PURPOSE AND FUNCTION The **onboard refueling vapor recovery (ORVR)** system was first introduced on some 1998 vehicles. Previously designed EVAP systems allowed fuel vapor to escape to the atmosphere during refueling.

OPERATION The primary feature of most ORVR systems is the restricted tank filler tube, which is about 1 inch (25 mm) in diameter. This reduced size filler tube creates an aspiration effect, which tends to draw outside air into the filler tube. During refueling, the fuel tank is vented to the charcoal canister, which captures the gas fumes, and with air flowing into the filler tube, no vapors can escape to the atmosphere. ● **SEE FIGURE 83–7.**

DIAGNOSING THE EVAP SYSTEM

SYMPTOMS Before vehicle emissions testing began in many parts of the country, little service work was done on the evaporative emission system. Common engine performance



FIGURE 83–8 Some vehicles will display a message if an evaporative control system leak is detected that could be the result of a loose gas cap.



FIGURE 83–9 To test for a leak, this tester was set to the 0.020-inch hole and turned on. The ball rose in the scale on the left, and the red arrow was moved to that location. If when testing the system for leaks the ball rises higher than the arrow, then the leak is larger than 0.02 inch. If the ball does not rise to the level of the arrow, the leak is smaller than 0.020 inch.

problems that can be caused by a fault in this system include the following:

- **Poor fuel economy.** A leak in a vacuum-valve diaphragm can result in engine vacuum drawing in a constant flow of gasoline vapors from the fuel tank. This usually results in a drop in fuel economy of 2 to 4 miles per gallon (mpg). Use a hand-operated vacuum pump to check that the vacuum diaphragm can hold vacuum.
- **Poor performance.** A vacuum leak in the system can cause the engine to run rough. Age, heat, and time all contribute to the deterioration of rubber hoses.

STATE EVAP TESTS

Enhanced exhaust emissions (I/M-240) testing tests the evaporative emission system. A leak in the system is tested by pressurizing the entire fuel system to a level below 1 PSI (about 14 in. H_2O). The system is typically pressurized with nitrogen, a nonflammable gas that makes up 78% of our atmosphere. The pressure in the system is then shut off and the pressure monitored. If the pressure drops below a set standard, then the vehicle fails the test. This test determines if there is a leak in the system.

HINT: To help pass the evaporative section of an enhanced emissions test, arrive at the test site with less than a half tank of fuel. This means that the rest of the volume of the fuel tank is filled with air. It takes longer for the pressure to drop from a small leak when the volume of the air is greater compared to when the tank is full and the volume of air remaining in the tank is small.



FIGURE 83–10 This unit is applying smoke to the fuel tank through an adapter, and the leak was easily found to be the gas cap seal.

LOCATING LEAKS IN THE SYSTEM

Leaks in the evaporative emission control system will cause the malfunction check gas cap indication lamp to light on some vehicles. ● **SEE FIGURE 83–8.**

A leak will also cause a gas smell, which would be most noticeable if the vehicle were parked in an enclosed garage. The first step is to determine if there is a leak in the system by setting the EVAP tester to rate the system for either a 0.040-inch-or a 0.020-inch-hole-size leak. ● **SEE FIGURE 83–9.**

After it has been determined that a leak exists and it is larger than specified, one of two methods can be used to check for leaks in the evaporative system:

- **Smoke machine testing.** The most efficient method of leak detection is to introduce smoke under low pressure from a machine specifically designed for this purpose. ● **SEE FIGURE 83–10.**
- **Nitrogen gas pressurization.** This method uses nitrogen gas under a very low pressure (lower than 1 PSI) in the fuel system. The service technician then listens for the escaping air, using amplified headphones. ● **SEE FIGURE 83–11.**

EVAPORATIVE SYSTEM MONITOR

OBD-II REQUIREMENTS

OBD-II computer programs not only detect faults but also *periodically test various systems* and alert the driver before emissions-related components are harmed by system faults:

- Serious faults cause a blinking malfunction indicator lamp (MIL) or even an engine shutdown.
- Less serious faults may simply store a code but not illuminate the MIL.

The OBD-II requirements did not affect fuel system design. However, one new component, a fuel evaporative canister purge line pressure sensor, was added for monitoring purge line pressure during tests. The OBD-II requirements state that vehicle fuel systems are to be routinely tested *while under way* by the PCM.

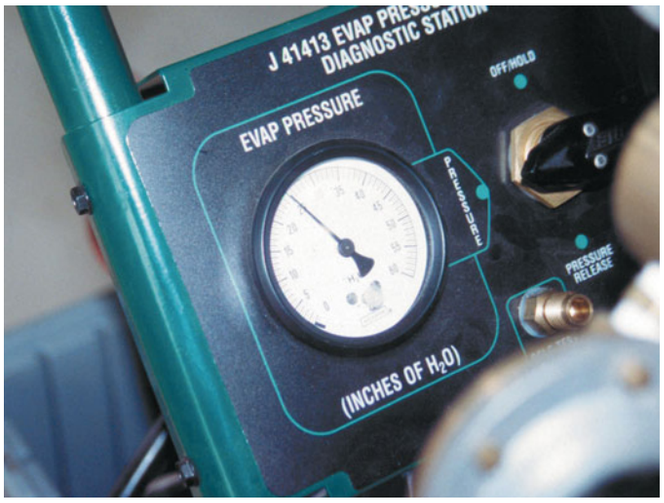


FIGURE 83–11 An emission tester that uses nitrogen to pressurize the fuel system.



FIGURE 83–12 The fuel tank pressure sensor (black unit with three wires) looks like a MAP sensor and is usually located on top of the fuel pump module (white unit).

All OBD-II vehicles perform a canister purge system pressure test, as commanded by the PCM. While the vehicle is being driven, the vapor line between the canister and the purge valve is monitored for pressure changes:

- When the canister purge solenoid is open, the line should be under a vacuum since vapors must be drawn from the canister into the intake system. However, when the purge solenoid is closed, there should be no vacuum in the line. The pressure sensor detects if a vacuum is present, and the information is compared to the command given to the solenoid.
- If, during the canister purge cycle, no vacuum exists in the canister purge line, a code is set indicating a possible fault, which could be caused by an inoperative or clogged solenoid or a blocked or leaking canister purge fuel line. Likewise, if vacuum exists when no command for purge is given, a stuck solenoid is evident, and a code is set. The EVAP system monitor tests for purge volume and leaks.

A typical EVAP monitor first closes off the system to atmospheric pressure and opens the purge valve during cruise operation. A **fuel tank pressure (FTP)** sensor then monitors the rate with which vacuum increases in the system. The monitor uses this information to determine the purge volume flow rate. To test for leaks, the EVAP monitor closes the purge valve, creating a completely closed system. The fuel tank pressure sensor then monitors the leak-down rate. If the rate exceeds PCM-stored values, a leak greater than or equal to the OBD-II standard of 0.04 inch (1 mm) or 0.02 inch (0.5 mm) exists. After two consecutive failed trips testing either purge volume or the presence of a leak, the PCM lights the MIL and sets a DTC.

The fuel tank pressure sensor is similar to a MAP sensor, and instead of monitoring intake manifold absolute pressure, it is used to monitor fuel tank pressure. ● **SEE FIGURE 83–12.**

ENGINE-OFF NATURAL VACUUM System integrity (leakage) can also be checked after the engine is shut off. The premise is that a warm evaporative system will cool down after the engine is shut off and the vehicle is stable. A slight vacuum will be created in the gas tank during this cool-down period. If a specific level of vacuum is reached and maintained, the system is said to have integrity (no leakage). Actually, the vacuum is created after a period of time because the vapor pressure tends to increase after the engine is shut off and gradually decreases over time. The PCM monitors the pressure rise and decrease over time and triggers a diagnostic trouble code (DTC) if the pressure indicates a leak in the system. ● **SEE FIGURE 83–13.**

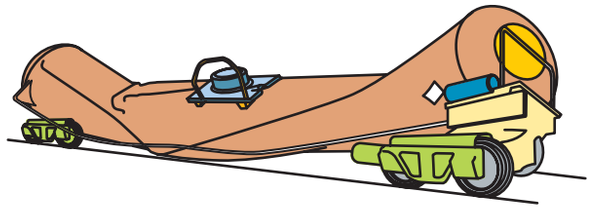


FIGURE 83–13 A tank car was cleaned using steam, and then both the bottom drain and the top vent were closed. The next day, the tank had collapsed because of the air pressure difference when the inside cooled. The higher outside air pressure caused the tank to collapse.

TECH TIP

Always Tighten the Cap Correctly

Many diagnostic trouble codes (DTCs) are set because the gas cap has not been properly installed. To be sure that a screw-type gas cap is properly sealed, tighten it until you hear three clicks. The clicking is a ratchet device, and the clicking does not harm the cap. Therefore, if a P0440 or similar DTC is set, check the cap. ● **SEE FIGURE 83–14.**

TYPICAL EVAP MONITOR

The PCM will run the EVAP monitor when the following enable criteria are met:

- Barometric pressure (BARO) greater than 70 kPa (20.7 in. Hg or 10.2 PSI)
- Intake air temperature (IAT) between 39°F and 86°F (4°C to 30°C) at engine start-up
- Engine coolant temperature (ECT) between 39°F and 86°F (4°C to 30°C) at engine start-up
- ECT and IAT within 3°F of each other at engine start-up
- Fuel level within 15% to 85%
- Throttle position (TP) sensor between 9% and 35%

A typical EVAP monitor first closes off the system to atmospheric pressure and opens the purge valve during cruise operation.



FIGURE 83–14 This Toyota cap warns that the check engine light will come on if not tightened until one click.



FIGURE 83–16 The fuel level must be above 15% and below 85% before the EVAP monitor will run on most vehicles.

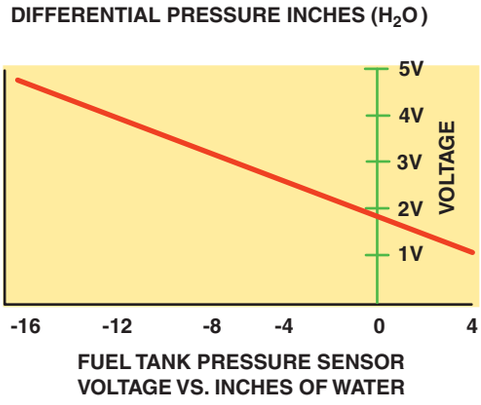


FIGURE 83–15 To easily check the fuel tank pressure sensor, remove the cap, and the sensor should read about 1.7 volts.

A fuel tank pressure (FTP) sensor then monitors the rate with which vacuum increases in the system. ● **SEE FIGURE 83–15.**

The monitor uses this information to determine the purge volume flow rate. To test for leaks, the EVAP monitor closes the purge valve, creating a completely closed system. The fuel tank pressure sensor then monitors the leak-down rate. If the rate exceeds PCM-stored values, a leak greater than or equal to the OBD-II standard of 0.04 inch (1 mm) or 0.02 inch (0.5 mm) exists.

RUNNING THE EVAP MONITOR Four tests are performed during a typical EVAP monitor. A DTC is assigned to each test:

1. **Weak vacuum test (P0440–large leak).** This test identifies gross leaks. During the monitor, the vent solenoid is closed, and the purge solenoid is duty cycled. The fuel tank pressure (FTP) should indicate a vacuum of approximately 6 to 10 in. H_2O.
2. **No flow during purging (P0441–no flow during purging).** This test uses the fuel tank pressure (FTP) sensor to determine that there was no change in fuel tank pressure during purging. This fault could be due to a defective purge valve or a gross leak caused by faults such as a defective or missing gas cap.
3. **Small leak test (P0442–small leak).** After the large leak test passes, the PCM checks for a small leak by keeping the vent solenoid closed and closing the purge solenoid. The system is now sealed. The PCM measures the change in FTP voltage over time.

TECH TIP

Keep the Fuel Tank Properly Filled

Most evaporative system monitors will not run unless the fuel level is between 15% and 85%. In other words, if a driver always runs with close to an empty tank or always tries to keep the tank full, the EVAP monitor may not run. ● **SEE FIGURE 83–16.**

4. **Excess vacuum test (P0446).** This test checks for vent path restrictions. With the vent solenoid open and purge commanded, the PCM should not see excessive vacuum in the EVAP system. Typical EVAP system vacuum with the vent solenoid open is about 5 to 6 in. H_2O.

EVAP SYSTEM-RELATED DIAGNOSTIC TROUBLE CODES

Diagnostic Trouble Code	Description	Possible Causes
P0440	Evaporative system fault	• Loose gas cap • Defective EVAP vent • Cracked charcoal canister • EVAP vent or purge vapor line problems
P0442	Small leak detected	• Loose gas cap • Defective EVAP vent or purge solenoid • EVAP vent or purge line problems
P0446	EVAP canister vent blocked	• EVAP vent or purge solenoid electrical problems • Restricted EVAP canister vent line

REVIEW QUESTIONS

1. What components are used in a typical evaporative emission control system?
2. How does the computer control the purging of the vapor canister?
3. What is the difference between an enhanced and a nonenhanced evaporative control system?
4. Why is the vent valve subject to rust and corrosion?
5. What are the parameters (enable criteria) that must be met for the evaporative system monitor to run?

CHAPTER QUIZ

1. What is the substance used in a vapor canister to absorb volatile organic compounds?
   a. Desiccant **c.** Pleated paper
   b. Organic absorber **d.** Carbon
2. Which valve(s) is (are) normally closed?
   a. Canister purge valve
   b. Canister vent valve
   c. Both canister purge and canister vent valves
   d. Neither canister purge nor canister vent valve
3. All of the following can increase the pressure in the evaporative emission control system *except* _____.
   a. Fuel temperature
   b. Returned fuel from the fuel-injection system
   c. Inlet fuel to the fuel pump
   d. Volatility of the fuel
4. Evaporative emission control systems operate on low pressure measured in inches of water (in. H_2O). One PSI is equal to how many inches of water?
   a. 1 **c.** 18
   b. 10 **d.** 28
5. Inadequate purge flow rate will trigger which DTC?
   a. P0440 **c.** P0300
   b. P0446 **d.** P0440 or P0446
6. Two technicians are discussing a state emission test. Technician A says that a vent valve that is not able to close can cause the system to fail the on-board test. Technician B says that a leaking gas cap can cause a failure of the EVAP test. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
7. Which EVAP valve is subject to rust and corrosion more than all of the others?
   a. Purge valve **c.** Vent valve
   b. Vacuum control valve **d.** roll over check valve
8. Before an evaporative emission monitor will run, the fuel level must be where?
   a. At least 75% full
   b. Over 25%
   c. Between 15% and 85%
   d. The level of the fuel in the tank is not needed to run the monitor test
9. Technician A says that low-pressure smoke installed in the fuel system can be used to check for leaks. Technician B says that nitrogen under low pressure can be installed in the fuel system to check for leaks. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
10. A small leak is detected by the evaporative emission control system monitor that could be caused by a loose gas cap. Which DTC will likely be set?
    a. P0440 **c.** P0446
    b. P0442 **d.** P0440, P0441, or P0442

chapter 84

EXHAUST GAS RECIRCULATION SYSTEMS

OBJECTIVES: **After studying Chapter 84, the reader should be able to:** • Prepare for the ASE Engine Performance (A8) certification test content area "D" (Emission Control Systems). • Describe the purpose and function of the exhaust gas recirculation system. • Discuss how the exhaust gas recirculation system is tested under OBD-II regulations. • Explain methods for diagnosing and testing for faults in the exhaust gas recirculation system.

KEY TERMS: Delta pressure feedback EGR (DPFE) sensor 939 • Detonation 936 • Digital EGR valve 938 • EGR valve position (EVP) sensor 938 • Electronic vacuum regulator valve (EVRV) 940 • Exhaust gas recirculation (EGR) 936 • Inert 936 • Linear EGR valve 938 • Nitrogen oxides (NO_x) 936 • Pressure feedback EGR (PFE) sensor 938



FIGURE 84–1 Nitrogen oxides (NO_x) create a red-brown haze that often hangs over major cities.

EXHAUST GAS RECIRCULATION SYSTEMS

INTRODUCTION **Exhaust gas recirculation (EGR)** is an emission control system that lowers the amount of **nitrogen oxides (NO_x)** formed during combustion. In the presence of sunlight, NO_x reacts with hydrocarbons in the atmosphere to form ozone (O_3) or photochemical smog, an air pollutant.

NO_x FORMATION Nitrogen (N_2) and oxygen (O_2) molecules are separated into individual atoms of nitrogen and oxygen during the combustion process. These molecules then bond to form NO_x (NO, NO_2). When combustion flame front temperatures exceed 2,500°F (1,370°C), NO_x is formed inside the cylinder, which is then discharged into the atmosphere from the tailpipe. ● **SEE FIGURE 84–1.**

CONTROLLING NO_x To handle the NO_x generated above 2,500°F (1,370°C), the most efficient method to meet NO_x emissions without significantly affecting engine performance, fuel economy, and other exhaust emissions is to use exhaust gas recirculation (EGR). The EGR system routes small quantities, usually between 6% and 10%, of exhaust gas into the intake manifold.

Here, the exhaust gas mixes with and takes the place of some intake charge. This leaves less room for the intake charge to enter the combustion chamber. The recirculated exhaust gas is **inert** (chemically inactive) and does not enter into the combustion process. The result is a lower peak combustion temperature. When the combustion temperature is lowered, the production of oxides of nitrogen is reduced.

The EGR system has some means of interconnecting the exhaust and intake manifolds. ● **SEE FIGURE 84–2.**

The EGR valve controls the flow of exhaust gases through the interconnecting passages:

- On V-type engines, the intake manifold crossover is used as a source of exhaust gas for the EGR system. A cast passage connects the exhaust crossover to the EGR valve. The exhaust gas is sent from the EGR valve to openings in the manifold.
- On inline-type engines, an external tube is generally used to carry exhaust gas to the EGR valve. This tube is often designed to be long so that the exhaust gas is cooled before it enters the EGR valve.

EGR SYSTEM OPERATION Since small amounts of exhaust are all that is needed to lower peak combustion temperatures, the orifice through which the exhaust passes is small.

EGR is usually not required during the following conditions because the combustion temperatures are low:

- During idle speed
- When the engine is cold
- At wide-open throttle (WOT) (Not allowing EGR allows the engine to provide extra power when demanded. While the NO_x formation is high during these times, the overall effect of not using EGR during WOT conditions is minor.)

The level of NO_x emission changes according to engine speed, temperature, and load. Many systems use a cooler to reduce the temperature of the exhaust gases before they enter the intake manifold. The cooler the exhaust gases, the more effective they are at reducing the formation of NOx.

EGR BENEFITS In addition to lowering NO_x levels, the EGR system also helps control detonation. **Detonation,** also called spark knock or ping, occurs when high pressure and heat cause the air-fuel mixture to ignite. This uncontrolled combustion can severely damage the engine.

Using the EGR system allows for greater ignition timing advance and for the advance to occur sooner without detonation problems, which increases power and efficiency.

POSITIVE AND NEGATIVE BACK PRESSURE EGR VALVES Some vacuum-operated EGR valves used on older engines are designed with a small valve inside that bleeds off any applied vacuum and prevents the valve from opening:

- **Positive back pressure EGR valves.** These EGR valves require a positive back pressure in the exhaust system. At low engine speeds and light engine loads, the EGR system is not needed, and the back pressure in it is also low. Without enough back pressure, the EGR valve does not open even though vacuum may be present at the EGR valve. ● **SEE FIGURE 84–3.**
- **Negative back pressure EGR valves.** On each exhaust stroke, the engine emits an exhaust "pulse." Each pulse represents a positive pressure. Behind each pulse is a small area of low pressure. Some EGR valves react to this low-pressure area by closing a small internal valve, which allows the EGR valve to be opened by vacuum.

The following conditions must occur before a back pressure-type vacuum-controlled EGR will operate:

1. Vacuum must be applied to the EGR valve itself. The vacuum source can be ported vacuum (above the throttle plate) or manifold vacuum (below the throttle plate) and by the computer through a solenoid valve.
2. Exhaust back pressure must be present to close an internal valve inside the EGR to allow the vacuum to move the diaphragm.

NOTE: Installing a high-performance exhaust system could prevent a back pressure vacuum-operated EGR valve from opening. If this occurs, excessive combustion chamber pressure may lead to severe spark knock, piston damage, or a blown head gasket.

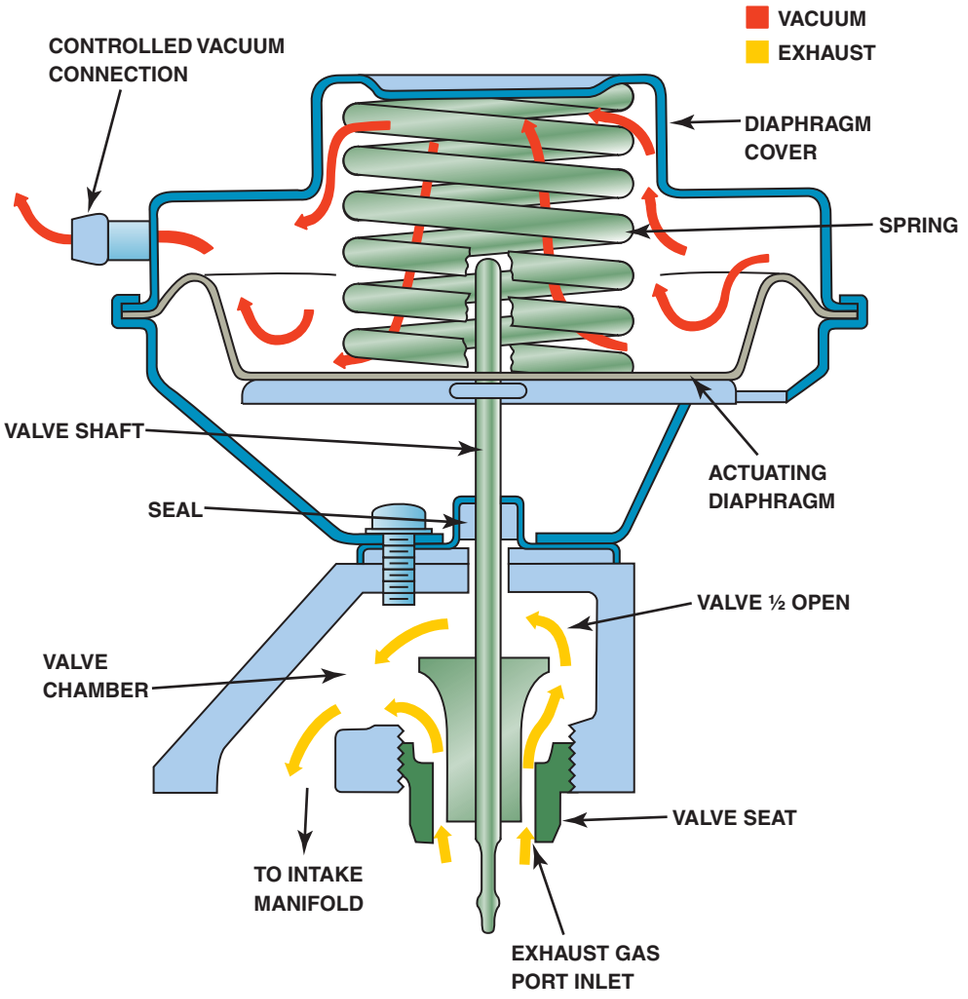


FIGURE 84–2 When the EGR valve opens, the exhaust gases flow through the valve and into passages in the intake manifold.

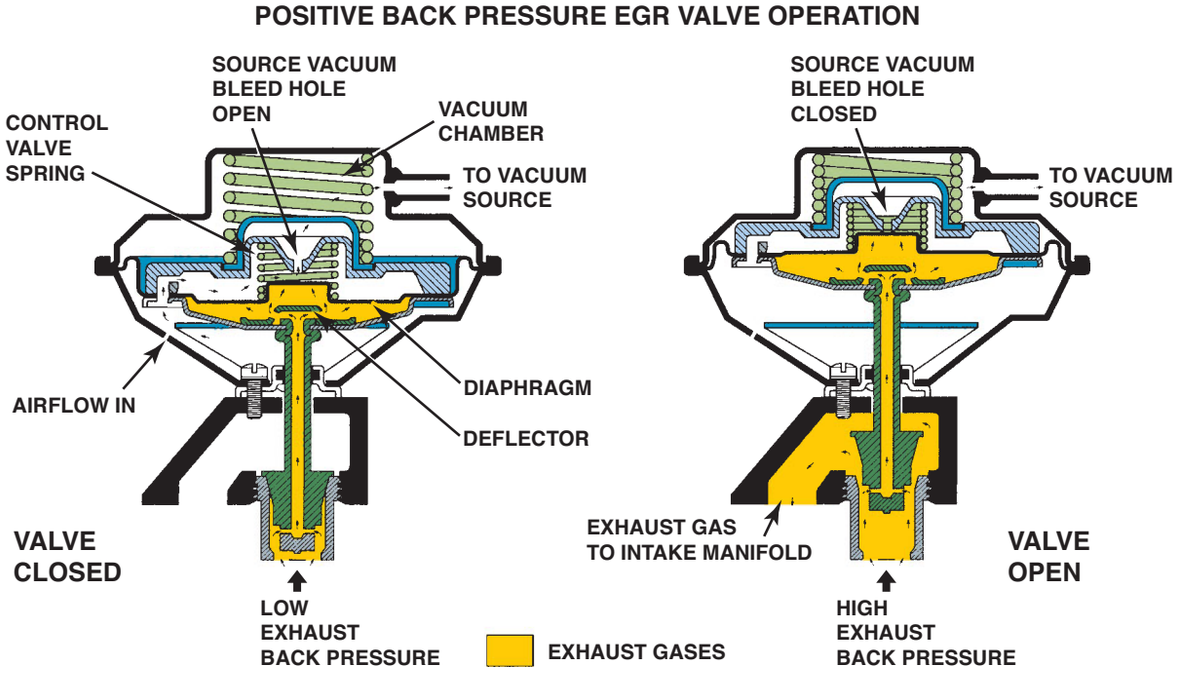


FIGURE 84–3 Back pressure in the exhaust system is used to close the control valve, allowing engine vacuum to open the EGR valve.

COMPUTER-CONTROLLED EGR SYSTEMS Most vehicles today use the powertrain control module (PCM) to operate the EGR system. Many PCM-controlled EGR systems have one or more solenoids controlling the EGR vacuum. The PCM controls a solenoid to shut off vacuum to the EGR valve at cold engine temperatures, idle speed, and WOT operation. If two solenoids are used, one acts as an off/on control of supply vacuum, while the second solenoid vents vacuum when EGR flow is not desired or needs to be reduced.

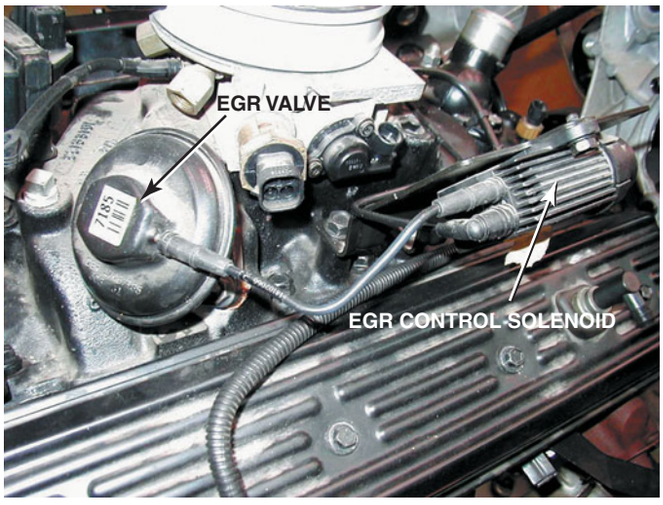


FIGURE 84–4 Typical vacuum-operated EGR valve. The operation of the valve is controlled by the PCM by pulsing the EGR control solenoid on and off.

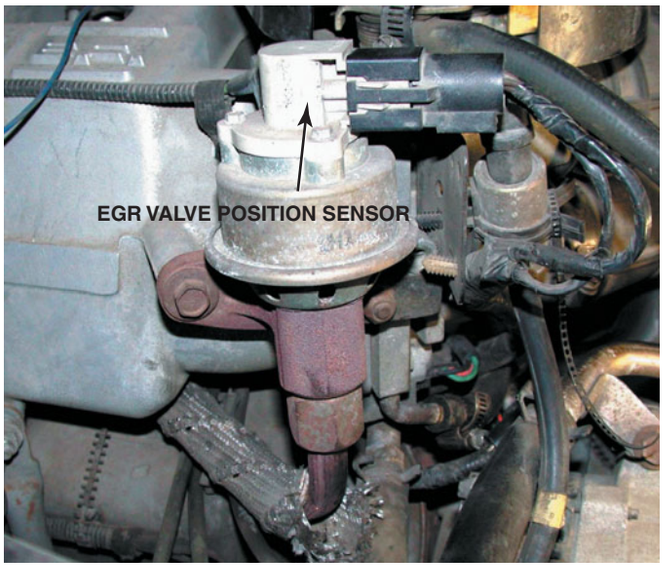


FIGURE 84–5 An EGR valve position sensor on top of an EGR valve.

The second solenoid is used to control a vacuum air bleed, allowing atmospheric pressure in to modulate EGR flow according to vehicle operating conditions. ● **SEE FIGURE 84–4.**

EGR VALVE POSITION SENSORS Most PCM vacuum-operated EGR systems use a sensor to indicate EGR operation. Onboard diagnostics generation II (OBD-II) EGR system monitors require an EGR sensor to verify that the valve opened. A linear potentiometer on the top of the EGR valve stem indicates valve position to the PCM. This is called an **EGR valve position (EVP) sensor.** Some later-model Ford EGR systems, however, use a feedback signal provided by an EGR exhaust back pressure sensor that converts the exhaust back pressure to a voltage signal. This sensor is called a **pressure feedback EGR (PFE) sensor.**

On some EGR systems, the top of the valve contains a vacuum regulator and EGR pintle-position sensor in one assembly sealed inside a nonremovable plastic cover. The pintle-position sensor provides a voltage output to the PCM, which increases as the duty cycle increases, allowing the PCM to monitor valve operation. ● **SEE FIGURE 84–5.**

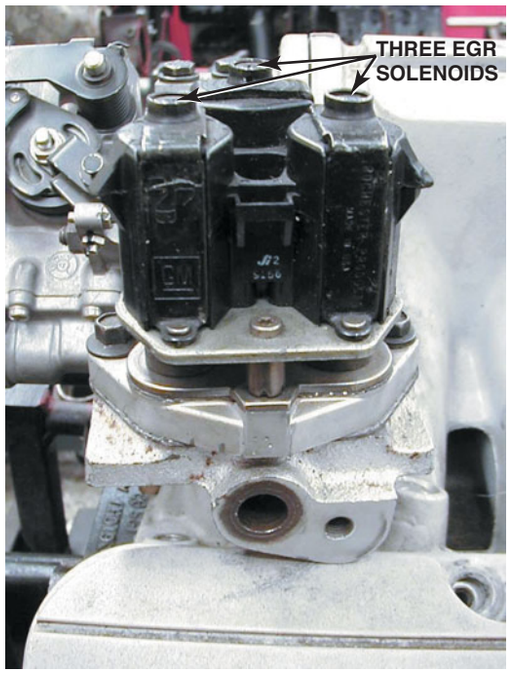


FIGURE 84–6 Digital EGR valve as used on some older General Motors engines.

TECH TIP

Find the Root Cause

Excessive back pressure, such as that caused by a partially clogged exhaust system, could cause the plastic sensors on the EGR valve to melt. Always check for a restricted exhaust whenever replacing a failed EGR valve sensor.

DIGITAL EGR VALVES General Motors used a **digital EGR valve** design on some engines. Unlike vacuum-operated EGR valves, the digital EGR valve consists of three solenoids controlled by the powertrain control module (PCM). Each solenoid controls a different size orifice in the base–small, medium, and large. The PCM controls the ground circuit of each of the solenoids individually. It can produce any of seven different flow rates, using the solenoids to open the three valves in different combinations. The digital EGR valve offers precise control and using a swivel pintle design helps prevent carbon deposit problems. ● **SEE FIGURE 84–6.**

LINEAR EGR Most General Motors and many other vehicles use a **linear EGR valve** that contains a pulse-width modulated solenoid to precisely regulate exhaust gas flow and a feedback potentiometer that signals the PCM regarding the actual position of the valve. ● **SEE FIGURES 84–7 AND 84–8.**

OBD-II EGR MONITORING STRATEGIES

PURPOSE AND FUNCTION In 1996, the U.S. EPA began requiring OBD-II systems in all passenger cars and most light-duty trucks. These systems include emission system monitors that alert

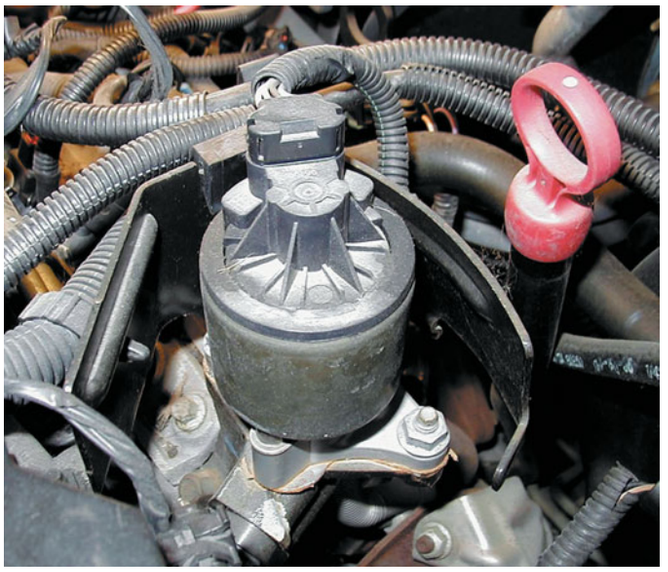


FIGURE 84–7 A General Motors linear EGR valve.

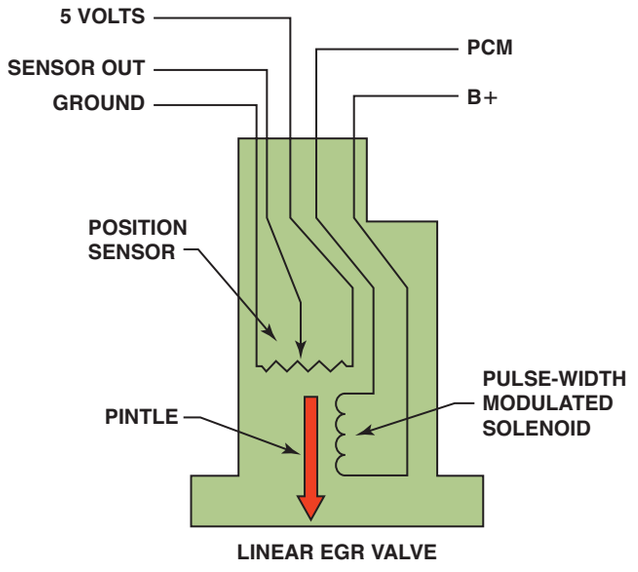


FIGURE 84–8 The EGR valve pintle is pulse-width modulated and a three-wire potentiometer provides pintle-position information back to the PCM.

the driver and the technician if an emission system is malfunctioning. The OBD-II system performs this test by opening and closing the EGR valve. The PCM monitors either the oxygen or MAP sensor for a change in signal voltage. If the EGR system fails, a diagnostic trouble code (DTC) is set. If the system fails two consecutive times, the malfunction indicator lamp (MIL) is lit.

MONITORING STRATEGIES EGR monitoring strategies include the following:

- Some vehicle manufacturers, such as Chrysler, monitor the difference in the exhaust oxygen sensor's voltage activity as the EGR valve opens and closes. Oxygen in the exhaust decreases when the EGR valve is open and increases when the EGR valve is closed because exhaust gas is inert (contains very little oxygen) and actually displaces oxygen. The PCM sets a DTC if the sensor signal does not change.
- Most Fords use an EGR monitor test sensor called a **delta pressure feedback EGR (DPFE) sensor.** This sensor measures the pressure differential between two sides of a metered orifice positioned just below the EGR valve's exhaust side. Pressure between the orifice and the EGR valve decreases when the EGR opens because it becomes exposed to the lower pressure in the intake. The DPFE sensor recognizes this pressure drop, compares it to the relatively higher pressure on the exhaust side of the orifice, and signals the value of the pressure difference to the PCM. ● **SEE FIGURE 84–9.**
- Many vehicle manufacturers use the manifold absolute pressure (MAP) sensor as the EGR monitor on some applications. After meeting the enable criteria (operating condition requirements), the EGR monitor is run. The PCM monitors the MAP sensor while it commands the EGR valve to open. The MAP sensor signal should change in response to the sudden change in manifold pressure or the fuel trim changes created by a change in the oxygen sensor voltage. If the signal value falls outside the acceptable value in the lookup table, a DTC sets. If the EGR fails on two consecutive trips, the PCM lights the MIL. ● **SEE FIGURE 84–10.**

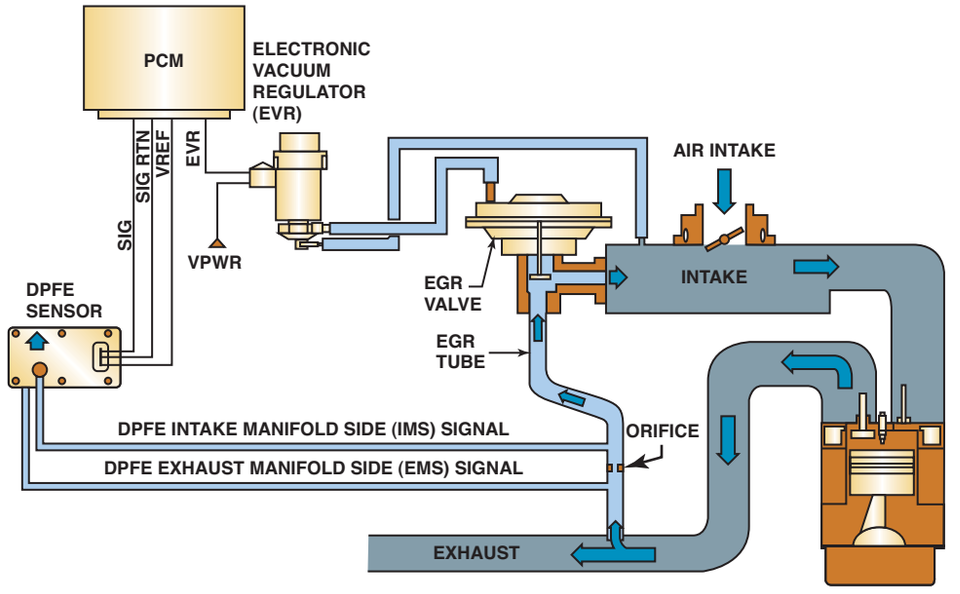


FIGURE 84–9 A typical Ford DPFE sensor and related components.

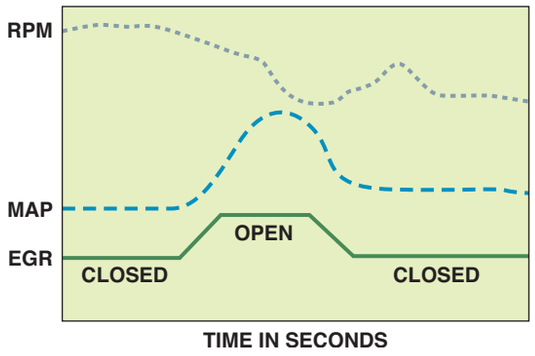


FIGURE 84–10 An OBD-II active test. The PCM opens the EGR valve and then monitors the MAP sensor and/or engine speed (RPM) to verify that it meets acceptable values.

TECH TIP

Watch Out for Carbon Balls!

EGR valves can get stuck partially open by a chunk of carbon, and the valve or solenoid will test as defective. When the valve (or solenoid) is removed, small chunks or balls of carbon often fall into the exhaust manifold passage. When the replacement valve is installed, the carbon balls can be drawn into the new valve again, causing the engine to idle roughly or stall.

To help prevent this problem, start the engine with the EGR valve or solenoid removed. Any balls or chunks of carbon will be blown out of the passage by the exhaust. Stop the engine and install the replacement EGR valve or solenoid.

DIAGNOSING A DEFECTIVE EGR SYSTEM

SYMPTOMS If the EGR valve is not opening or the flow of the exhaust gas is restricted, then the following symptoms are likely:

- Detonation (spark knock or ping) during acceleration or during cruise (steady-speed driving)
- Excessive oxides of nitrogen (NO_x) exhaust emissions

If the EGR valve is stuck open or partially open, then the following symptoms are likely:

- Rough idle or frequent stalling
- Poor performance/low power, especially at low engine speed

EGR TESTING PROCEDURES The first step in almost any diagnosis is to perform a thorough visual inspection. To check for proper operation of a vacuum-operated EGR valve, follow these steps:

STEP 1 **Check the vacuum diaphragm of the EGR valve to see if it can hold vacuum.** Because many EGR valves require exhaust back pressure to function correctly, the engine should be running at a fast idle during this test.

STEP 2 **Apply vacuum from a hand-operated vacuum pump and check for proper operation.** The valve itself should move when vacuum is applied, and the engine operation should be affected. The EGR valve should be able to hold the vacuum that was applied. If the vacuum drops off, then the valve is likely to be defective.

STEP 3 **Monitor engine vacuum drop.** Connect a vacuum gauge to an intake manifold vacuum source and monitor the engine vacuum at idle (should be 17 to 21 in. Hg at sea level). Raise the speed of the engine to 2,500 RPM and note the vacuum reading (should be 17 to 21 in. Hg or higher).

REAL WORLD FIX

The Blazer Story

The owner of a Chevrolet Blazer equipped with a 4.3-L, V-6 engine complained that the engine would stumble and hesitate at times. Everything seemed to be functioning correctly, except that the service technician discovered a weak vacuum going to the EGR valve at idle. This vehicle was equipped with an EGR valve-control solenoid, called an **electronic vacuum regulator valve (EVRV)** by General Motors Corporation. The PCM pulses the solenoid to control the vacuum that regulates the operation of the EGR valve. The technician checked the service manual for details on the workings of the system. The technician discovered that vacuum should be present at the EGR valve only when the gear selector indicates a drive gear (drive, low, reverse). Because the technician discovered the vacuum at the solenoid to be leaking, the solenoid was obviously defective and required replacement. After replacement of the solenoid (EVRV), the hesitation problem was solved.

NOTE: The technician also discovered in the service manual that blower-type exhaust hoses should not be connected to the tailpipe on any vehicle while performing an inspection of the EGR system. The vacuum created by the system could cause false EGR valve operation to occur.

TECH TIP

The Snake Trick

The EGR passages on many intake manifolds become clogged with carbon, which reduces the flow of exhaust and the amount of exhaust gases in the cylinders. This reduction can cause spark knock (detonation) and increased emissions of oxides of nitrogen (NO_x) (especially important in areas with enhanced exhaust emissions testing).

To quickly and easily remove carbon from exhaust passages, cut an approximately 1-foot (30-cm) length from stranded wire, such as garage door guide wire or an old speedometer cable. Flare the end and place the end of the wire into the passage. Set your drill on reverse and turn it on, and the wire will pull its way through the passage, cleaning the carbon as it goes, just like a snake in a drainpipe. Some vehicles, such as Hondas, require that plugs be drilled out to gain access to the EGR passages.
SEE FIGURE 84–11.



FIGURE 84–11 Removing the EGR passage plugs from the intake manifold on a Honda.

Activate the EGR valve using a scan tool or vacuum pump, if vacuum controlled, and observe the vacuum gauge. The results are as follows:

- The vacuum should drop 6 to 8 in. Hg.
- If the vacuum drops less than 6 to 8 in. Hg, the valve or the EGR passages are clogged.
- If the EGR valve is able to hold vacuum but the engine is not affected when the valve is opened, then the exhaust passage(s) must be checked for restriction.

See the Tech Tip "The Snake Trick." If the EGR valve will not hold vacuum, the valve itself is likely to be defective and require replacement.

EGR-RELATED OBD-II DIAGNOSTIC TROUBLE CODES

Diagnostic Trouble Code	Description	Possible Causes
P0400	Exhaust gas recirculation flow problems	• EGR valve • EGR valve hose or electrical connection • Defective PCM
P0401	Exhaust gas recirculation flow insufficient	• EGR valve • Clogged EGR ports or passages
P0402	Exhaust gas recirculation flow excessive	• Stuck-open EGR valve • Vacuum hose(s) misrouted • Electrical wiring shorted

REVIEW QUESTIONS

1. What causes the formation of oxides of nitrogen?
2. How does the use of exhaust gas reduce NO_x exhaust emission?
3. How does the DPFE sensor work?
4. How does the PCM determine that the exhaust flow through the EGR system meets OBD-II regulations?

CHAPTER QUIZ

1. What causes the nitrogen and the oxygen in the air to combine and form NO_x?
   a. Sunlight
   b. Any spark will cause this to occur
   c. Heat above 2,500°F (1,370°C)
   d. Chemical reaction in the catalytic converter
2. Exhaust gas recirculation (EGR) is generally not needed under all the following conditions *except* _____.
   a. Idle speed
   b. Cold engine
   c. Cruise speed
   d. Wide-open throttle (WOT)
3. Technician A says that a low-restriction exhaust system could prevent a back pressure-type vacuum-controlled EGR valve from opening correctly. Technician B says restricted exhaust can cause the EGR valve position sensor to fail. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. EGR is used to control which exhaust emission?
   a. Unburned hydrocarbons (HC)
   b. Oxides of nitrogen (NO_x)
   c. Carbon monoxide (CO)
   d. Both NO_x and CO
5. A typical EGR pintle-position sensor is what type of sensor?
   a. Rheostat
   b. Piezoelectric
   c. Wheatstone bridge
   d. Potentiometer
6. OBD-II regulations require that the EGR system be tested. Technician A says that the PCM can monitor the commanded position of the EGR valve to determine if it is functioning correctly. Technician B says that the PCM can open the EGR valve and monitor for a change in the MAP sensor or oxygen sensor reading to detect if the system is functioning correctly. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

7. Two technicians are discussing clogged EGR passages. Technician A says clogged EGR passages can cause excessive NO_x exhaust emission. Technician B says that clogged EGR passages can cause the engine to ping (spark knock or detonation). Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

8. An EGR valve that is partially stuck open would *most likely* cause what condition?
   a. Rough idle/stalling
   b. Excessive NO_x exhaust emissions
   c. Ping (spark knock or detonation)
   d. Missing at highway speed

9. When testing an EGR system for proper operation using a vacuum gauge, how much should the vacuum drop when the EGR is commanded on by a scan tool?
   a. 1 to 2 in. Hg
   b. 3 to 5 in. Hg
   c. 6 to 8 in. Hg
   d. 8 to 10 in. Hg

10. A P0401 DTC (exhaust gas recirculation flow insufficient) is being discussed. Technician A says that a defective EGR valve could be the cause. Technician B says that clogged EGR passages could be the cause. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

chapter 85

POSITIVE CRANKCASE VENTILATION AND SECONDARY AIR-INJECTION SYSTEMS

OBJECTIVES: **After studying Chapter 85, the reader should be able to:** • Prepare for the ASE Engine Performance (A8) certification test content area "D" (Emission Control Systems). • Describe the purpose and function of the positive crankcase ventilation (PCV) and secondary air-injection (SAI) systems. • Discuss how the PCV and SAI systems are tested under OBD-II regulations. • Explain methods for diagnosing and testing faults in the PCV and secondary air injection (SAI) systems.

KEY TERMS: Air-injection reaction (AIR) 945 • Blowby 942 • Check valve 946 • Positive crankcase ventilation (PCV) 942 • Secondary air injection (SAI) 945 • Smog pump 945 • Thermactor pump 945

CRANKCASE VENTILATION

PURPOSE AND FUNCTION

The problem of crankcase ventilation has existed since the beginning of the automobile because no piston ring, new or old, can provide a perfect seal between the piston and the cylinder wall. When an engine is running, the pressure of combustion forces the piston downward. This same pressure also forces gases and unburned fuel from the combustion chamber, past the piston rings, and into the crankcase. This process of gases leaking past the rings is called **blowby,** and the gases form crankcase vapors.

These combustion by-products, particularly unburned hydrocarbons (HC) caused by blowby, must be ventilated from the crankcase. However, the crankcase cannot be vented directly to the atmosphere because the hydrocarbon vapors add to air pollution. **Positive crankcase ventilation (PCV)** systems were developed to ventilate the crankcase and recirculate the vapors to the engine's induction system so they can be burned in the cylinders. PCV systems help reduce HC and CO emissions.

All systems use the following:

1. PCV valve or calibrated orifice, or orifice and separator
2. PCV inlet air filter plus all connecting hoses
   ● **SEE FIGURE 85–1.**

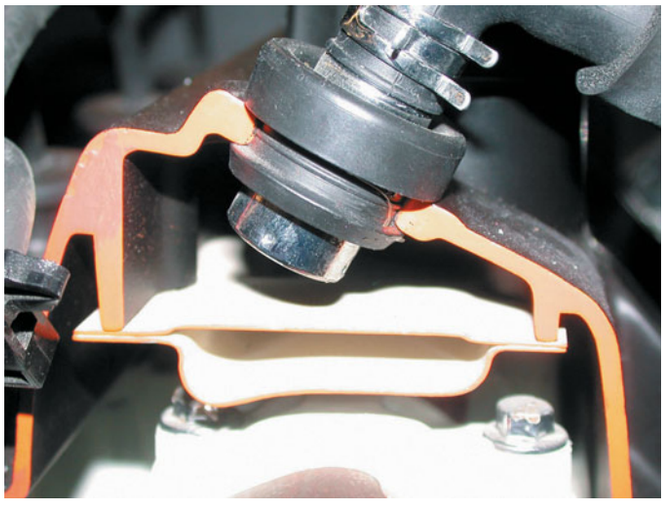


FIGURE 85–1 A PCV valve in a cutaway valve cover, showing the baffles that prevent liquid oil from being drawn into the intake manifold.

An oil/vapor or oil/water separator is used in some systems instead of a valve or orifice, particularly with turbocharged and fuel-injected engines. The oil/vapor separator lets oil condense and drain

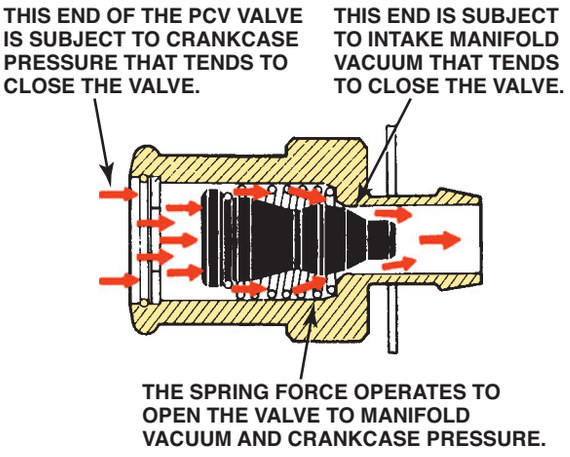


FIGURE 85–2 Spring force, crankcase pressure, and intake manifold vacuum work together to regulate the flow rate through the PCV valve.

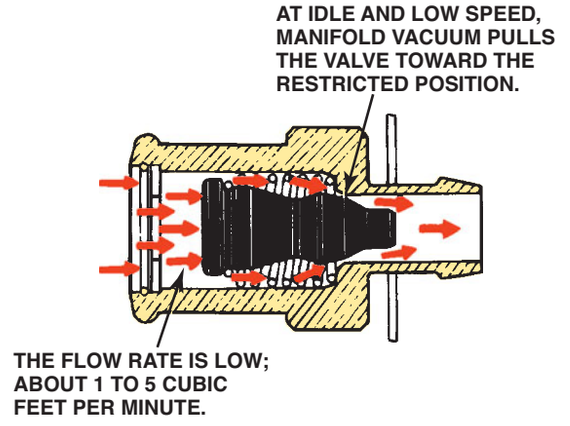


FIGURE 85–3 Air flows through the PCV valve during idle, cruising, and light-load conditions.

back into the crankcase. The oil/water separator accumulates moisture and prevents it from freezing during cold engine starts.

The air for the PCV system is drawn after the air cleaner filter, which acts as a PCV filter.

NOTE: Some older designs drew from the dirty side of the air cleaner, where a separate crankcase ventilation filter was used.

PCV VALVES

The PCV valve in most systems is a one-way valve containing a spring-operated plunger that controls valve flow rate. ● **SEE FIGURE 85–2.**

Flow rate is established for each engine, and a valve for a different engine should not be substituted. The flow rate is determined by the size of the plunger and the holes inside the valve. PCV valves usually are located in the valve cover or intake manifold.

The PCV valve regulates airflow through the crankcase under all driving conditions and speeds. When manifold vacuum is high (at idle, cruising, and light-load operation), the PCV valve restricts the airflow to maintain a balanced air-fuel ratio. ● **SEE FIGURE 85–3.**

It also prevents high intake manifold vacuum from pulling oil out of the crankcase and into the intake manifold. Under high speed or heavy loads, the valve opens and allows maximum airflow. ● **SEE FIGURE 85–4.**

If the engine backfires, the valve will close instantly to prevent a crankcase explosion. ● **SEE FIGURE 85–5.**

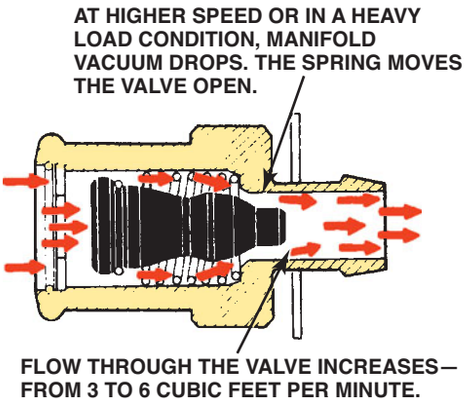


FIGURE 85–4 Air flows through the PCV valve during acceleration and when the engine is under a heavy load.

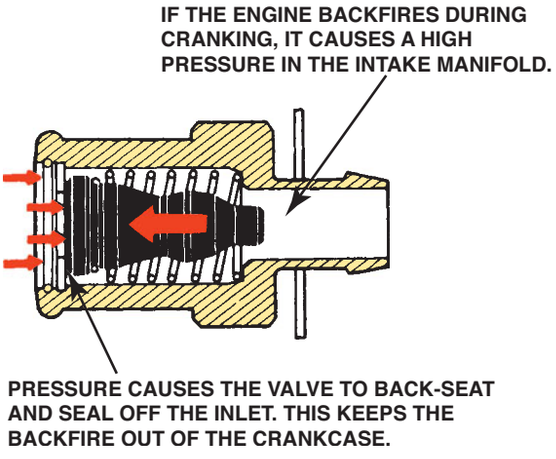


FIGURE 85–5 PCV valve operation in the event of a backfire.

ORIFICE-CONTROLLED SYSTEMS.

The closed PCV system used on some 4-cylinder engines contains a calibrated orifice instead of a PCV valve. The orifice may be located in the valve cover or intake manifold or in a hose connected between the valve cover, air cleaner, and intake manifold.

While most orifice flow control systems work the same as a PCV valve system, they may not use fresh air scavenging of the crankcase. Crankcase vapors are drawn into the intake manifold in calibrated amounts depending on manifold pressure and the orifice size. If vapor availability is low, as during idle, air is drawn in with the vapors. During off-idle operation, excess vapors are sent to the air cleaner.

At idle, PCV flow is controlled by a 0.05-inch (1.3-mm) orifice. As the engine moves off idle, ported vacuum pulls a spring-loaded valve off of its seat, allowing PCV flow to pass through a 0.09-inch (2.3-mm) orifice.

SEPARATOR SYSTEMS.

Turbocharged and many fuel-injected engines use an oil/vapor or oil/water separator and a calibrated orifice instead of a PCV valve. In the most common applications, the air intake throttle body acts as the source for crankcase ventilation vacuum, and a calibrated orifice acts as the metering device.

PCV SYSTEM DIAGNOSIS

SYMPTOMS. If the PCV valve or orifice is not clogged, intake air flows freely and the PCV system functions properly. Engine design includes the air and vapor flow as a calibrated part of the air-fuel mixture. In fact, some engines receive as much as 30% of the idle air through the PCV system. For this reason, a flow problem in the PCV system results in driveability problems.

REAL WORLD FIX

The Whistling Engine

An older vehicle was being diagnosed for a whistling sound whenever the engine was running, especially at idle. It was finally discovered that the breather in the valve cover was plugged and caused high vacuum in the crankcase. The engine was sucking air from what was likely the rear main seal lip, making the "whistle" noise. After replacing the breather and PCV, the noise stopped.

TECH TIP

Check for Oil Leaks with the Engine Off

The owner of an older vehicle equipped with a V-6 engine complained to his technician that he smelled burning oil, but only *after* shutting off the engine. The technician found that the rocker cover gaskets were leaking. But why did the owner only notice the smell of hot oil when the engine was shut off? Because of the positive crankcase ventilation (PCV) system, engine vacuum tends to draw oil away from gasket surfaces. When the engine stops, however, engine vacuum disappears, and the oil remaining in the upper regions of the engine will tend to flow down and out through any opening. Therefore, a good technician should check an engine for oil leaks not only with the engine running but also shortly after shutdown.

A blocked or plugged PCV system may cause the following to occur:

- Rough or unstable idle
- Excessive oil consumption
- Oil in the air filter housing
- Oil leaks due to excessive crankcase pressure

Before attempting expensive engine repairs, check the condition of the PCV system.

PCV SYSTEM PERFORMANCE CHECK. A properly operating positive crankcase ventilation system should be able to draw vapors from the crankcase and into the intake manifold. If the pipes, hoses, and PCV valve itself are not restricted, vacuum is applied to the crankcase. A slight vacuum is created in the crankcase (usually less than 1 in. Hg if measured at the dipstick) and is also applied to other areas of the engine. Oil drainback holes provide a path for oil to drain back into the oil pan. These holes also allow crankcase vacuum to be applied under the rocker covers and in the valley area of most V-type engines. Several methods can be used to test a PCV system.

RATTLE TEST. The rattle test is performed by simply removing the PCV valve and giving it a shake:

- If the PCV valve does *not* rattle, it is definitely defective and must be replaced.
- If the PCV valve *does* rattle, it does not necessarily mean that the PCV valve is good. All PCV valves contain springs that can become weaker with age and with heating and cooling cycles. Replace any PCV valve with the *exact* replacement according to the vehicle manufacturer's recommended intervals.

REAL WORLD FIX

The Oil-Burning Chevrolet Astro Van

An automotive instructor was driving a Chevrolet Astro van to Fairbanks, Alaska, in January. It was cold, around −32°F (−36°C). As he pulled into Fairbanks and stopped at a traffic light, he smelled burning oil. He thought it was the vehicle ahead of him because it was an older model and in poor condition. However, when he stopped at the hotel he still smelled burning oil. He looked under the van and discovered a large pool of oil. After checking the oil and finding very little left, he called a local shop and was told to bring it in. The technician looked over the situation and said, "You need to put some cardboard across the grill to stop the PCV valve from freezing up." Apparently the PCV valve froze, which then caused the normal blowby gases to force several quarts out the dipstick tube. After installing the cardboard, the instructor had no further problems.

CAUTION: Do not cover the radiator when driving unless under severe cold conditions and carefully watch the coolant temperature to avoid overheating the engine.

THE 3 × 5 CARD TEST. Remove the oil-fill cap (where oil is added to the engine) and start the engine.

NOTE: Use care on some overhead camshaft engines. With the engine running, oil may be sprayed from the open oil-fill opening.

Hold a 3 × 5 card over the opening (a dollar bill or any other piece of paper can be used for this test):

- If the PCV system, including the valve and hoses, is functioning correctly, the card should be held down on the oil-fill opening by the slight vacuum inside the crankcase.
- If the card will not stay, carefully inspect the PCV valve, hose(s), and manifold vacuum port for carbon buildup (restriction). Clean or replace as necessary.

NOTE: On some 4-cylinder engines, the 3 × 5 card may vibrate on the oil-fill opening when the engine is running at idle speed. This is normal because of the time intervals between intake strokes on a 4-cylinder engine.

SNAP-BACK TEST. The proper operation of the PCV valve can be checked by placing a finger over the inlet hole in the valve when the engine is running and removing the finger rapidly. Repeat several times. The valve should "snap back." If the valve does not snap back, replace the valve.

CRANKCASE VACUUM TEST. Sometimes the PCV system can be checked by testing for a weak vacuum at the oil dipstick tube using an inches-of-water manometer or gauge as follows:

STEP 1 Remove the oil-fill cap or vent PCV opening and cover the opening.

STEP 2 Remove the oil dipstick (oil level indicator).

STEP 3 Connect a water manometer or gauge to the dipstick tube.

STEP 4 Start the engine and observe the gauge at idle and at 2,500 RPM. ● **SEE FIGURE 85–6.**

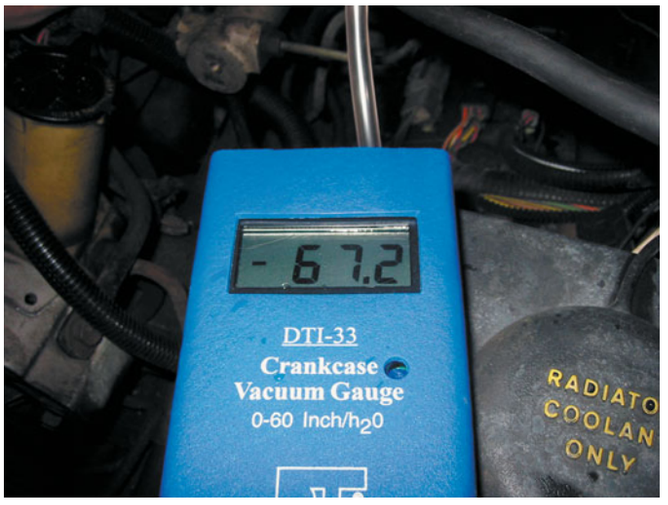


FIGURE 85–6 Using a gauge that measures vacuum in units of inches of water to test the vacuum at the dipstick tube, being sure that the PCV system is capable of drawing a vacuum on the crankcase (28 in. H_2O = 1 PSI, or about 2 in. Hg of vacuum).

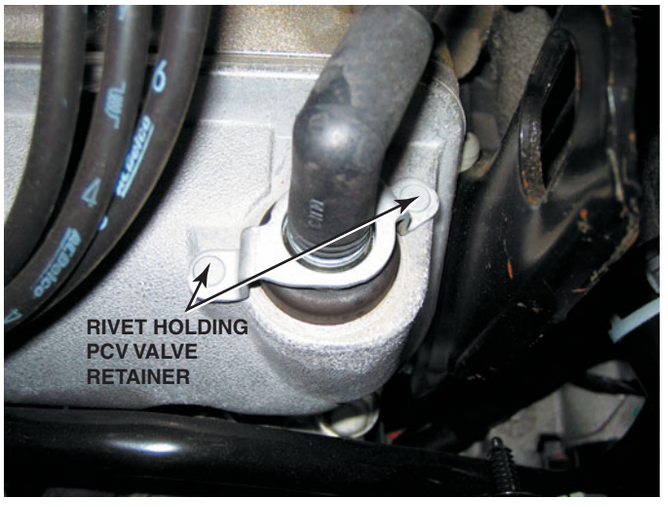


FIGURE 85–7 Most PCV valves used on newer vehicles are secured with fasteners, making it more difficult to disconnect and thereby less likely to increase emissions.

FREQUENTLY ASKED QUESTION

What Are the Wires for at the PCV Valve?

Ford uses an electric heater to prevent ice from forming inside the PCV valve and causing blockage.

Water is a by-product of combustion, and resulting moisture can freeze when the outside air temperature is low. General Motors and others clip a heater hose to the PCV hose to provide the heat needed to prevent an ice blockage.

The gauge should show some vacuum, especially at 2,500 RPM. If not, carefully inspect the PCV system for blockages or other faults.

PCV MONITOR. Starting with 2004 and newer vehicles, all vehicle PCMs monitor the PCV system for proper operation as part of the OBD-II system. The PCV monitor will fail if the PCM detects an opening between the crankcase and the PCV valve or between the PCV valve and the intake manifold. ● **SEE FIGURE 85–7.**

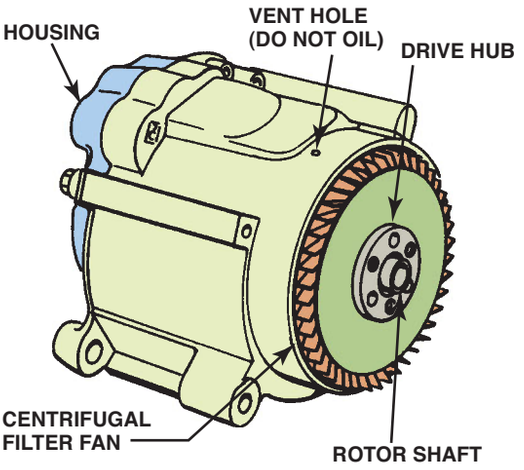


FIGURE 85–8 A typical belt-driven AIR pump. Air enters through the revolving fins behind the drive pulley. The fins act as an air filter because dirt is heavier than air, and therefore the dirt is deflected off of the fins at the same time air is being drawn into the pump.

PCV-RELATED DIAGNOSTIC TROUBLE CODES

Diagnostic Trouble Code	Description	Possible Causes
P0101	MAF or airflow circuit range problem	• Defective PCV valve or hose/connections or MAF circuit fault
P0505	Idle control system problem	• Defective PCV valve or hose/connections

SECONDARY AIR-INJECTION SYSTEM

PURPOSE AND FUNCTION The **secondary air-injection (SAI)** system provides the air necessary for the oxidizing process either at the exhaust manifold or inside the catalytic converter.

NOTE: This system is commonly called AIR, meaning air-injection reaction. Therefore, an AIR pump does pump air.

PARTS AND OPERATION The SAI pump, also called an AIR pump, a **smog pump,** or **thermactor pump,** is mounted at the front of the engine and can be driven by a belt from the crankshaft pulley. It pulls fresh air in through an external filter and pumps the air under slight pressure to each exhaust port through connecting hoses or a manifold. The typical SAI system includes the following components:

- A belt-driven pump with inlet air filter (older models) (● **SEE FIGURE 85–8.**)
- An electrically driven air pump (newer models)
- One or more air distribution manifolds and nozzles

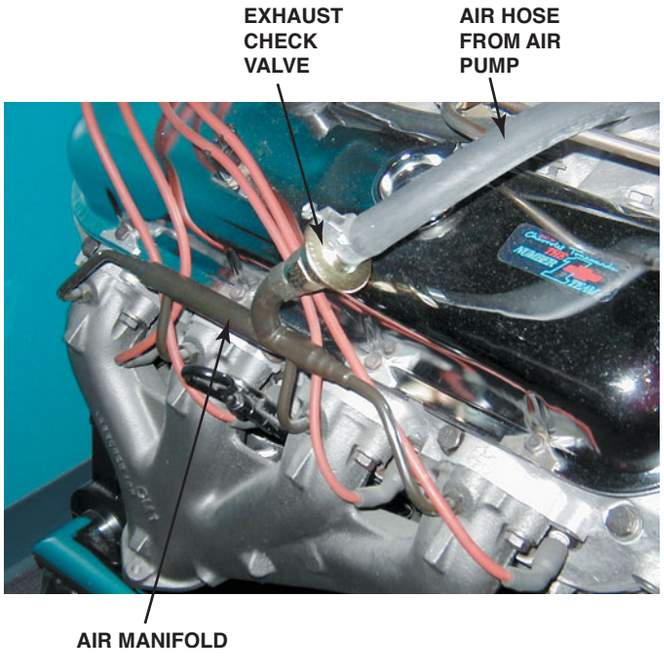


FIGURE 85–9 The external air manifold and exhaust check valve on a restored muscle car engine.

- One or more exhaust check valves
- Connecting hoses for air distribution
- Air management valves and solenoids on all newer applications

With the introduction of NOx reduction converters (also called dual-bed, three-way converters, or TWC), the output of the SAI pump is sent to the center of the converter, where the extra air can help oxidize unburned hydrocarbons (HC) and carbon monoxide (CO) into water vapor (H_2O) and carbon dioxide (CO_2).

The computer controls the airflow from the pump by switching on and off various solenoid valves.

AIR DISTRIBUTION MANIFOLDS AND NOZZLES

The secondary air-injection system sends air from the pump to a nozzle installed near each exhaust port in the cylinder head. This provides equal air injection for the exhaust from each cylinder and makes it available at a point in the system where exhaust gases are the hottest.

Air is delivered to the exhaust system in one of two ways:

1. An external air manifold, or manifolds, distributes the air through injection tubes with stainless-steel nozzles. The nozzles are threaded into the cylinder heads or exhaust manifolds close to each exhaust valve. This method is used primarily with smaller engines.
2. An internal air manifold distributes the air to the exhaust ports near each exhaust valve through passages cast in the cylinder head or the exhaust manifold. This method is used mainly with larger engines.

EXHAUST CHECK VALVES

All air-injection systems use one or more one-way check valves to protect the air pump and other components from reverse exhaust flow. A **check valve** contains a spring-type metallic disc or reed that closes under exhaust back pressure. Check valves are located between the air manifold and the switching valve(s). If exhaust pressure exceeds injection pressure or if the air pump fails, the check valve spring closes the valve to prevent reverse exhaust flow. ● **SEE FIGURE 85–9.**

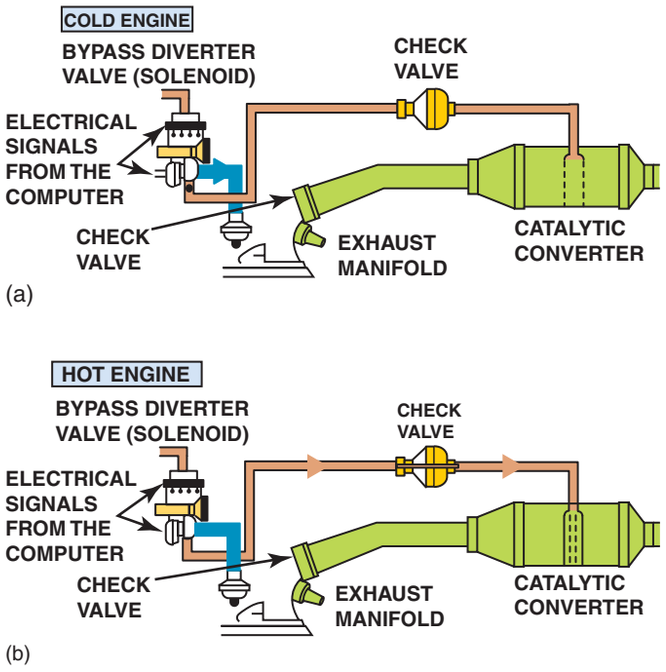


FIGURE 85–10 (a) When the engine is cold and before the oxygen sensor is hot enough to achieve closed loop, the airflow from the air pump is directed to the exhaust manifold(s) through the one-way check valves, which keep the exhaust gases from entering the switching solenoids and the pump itself. (b) When the engine achieves closed loop, the air is directed to the catalytic converter.

NOTE: These check valves commonly fail, resulting in excessive exhaust emissions (CO, especially). When the check valve fails, hot exhaust can travel up to and destroy the switching valve(s) and air pump itself.

BELT-DRIVEN AIR PUMPS

The belt-driven air pump uses a centrifugal filter just behind the drive pulley. As the pump rotates, underhood air is drawn into the pump and slightly compressed. The system uses either vacuum- or solenoid-controlled diverter valves to air directed to the following:

- The exhaust manifold, when the engine is cold to help oxidize carbon monoxide (CO) and unburned hydrocarbons (HC) into carbon dioxide (CO_2) and water vapor (H_2O)
- The catalytic converter when the engine is warm on some models to help provide the extra oxygen needed for the efficient conversion of CO and HC into CO_2 and H_2O
- The air cleaner, during deceleration or wide-open throttle (WOT) engine operation ● **SEE FIGURE 85–10.**

ELECTRIC MOTOR–DRIVEN AIR PUMPS

This style of pump is generally used only during cold engine operation and is computer controlled. The secondary air-injection (SAI) system helps reduce hydrocarbons (HC) and carbon monoxide (CO). The air flowing to the exhaust manifold also helps to warm the three-way catalytic converters quickly on engine start-up so conversion of exhaust gases may occur sooner:

- The SAI pump solenoids are controlled by the PCM. The PCM turns on the SAI pump by providing the ground to complete the circuit, which energizes the SAI pump solenoid relay. When air to the exhaust ports is desired, the PCM energizes the relay in order to turn on the solenoid and the SAI pump. ● **SEE FIGURE 85–11.**

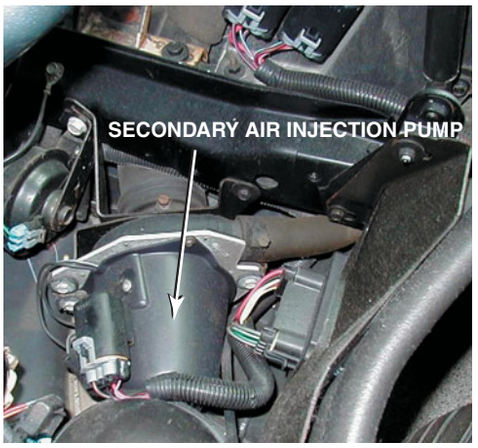


FIGURE 85–11 A typical electric motor–driven SAI pump. This unit is on a Chevrolet Corvette and only works when the engine is cold.

- The PCM turns on the SAI pump during start-up any time the engine coolant temperature is above 32°F (0°C). A typical electric SAI pump operates for a maximum of four minutes or until the system enters closed-loop operation.

SECONDARY AIR-INJECTION SYSTEM DIAGNOSIS

SYMPTOMS The air pump system should be inspected if an exhaust emissions test failure occurs. In severe cases, the exhaust will enter the air cleaner assembly, resulting in a horribly running engine because the extra exhaust displaces the oxygen needed for proper combustion. With the engine running, check for normal operation. ● **SEE CHART 85–1.**

VISUAL INSPECTION Carefully inspect all parts of the SAI system, including the following:

- Hoses and pipes (Any that have holes and leak air or exhaust require replacement.)
- Check valve(s), when a pump has become inoperative
- Exhaust gases, which could have gotten past the check valve and damaged the pump (Look for signs of overheated areas upstream from the check valves. In severe cases, the exhaust can enter the air cleaner assembly, destroying the air filter and greatly reducing engine power.)
- Drive belt on an engine-driven pump, for wear and proper tension (If the belt is worn or damaged, check that the AIR pump rotates.)

Engine Operation	Normal Operation of a Typical SAI System
Cold engine (open-loop operation)	Air is diverted to the exhaust manifold(s) or cylinder head
Warm engine (closed-loop operation)	Air is diverted to the catalytic converter
Deceleration	Air is diverted to the air cleaner assembly
Wide-open throttle	Air is diverted to the air cleaner assembly

CHART 85–1

Typical SAI system operation showing location of airflow from the pump.

FOUR-GAS EXHAUST ANALYSIS An SAI system can be easily tested using an exhaust gas analyzer and the following steps:

1. Start the engine and allow it to run until normal operating temperature is achieved.
2. Connect the analyzer probe to the tailpipe and observe the exhaust readings for hydrocarbons (HC) and carbon monoxide (CO).
3. Using the appropriate pinch-off pliers, shut off the airflow from the SAI system. Observe the HC and CO readings. If the SAI system is working correctly, the HC and CO levels should increase when the SAI system is shut off.
4. Record the O_2 reading with the SAI system still inoperative. Unclamp the pliers and watch the O_2 readings. If the system is functioning correctly, the O_2 level should increase by 1% to 4%.

SAI-RELATED DIAGNOSTIC TROUBLE CODE

Diagnostic Trouble Code	Description	Possible Causes
P0410	SAI solenoid circuit fault	• Defective SAI solenoid • Loose or corroded electrical connections • Loose, missing, or defective rubber hose(s)

REVIEW QUESTIONS

1. What exhaust emissions do the PCV valve and the SAI system control?
2. How does a PCV valve work?
3. What does the abbreviation PCV mean?
4. What does the abbreviation AIR mean?

CHAPTER QUIZ

1. The PCV system controls which exhaust emission(s)?
   a. HC
   b. CO
   c. NO_x
   d. Both HC and CO
2. How much of the air needed by the engine flows through the PCV system when the engine is at idle speed?
   a. 1% to 3%
   b. 5% to 10%
   c. 10% to 20%
   d. Up to 30%
3. Technician A says that if the PCV valve was defective or clogged, the engine could idle rough. Technician B says that the engine may stall. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. Technician A says that if a PCV valve rattles, then it is okay and does not need to be replaced. Technician B says that if a PCV valve does not rattle, it should be replaced. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
5. Technician A says that the PCV system should create a slight pressure in the crankcase at idle. Technician B says that the PCV system should create a slight vacuum in the crankcase at 2,500 RPM. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. The SAI system is used to reduce which exhaust emission(s)?
   a. HC
   b. CO
   c. NO_x
   d. Both HC and CO
7. Two technicians are discussing exhaust check valves used in SAI systems. Technician A says that they are used to prevent the output from the SAI pump from entering the intake manifold. Technician B says the check valves are used to keep the exhaust from entering the AIR pump. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. Where is the output of the AIR pump directed when the engine is cold?
   a. Exhaust manifold
   b. Catalytic converter
   c. Air cleaner assembly
   d. To the atmosphere
9. The switching valves on the AIR pump have failed several times. Technician A says that a defective exhaust check valve could be the cause. Technician B says that a leaking exhaust system at the muffler could be the cause. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. When checking for the proper operation of the AIR system using an exhaust gas analyzer, how much should the oxygen (O_2) levels increase when the pump is allowed to function?
    a. 1% to 4%
    b. 5% to 10%
    c. 10% to 20%
    d. Up to 30%

chapter 86

CATALYTIC CONVERTERS

OBJECTIVES: **After studying Chapter 86, the reader should be able to:** • Prepare for ASE Engine Performance (A8) certification test content area "D" (Emission Control Systems). • Describe the purpose and function of the catalytic converter. • Discuss how the catalytic converter is tested under OBD-II regulations. • Explain the method for diagnosing and testing the catalytic converter.

KEY TERMS: Catalysts 949 • Catalytic converter 949 • Cerium 949 • Light-off temperature 949 • Light-off converter (LOC) 950 • Oxygen storage capacity (OSC) 950 • Palladium 949 • Platinum 949 • Preconverter 950 • Pup (mini) converter 950 • Rhodium 949 • Tap test 952 • Three-way converter (TWC) 949 • Washcoat 949

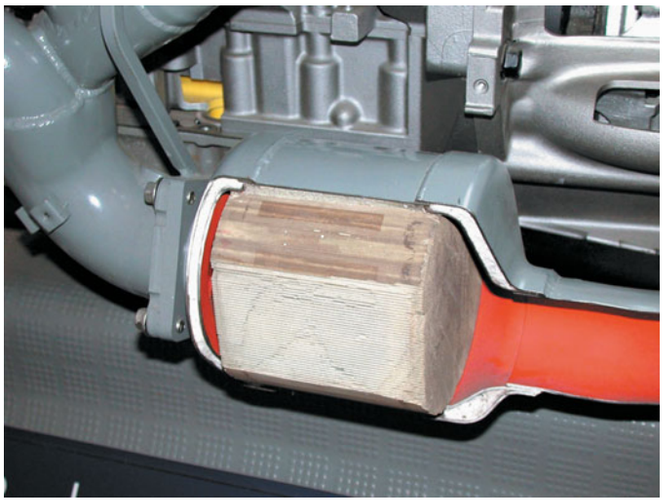


FIGURE 86–1 Most catalytic converters are located as close to the exhaust manifold as possible, as seen in this display of a Chevrolet Corvette.

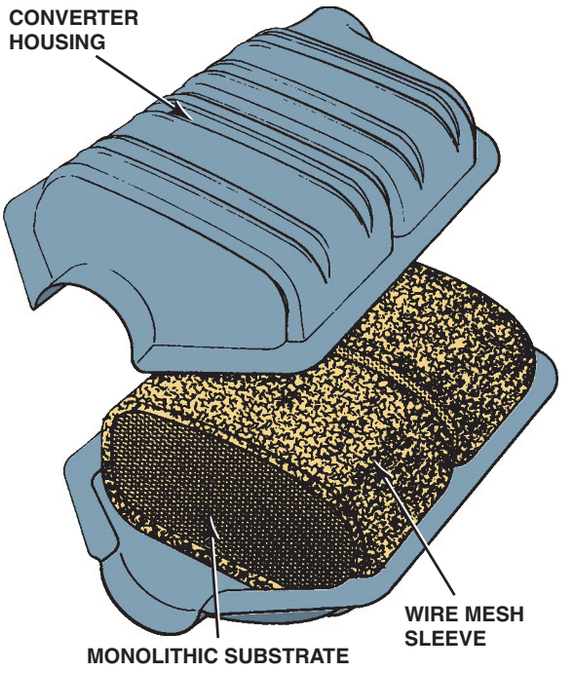


FIGURE 86–2 A typical catalytic converter with a monolithic substrate.

CATALYTIC CONVERTERS

PURPOSE AND FUNCTION

A **catalytic converter** is an after-treatment device used to reduce exhaust emissions outside of the engine. The catalytic converter uses a *catalyst:*

- A **catalyst** is a chemical that helps start a chemical reaction but does not enter into the chemical reaction.
- The catalyst materials on the surface of the material inside the converter help create a chemical reaction.
- The chemical reaction changes harmful exhaust emissions into nonharmful exhaust emissions.
- The *converter* therefore converts harmful exhaust gases into water vapor (H_2O) and carbon dioxide (CO_2).

This device is installed in the exhaust system between the exhaust manifold and the muffler and usually is positioned beneath the passenger compartment. The location of the converter is important since as much of the exhaust heat as possible must be retained for effective operation. The nearer it is to the engine, the better. ● **SEE FIGURE 86–1.**

CATALYTIC CONVERTER CONSTRUCTION

Most catalytic converters are constructed of a ceramic material in a honeycomb shape with square openings for the exhaust gases:

- There are approximately 400 openings per square inch (62 per sq. cm), and the wall thickness is about 0.006 inch (1.5 mm).
- The substrate is then coated with a porous aluminum material called the **washcoat,** which makes the surface rough.
- The catalytic materials are then applied on top of the washcoat. The substrate is contained within a round or oval shell made by welding together two stamped pieces of aluminum or stainless steel. ● **SEE FIGURE 86–2.**

The ceramic substrate in monolithic converters is not restrictive; however, the converter can be physically broken if exposed to shock or severe jolts. Monolithic converters can be serviced only as a unit.

An exhaust pipe is connected to the manifold or header to carry gases through a catalytic converter and then to the muffler or silencer. V-type engines can use dual converters or route the exhaust into one catalytic converter by using a Y-exhaust pipe.

CATALYTIC CONVERTER OPERATION

The converter substrate contains small amounts of **rhodium, palladium,** and **platinum.** These elements act as catalysts. As mentioned, a catalyst is an element that starts a chemical reaction without becoming a part of, or being consumed in, the process. In a **three-way** (catalytic) **converter (TWC)** all three exhaust emissions (NO_x, HC, and CO) are converted to carbon dioxide (CO_2) and water (H_2O). As the exhaust gas passes through the catalyst, oxides of nitrogen (NO_x) are chemically reduced (that is, nitrogen and oxygen are separated) in the first section of the catalytic converter. In the second section of the catalytic converter, most of the hydrocarbons and carbon monoxide remaining in the exhaust gas are oxidized to form harmless carbon dioxide (CO_2) and water vapor (H_2O). ● **SEE FIGURE 86–3.**

Since the early 1990s, many converters also contain **cerium,** an element that can store oxygen. The purpose of the cerium is to provide oxygen to the oxidation bed of the converter when the exhaust is rich and lacks enough oxygen for proper oxidation. When the exhaust is lean, the cerium absorbs the extra oxygen. For the most efficient operation, the converter should have a 14.7:1 air-fuel ratio but can use a mixture that varies slightly:

- A rich exhaust is required for reduction–stripping the oxygen (O_2) from the nitrogen in NO_x.
- A lean exhaust is required to provide the oxygen necessary to oxidize HC and CO (combining oxygen with HC and CO to form H_2O and CO_2).

If the catalytic converter is not functioning correctly, ensure that the air-fuel mixture being supplied to the engine is correct and that the ignition system is free of defects.

CONVERTER LIGHT-OFF TEMPERATURE

The catalytic converter does not work when cold, so it must be heated to its **light-off temperature** of close to 500°F (260°C) before it starts working at 50% effectiveness. When fully effective, the converter reaches a

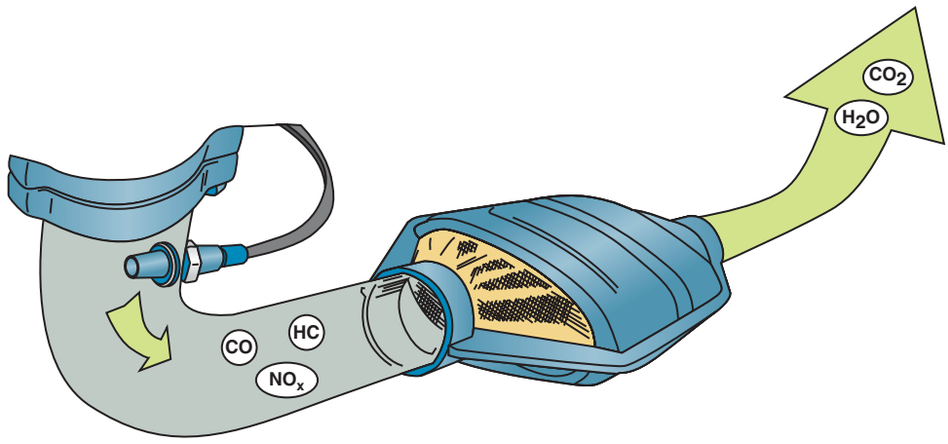


FIGURE 86–3 The three-way catalytic converter first separates the NO_x into nitrogen and oxygen and then converts the HC and CO into harmless water (H_2O) and carbon dioxide (CO_2). The nitrogen (N) passes through the converter and exits the tailpipe and enters the atmosphere which is about 78% nitrogen.

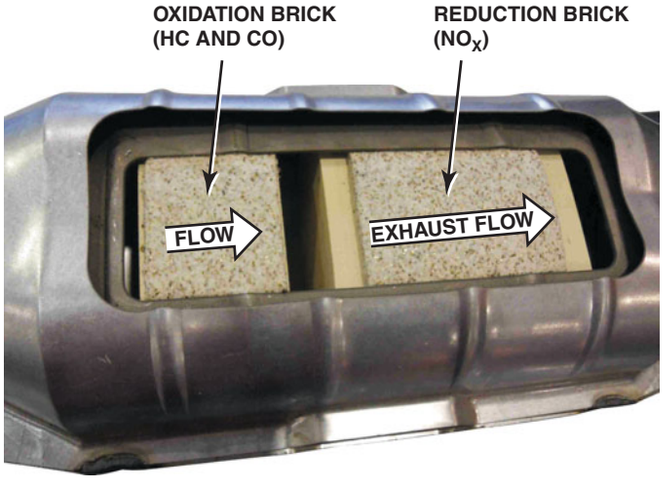


FIGURE 86–4 The small oxidation section of the converter helps build heat for the reduction section to reduce NO_x emissions in the rear brick on most newer vehicles.

temperature range of 900°F to 1,600°F (482°C to 871°C). In spite of the intense heat, however, catalytic reactions do not generate a flame associated with a simple burning reaction. Because of the extreme heat (almost as hot as combustion chamber temperatures), a converter remains hot long after the engine is shut off. Most vehicles use a series of heat shields to protect the passenger compartment and other parts of the chassis from excessive heat. Vehicles have been known to start fires because of the hot converter causing tall grass or dry leaves beneath the just-parked vehicle to ignite, especially if the engine is idling. This is most likely to occur if the heat shields have been removed from the converter.

CONVERTER USAGE A catalytic converter must be located as close as possible to the exhaust manifold to work effectively. The farther back the converter is positioned in the exhaust system, the more the exhaust gases cool before they reach the converter. Since positioning in the exhaust system affects the oxidation process, vehicle manufacturers that use only an oxidation converter generally locate it underneath the front of the passenger compartment.

Some vehicles have used a small, quick heating oxidation converter called a **preconverter** or a **pup (mini) converter** that connects directly to the exhaust manifold outlet. These have a small catalyst surface area close to the engine that heats up rapidly to start the oxidation process more quickly during cold engine warm-up. For this reason, they were often called **light-off converters (LOCs).** The larger main converter, under the passenger compartment, completes the oxidation reaction started in the LOC.

Most older vehicles used a catalytic converter that had the reduction section first to separate the oxygen from the nitrogen in NOx. The oxygen released during this action help provide extra oxygen to help oxidize the HC and CO into harmless water (H_2O) and carbon dioxide (CO_2). However, since 2004, emission standards for oxides of nitrogen are stricter, and therefore a larger reduction section is often needed. Therefore, the reduction section is now often after the oxidation section, which is the opposite of the way it was in converters for older models. ● **SEE FIGURE 86–4.**

OBD-II CATALYTIC CONVERTER PERFORMANCE The PCM determines if the catalytic converter is ready for testing based on the following conditions, which may vary by vehicle make, model, and year:

- Closed-loop status achieved
- IAT sensor temperature higher than 32°F (0°C)
- ECT sensor temperature higher than 165°F (18°C)
- MAF sensor input from 15 to 32 g/sec
- Engine load less than 65% and steady
- Engine speed less than 4,000 RPM
- All of the above conditions met for at least four minutes

These factors are the enable criteria that must be achieved before the OBD-II catalyst monitor will run.

OBD-II CATALYTIC CONVERTER PERFORMANCE

With OBD-II-equipped vehicles, catalytic converter performance is monitored by a heated oxygen sensor (HO_2S) both before and after the converter. ● **SEE FIGURE 86–5.**

The converters used on these vehicles have **oxygen storage capacity (OSC),** due mostly to the cerium coating in the catalyst rather than the precious metals used. When the three-way converter

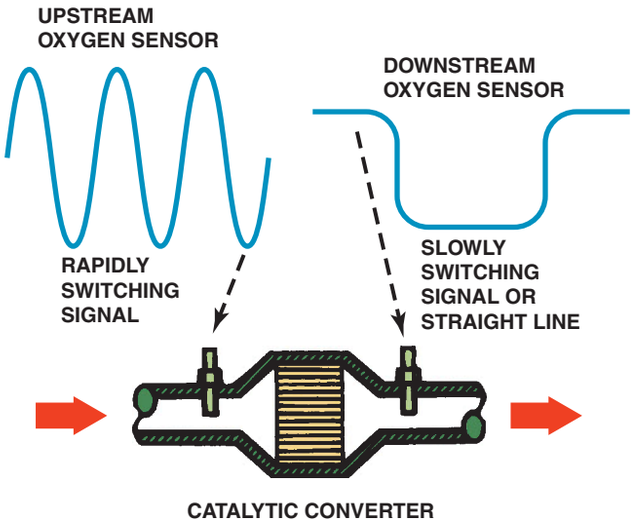


FIGURE 86–5 The OBD-II catalytic converter monitor compares the signals of upstream and downstream oxygen sensors to determine converter efficiency.

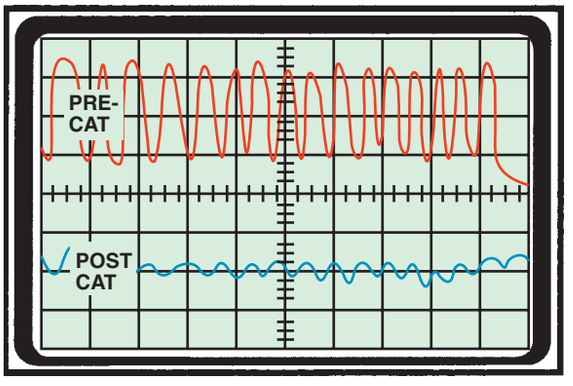


FIGURE 86–6 The waveform of a downstream O2S sensor from a properly functioning converter shows little, if any, activity.

(TWC) is operating as it should, the postconverter HO_2S is far less active than the preconverter sensor. The converter stores, then releases, the oxygen during normal reduction and oxidation of the exhaust gases, smoothing out the variations in oxygen being released.

Where a cycling sensor voltage output is expected before the converter, because of the converter action, the postconverter HO_2S should read a steady signal with little fluctuation. ● **SEE FIGURE 86–6.**

NOTE: Because of more demanding exhaust emission standards for oxides of nitrogen (NO_x) starting in 2004, the reduction part of the converter is now usually located downstream from the oxidation section. This is opposite of the way an older style converter was constructed. With better fuel injection systems and ignition systems, the amount of CO and HC exhaust emissions is lower than in the past. By using the oxidation section first creates heat to help the reduction section better control oxides of nitrogen emissions. The rear "brick" or reduction section is also larger than the oxidation section.

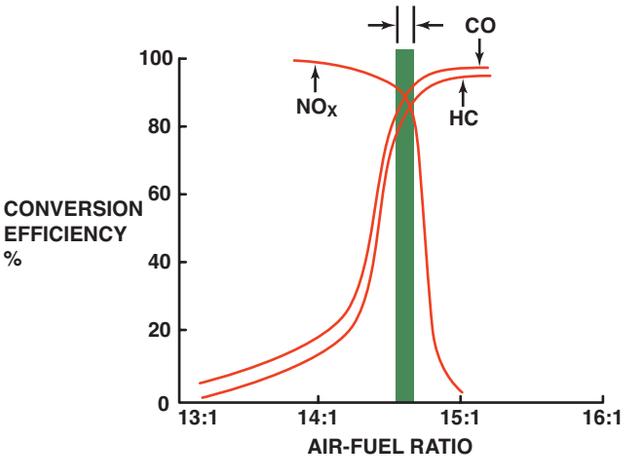


FIGURE 86–7 The highest catalytic converter efficiency occurs when the air-fuel mixture is about 14.7:1.

CONVERTER-DAMAGING CONDITIONS

Since converters have no moving parts, they require no periodic service. Under federal law, catalyst effectiveness is warranted for 80,000 miles or eight years.

The three main causes of premature converter failure are the following:

- **Contamination.** Substances that can destroy the converter include exhaust that contains excess engine oil, antifreeze, sulfur (from poor fuel), and various other chemical substances.
- **Excessive temperatures.** Although a converter operates at high temperatures, it can be destroyed by excessive temperatures. This most often occurs either when too much unburned fuel enters the converter, or with excessively lean mixtures. Excessive temperatures may be caused by long idling periods on some vehicles since more heat develops at those times than when driving at normal highway speeds. Severe high temperatures can cause the converter to melt down, leading to the internal parts breaking apart and either clogging the converter or moving downstream to plug the muffler. In either case, the restricted exhaust flow severely reduces engine power.
- **Improper air-fuel mixtures.** Rich mixtures or raw fuel in the exhaust can be caused by engine misfiring or an excessively rich air-fuel mixture resulting from a defective coolant temp sensor or defective fuel injectors. Lean mixtures are commonly caused by intake manifold leaks. When either of these circumstances occurs, the converter can become a catalytic furnace, causing the previously described damage. For most efficient catalytic converter operation, the air-fuel mixture should be near 14.7:1. ● **SEE FIGURE 86–7.**

To avoid excessive catalyst temperatures and the possibility of fuel vapors reaching the converter, observe the following rules:

1. Do not use fuel additives or cleaners that are not converter safe.
2. Do not crank an engine for more than 40 seconds when it is flooded or misfiring.
3. Do not turn off the ignition switch when the vehicle is in motion.
4. Do not disconnect a spark plug wire for more than 30 seconds.
5. Repair engine problems such as dieseling, misfiring, or stumbling as soon as possible.

DIAGNOSING CATALYTIC CONVERTERS

TAP TEST The simple **tap test** involves tapping (not pounding) on the catalytic converter using a rubber mallet. If the substrate inside the converter is broken, the converter will rattle when hit. If the converter rattles, a replacement converter is required. ● **SEE FIGURE 86–8.**

TESTING BACK PRESSURE WITH A PRESSURE GAUGE Exhaust system back pressure can be measured directly by installing a pressure gauge in an exhaust opening. This can be accomplished in one of the following ways:

1. To test backpressure, remove the inside of an old, discarded oxygen sensor and thread in an adapter to convert it to a vacuum or pressure gauge.

   NOTE: An adapter can be easily made by inserting a metal tube or pipe into an old oxygen sensor housing. A short section of brake line works great. The pipe can be brazed to the oxygen sensor housing, or it can be glued with epoxy. An 18-mm compression gauge adapter can also be adapted to fit into the oxygen sensor opening. ● **SEE FIGURE 86–9.**



FIGURE 86–8 A catalytic converter that rattles when tapped was removed, and the substrate, or what was left of it, fell out. This converter has to be replaced and the root cause of why it failed found and corrected.

FREQUENTLY ASKED QUESTION

Can a Catalytic Converter Be Defective without Being Clogged?

Yes. Catalytic converters can fail by being chemically damaged or poisoned without being mechanically clogged. Therefore, the catalytic converter should be tested not only for physical damage (clogging) by performing a back pressure or vacuum test and a rattle test but also for temperature rise, usually with a pyrometer or propane test, to check the efficiency of the converter.

2. To test the exhaust back pressure at the exhaust gas recirculation (EGR) valve, remove the EGR valve and fabricate a plate equipped with a fitting for a pressure gauge.
3. To test at the secondary air-injection (SAI) check valve, remove the check valve from the exhaust tubes leading to the exhaust manifold. Use a rubber cone with a tube inside to seal against the exhaust tube. Connect the tube to a pressure gauge.

At idle, the maximum back pressure should be less than 1.5 PSI (10 kPa), and it should be less than 2.5 PSI (15 kPa) at 2,500 RPM. Pressure readings higher than these indicate that the exhaust system is restricted, and further testing will be needed to determine the location of the restriction. ● **SEE FIGURE 86–10.**

TESTING FOR BACK PRESSURE USING A VACUUM GAUGE An exhaust restriction can be tested indirectly by checking the intake manifold vacuum with the engine operating at a fast idle speed (about 2,500 RPM). If the exhaust is restricted, some exhaust can pass, and the effect may not be noticeable when the engine is at idle speed. However, when the engine is operating at a higher speed,

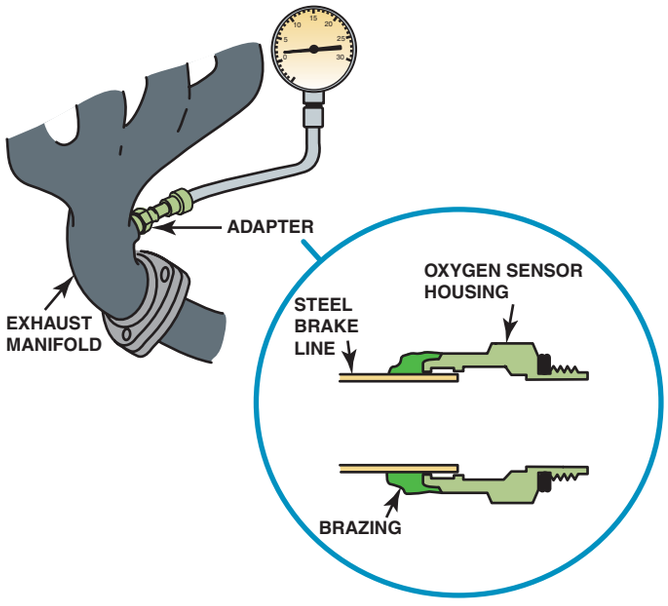


FIGURE 86–9 A back pressure tool can be made by using an oxygen sensor housing and epoxy or braze to hold the tube to the housing.



FIGURE 86–10 This partially melted catalytic converter tested okay at idle but had excessive back pressure at higher engine speeds.

the exhaust gases can build up behind the restriction and eventually will not be able to leave the combustion chamber. When some of the exhaust is left behind at the end of the exhaust stroke, the resulting pressure in the combustion chamber reduces engine vacuum. To test for an exhaust restriction using a vacuum gauge, perform the following steps:

STEP 1 Attach a vacuum gauge to an intake manifold vacuum source.

STEP 2 Start the engine. Record the engine manifold vacuum reading. The engine vacuum should read 17 to 21 in. Hg when the engine is at idle speed.

STEP 3 Increase the engine speed to 2,500 RPM and hold that speed for 60 seconds while looking at the vacuum gauge.

Results

- If the vacuum reading is equal to or higher than the vacuum reading when the engine was at idle speed, the exhaust system is *not* restricted.
- If the vacuum reading is lower than the vacuum reading when the engine was at idle speed, then the exhaust *is* restricted. Further testing will be needed to determine the location of the restriction.

TESTING A CATALYTIC CONVERTER FOR TEMPERATURE RISE

A properly working catalytic converter should be able to reduce NO_x exhaust emissions into nitrogen (N) and oxygen (O_2) and oxidize unburned hydrocarbon (HC) and carbon monoxide (CO) into harmless carbon dioxide (CO_2) and water vapor (H_2O). During these chemical processes, the catalytic converter should increase in temperature at least 10% if the converter is working properly. To test the converter, operate the engine at 2,500 RPM for at least two minutes to fully warm the converter. Measure the inlet and the outlet temperatures using an infrared pyrometer as show in ● **FIGURE 86–11.**

NOTE: If the engine is extremely efficient, the converter may not have any excessive unburned hydrocarbons or carbon monoxide to convert! In this case, a spark plug wire could be grounded out using a vacuum hose and a test light to create some unburned hydrocarbon in the exhaust. Do not ground out a cylinder for longer than 10 seconds, or the excessive amount of unburned hydrocarbon could overheat and damage the converter.

CATALYTIC CONVERTER EFFICIENCY TESTS

The efficiency of a catalytic converter can be determined using an exhaust gas analyzer:

- **Oxygen level test.** With the engine warm and in closed loop, check the oxygen (O_2) and carbon monoxide (CO) levels. A good converter should be able to oxide the extra hydrocarbons caused by the rapid acceleration:
  - If O_2 is zero, go to the snap-throttle test.
  - If O_2 is greater than zero, check the CO level.
  - If CO is greater than zero, the converter is *not* functioning correctly.



FIGURE 86–11 The temperature of the outlet should be at least 10% hotter than the temperature of the inlet. If a converter is not working, the inlet temperature will be hotter than the outlet temperature.

TECH TIP

Aftermarket Catalytic Converters

Some replacement aftermarket (nonfactory) catalytic converters do not contain the same amount of cerium as the original part. Cerium is the element that is used in catalytic converters to store oxygen. As a result of the lack of cerium, the correlation between the oxygen storage and the conversion efficiency may be affected enough to set a false diagnostic trouble code (P0422).

NOTE: If an aftermarket converter is being installed, be sure that the distance between the rear of the catalyst block is the same distance from the rear oxygen sensor as the factory converter to be ensured of proper operation. Always follow the instructions that come with the replacement converter. ● **SEE FIGURE 86–12.**

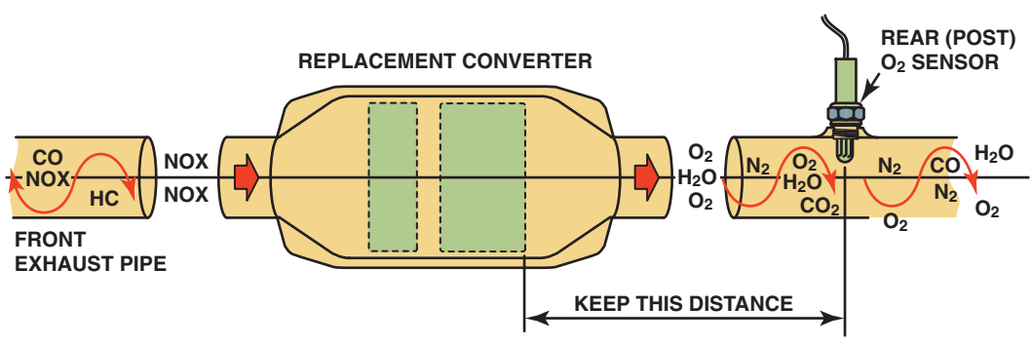


FIGURE 86–12 Whenever replacing a catalytic converter with a universal unit, first measure the distance between the rear brick and the center of the rear oxygen sensor. Be sure that the replacement unit is installed to the same dimension.

- **Snap-throttle test.** With the engine warm and in closed loop, snap the throttle to wide-open throttle (WOT) in park or neutral and observe the oxygen reading:
  - The O_2 reading should not exceed 1.2%; if it does, the converter is *not* working.
  - If the O_2 rises to 1.2%, the converter may have low efficiency.
  - If the O_2 remains below 1.2%, then the converter is okay.

CATALYTIC CONVERTER REPLACEMENT GUIDELINES

Because a catalytic converter is a major exhaust gas emission control device, the U.S. Environmental Protection Agency (EPA) has strict guidelines for its replacement, including the following:

- If a converter is replaced on a vehicle with less than 80,000 miles or eight years, depending on the year of the vehicle, an original equipment catalytic converter *must* be used as a replacement.
- The replacement converter must be of the same design as the original. If the original had an AIR pump fitting, so must the replacement.
- The old converter must be kept for possible inspection by the authorities for 60 days.
- A form must be completed and signed by both the vehicle owner and a representative from the service facility. This form must state the cause of the converter failure and must remain on file for two years.



TECH TIP

Catalytic Converters Are Murdered

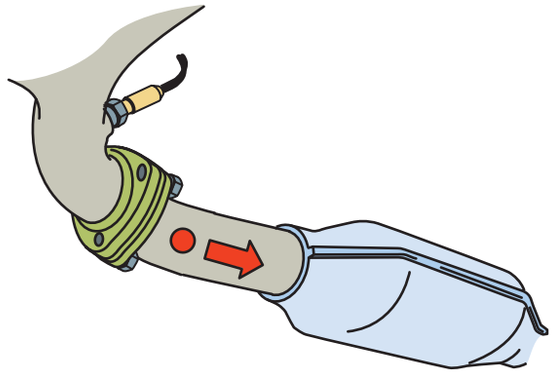
Catalytic converters start a chemical reaction but do not enter into the chemical reaction. Therefore, catalytic converters neither wear out nor die of old age. If a catalytic converter is found to be defective (nonfunctioning or clogged), look for the *root* cause. Remember this:

"Catalytic converters do not commit suicide–they're murdered."

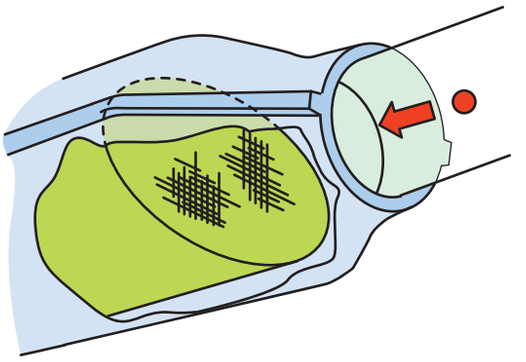
Items that should be checked when a defective catalytic converter is discovered include all components of the ignition and fuel systems. Excessive unburned fuel can cause the catalytic converter to overheat and fail. The oxygen sensor must be working and fluctuating from 0.5 to 5 Hz (times per second) to provide the necessary air-fuel mixture variations for maximum catalytic converter efficiency.

CATALYTIC CONVERTER–RELATED DIAGNOSTIC TROUBLE CODE

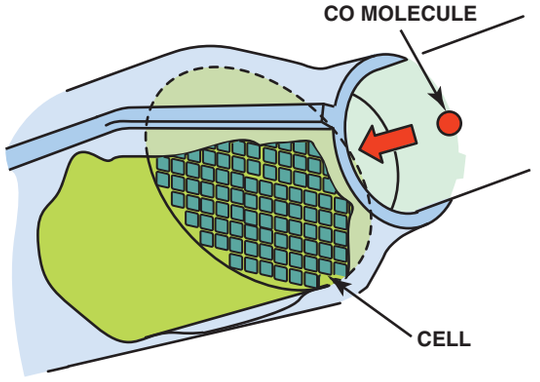
Diagnostic Trouble Code	Description	Possible Causes
P0422	Catalytic converter efficiency failure	• Engine mechanical fault • Exhaust leaks • Fuel contaminants, such as engine oil, coolant, or sulfur



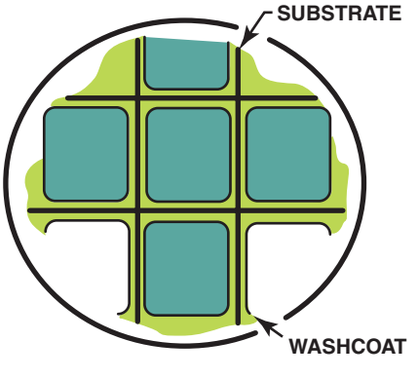
1 Carbon monoxide leaves the engine through the exhaust valve on the exhaust stroke.



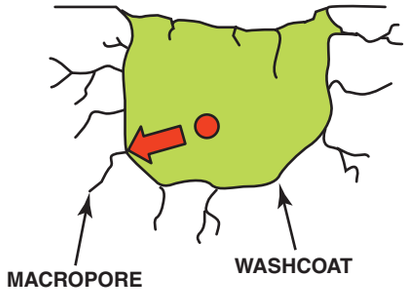
2 The CO molecule is starting to enter the converter.



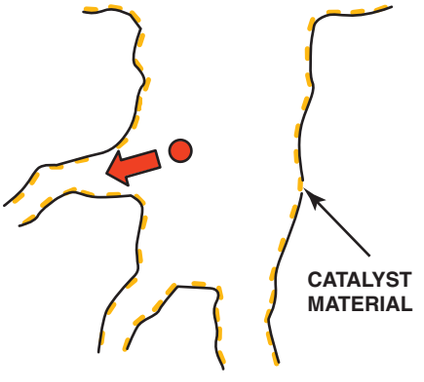
3 A CO molecule is ready to enter a cell. The number of cells ranges from 300 to 900 per sq. in. The substrate is cordierite (Mg, AL, Si) or foil-backed metal with a 0.002- to 0.006-inch (0.05- to 0.15-mm)-thick wall.



4 The CO molecule enters a cell. The substrate is coated with porous aluminum (AL_2O_3) called the washcoat. The catalytic material is sprayed onto the washcoat.



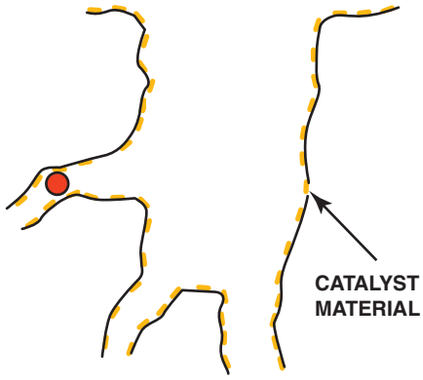
5 The CO molecule enters a micropore, which has been created in the porous washcoat.



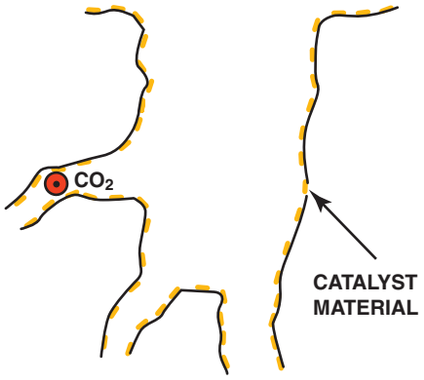
6 The CO molecule enters a smaller micropore.

CONTINUED ▶

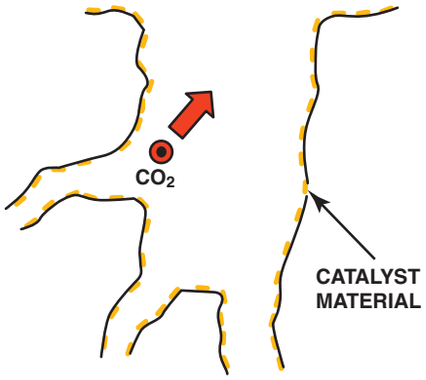
CATALYTIC CONVERTER OPERATION (CONTINUED)



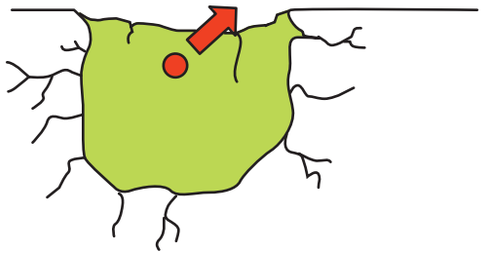
7 The CO molecule is absorbed onto a catalyst side. Only a few grams of catalyst material are applied to the washcoat.



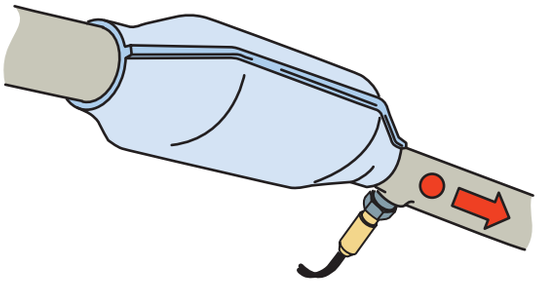
8 The CO molecule is converted to a CO_2 molecule.



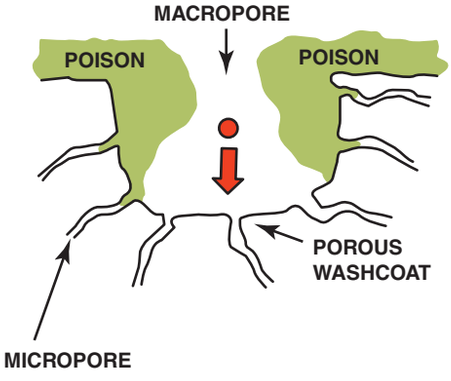
9 The CO_2 molecule is exiting the small micropore.



10 The CO_2 molecule is exiting the larger micropore.



11 The CO_2 molecule is exiting the converter.



12 A poisoned converter.

REVIEW QUESTIONS

1. What are the three most commonly used catalysts in a catalytic converter?
2. How does a catalytic converter reduce NO_x to nitrogen and oxygen?
3. Why must a catalytic converter be mounted close to the exhaust ports of the engine?
4. How does the computer monitor catalytic converter performance?
5. What tests can be performed by a service technician to test the catalytic converter?

CHAPTER QUIZ

1. What is applied to the ceramic substrate to make the surface porous?
   a. Honeycomb filler **c.** Aluminum
   b. Washcoat **d.** Cerium
2. Two technicians are discussing catalytic converters. Technician A says that the exhaust mixture must fluctuate between rich and lean for the best efficiency. Technician B says that the air-fuel mixture must be leaner than 14.7:1 for best performance from a three-way catalytic converter. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. A catalytic converter has to be at least how hot before it starts to work?
   a. 500°F (260°C)
   b. 1,000°F (540°C)
   c. 1,500°F (815°C)
   d. 2,000°F (1,100°C)
4. What two primary sensors does the PCM use to check the catalytic converter?
   a. Catalytic converter temperature sensor and rear oxygen sensor
   b. Precat and postcat oxygen sensor
   c. Precat oxygen sensor and MAF
   d. MAP and TP
5. A catalytic converter can be harmed by _____.
   a. Excessive engine oil **c.** Sulfur from poor-quality fuel
   b. Antifreeze **d.** Any of the above
6. Two technicians are discussing testing a catalytic converter. Technician A says that a vacuum gauge can be used and observed to see if the vacuum drops with the engine at 2,500 RPM for 30 seconds. Technician B says that a pressure gauge can be used to check for back pressure. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
7. A catalytic converter is being tested with an infrared pyrometer. Which is an acceptable (good converter) result?
   a. The inlet should be hotter than the outlet by 10%.
   b. The outlet should be hotter than the inlet by 10%.
   c. Both the inlet and the outlet should be the same temperature after the converter reaches operating temperature.
   d. The temperature of a catalytic converter is the best test to perform to locate a restricted (clogged) unit.
8. Which exhaust gas reading indicates a good catalytic converter?
   a. O_2 is zero **c.** Both a and b
   b. CO is zero **d.** Neither a nor b
9. A P0422 (catalytic converter efficiency failure) is set. What is a possible cause?
   a. Engine mechanical fault **c.** Fuel contamination
   b. Exhaust leak **d.** Any of the above
10. Technician A says that the catalytic converter is warranted for eight years or 80,000 miles, whichever comes first. Technician B says that after replacing the catalytic converter, the old converter must be kept for possible inspection for 60 days. Which technician is correct?
    a. Technician A only **c.** Both Technicians A and B
    b. Technician B only **d.** Neither Technician A nor B

chapter 87

ONBOARD DIAGNOSIS

OBJECTIVES: **After studying Chapter 87, the reader will be able to:** • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "A" (General Electrical/Electronic Systems Diagnosis). • Explain the purpose and function of onboard diagnosis. • List the various duties of the diagnostic executive (task master). • List five continuous monitors. • List five noncontinuous monitors.

KEY TERMS: California Air Resources Board (CARB) 958 • Component identification (CID) 964 • Comprehensive component monitor (CCM) 959 • Diagnostic executive 958 • Enable criteria 960 • Exponentially weighted moving average (EWMA) monitor 960 • Federal Test Procedure (FTP) 958 • Freeze-frame 958 • Functionality 959 • Malfunction indicator lamp (MIL) 958 • On-board diagnosis (OBD) 958 • Parameter identification (PID) 964 • Rationality 959 • Society of Automotive Engineers (SAE) 961 • Task manager 958 • Test identification (TID) 964

ON-BOARD DIAGNOSTICS GENERATION-II (OBD-II) SYSTEMS

PURPOSE AND FUNCTION OF OBD II

During the 1980s, most manufacturers began equipping their vehicles with full-function control systems capable of alerting the driver of a malfunction and of allowing the technician to retrieve codes that identify circuit faults. These early diagnostic systems were meant to reduce emissions and speed up vehicle repair.

The automotive industry calls these systems **On-Board Diagnostics (OBDs).** The **California Air Resources Board (CARB)** developed the first regulation requiring manufacturers selling vehicles in that state to install OBD. OBD Generation I (OBD I) applies to all vehicles sold in California beginning with the 1988 model year. It specifies the following requirements:

1. An instrument panel warning lamp able to alert the driver of certain control system failures, now called a **malfunction indicator lamp (MIL).** ● **SEE FIGURE 87–1.**
2. The system's ability to record and transmit diagnostic trouble codes (DTCs) for emission-related failures.
3. Electronic system monitoring of the HO2S, EGR valve, and evaporative purge solenoid. Although not U.S. EPA-required, during this time most manufacturers also equipped vehicles sold outside of California with OBD I.

By failing to monitor the catalytic converter, the evaporative system for leaks, and the presence of engine misfire, OBD I did not do enough to lower automotive emissions. This led the CARB and the EPA to develop OBD Generation II (OBD II).



FIGURE 87–1 A typical malfunction indicator lamp (MIL) often labeled "check engine" or "service engine soon" (SES).

OBD-II OBJECTIVES

Generally, the CARB defines an OBD-II-equipped vehicle by its ability to do the following:

1. Detect component degradation or a faulty emission-related system that prevents compliance with federal emission standards.
2. Alert the driver of needed emission-related repair or maintenance.
3. Use standardized DTCs and accept a generic scan tool.

These requirements apply to all 1996 and later model light-duty vehicles. The Clean Air Act of 1990 directed the EPA to develop new regulations for OBD. The primary purpose of OBD II is emission-related, whereas the primary purpose of OBD I (1988) was to detect faults in sensors or sensor circuits. OBD-II regulations require that not only sensors be tested but also all exhaust emission control devices, and that they be verified for proper operation.

All new vehicles must pass the **Federal Test Procedure (FTP)** for exhaust emissions while being tested for 1874 seconds on dynamometer rollers that simulate the urban drive cycle around downtown Los Angeles.

NOTE: IM 240 is simply a shorter 240-second version of the 505-second federal test procedure.

The regulations for OBD-II vehicles state that the vehicle computer must be capable of testing for, and determining, if the exhaust emissions are within 1.5 times the FTP limits. To achieve this goal, the computer must do the following:

1. Test all exhaust emission system components for correct operation.
2. Actively operate the system and measure the results.
3. Continuously monitor all aspects of the engine operation to be certain that the exhaust emissions do not exceed 1.5 times the FTP.
4. Check engine operation for misfire.
5. Turn on the MIL (check engine) if the computer senses a fault in a circuit or system.
6. Record a **freeze-frame,** which is a snapshot of important engine data at the time the DTC was set.
7. Flash the MIL if an engine misfire occurs that could damage the catalytic converter.

DIAGNOSTIC EXECUTIVE AND TASK MANAGER

On OBD-II systems, the powertrain control module (PCM) incorporates a special segment of software. On Ford and GM systems, this software is called the **diagnostic executive.** On Chrysler systems, it is called the **task manager.** This software program is designed to manage the operation of all OBD-II monitors by controlling the sequence of steps necessary to execute the diagnostic tests and monitors.

MONITORS

A monitor is an organized method of testing a specific part of the system. Monitors are simply tests that the computer performs to evaluate components and systems. If a component or system failure is detected while a monitor is running, a DTC will be stored and the MIL illuminated during the second trip. The two types of monitors are continuous and noncontinuous.

CONTINUOUS MONITORS

As required conditions are met, continuous monitors begin to run. These continuous monitors will run for the remainder of the vehicle drive cycle. The three continuous monitors are as follows:

- **Comprehensive component monitor (CCM).** This monitor watches the sensors and actuators in the OBD-II system. Sensor values are constantly compared with known-good values stored in the PCM's memory.

  The CCM is an internal program in the PCM designed to monitor a failure in any electronic component or circuit (including emission-related and non-emission-related circuits) that provide input or output signals to the PCM. The PCM considers that an input or output signal is inoperative when a failure exists due to an open circuit, out-of-range value, or if an onboard rationality check fails. If an emission-related fault is detected, the PCM will set a code and activate the MIL (requires two consecutive trips).

  Many PCM sensors and output devices are tested at key-on or immediately after engine start-up. However, some devices are only tested by the CCM after the engine meets certain engine conditions. The number of times the CCM must detect a fault before it will activate the MIL depends upon the manufacturer, but most require two consecutive trips to activate the MIL. The components tested by the CCM include:

  Four-wheel-drive low switch
  Brake switch
  Camshaft (CMP) and crankshaft (CKP) sensors
  Clutch switch (manual transmissions/transaxles only)
  Cruise servo switch
  Engine coolant temperature (ECT) sensor
  EVAP purge sensor or switch
  Fuel composition sensor
  Intake air temperature (IAT) sensor
  Knock sensor (KS)
  Manifold absolute pressure (MAP) sensor
  Mass airflow (MAF) sensor
  Throttle-position (TP) sensor
  Transmission temperature sensor
  Transmission turbine speed sensor
  Vacuum sensor
  Vehicle speed (VS) sensor
  EVAP canister purge and EVAP purge vent solenoid
  Idle air control (IAC)
  Ignition control system
  Transmission torque converter clutch solenoid
  Transmission shift solenoids

- **Misfire monitor.** This monitor watches for engine misfire. The PCM uses the information received from the crankshaft position sensor (CKP) to calculate the time between the edges of the reluctor, as well as the rotational speed and acceleration. By comparing the acceleration of each firing event, the PCM can determine if a cylinder is not firing correctly.

  Misfire type A. Upon detection of a misfire type A (200 revolutions), which would cause catalyst damage, the MIL will blink once per second during the actual misfire, and a DTC will be stored.

  Misfire type B. Upon detection of a misfire type B (1,000 revolutions), which will exceed 1.5 times the EPA federal test procedure (FTP) standard or cause a vehicle to fail an inspection and maintenance tailpipe emissions test, the MIL will illuminate and a DTC will be stored.

  The DTC associated with multiple cylinder misfire for a type A or type B misfire is DTC P0300. The DTCs associated with an individual cylinder misfire for a type A or type B misfire are DTCs P0301, P0302, P0303, P0304, P0305, P0306, P0307, P0308, P0309, and P0310.

- **Fuel trim monitor.** The PCM continuously monitors short- and long-term fuel trim. Constantly updated adaptive fuel tables are stored in long-term memory (KAM), and used by the PCM for compensation due to wear and aging of the fuel system components. The MIL will illuminate when the PCM determines the fuel trim values have reached and stayed at their limits for too long a period of time.

NONCONTINUOUS MONITORS

Noncontinuous monitors run (at most) once per vehicle drive cycle. The noncontinuous monitors are as follows:

O2S monitor
O2S heater monitor
Catalyst monitor
EGR monitor
EVAP monitor
Secondary AIR monitor
Transmission monitor
PCV system monitor
Thermostat monitor

Once a noncontinuous monitor has run to completion, it will not be run again until the conditions are met during the next vehicle drive cycle. Also after a noncontinuous monitor has run to completion, the readiness status on your scan tool will show "complete" or "done" for that monitor. Monitors that have not run to completion will show up on your scanner as "incomplete."

OBD-II MONITOR INFORMATION

COMPREHENSIVE COMPONENT MONITOR

The circuits and components covered by the comprehensive component monitor (CCM) do not include those directly monitored by another monitor.

However, OBD II also requires that inputs from powertrain components to the PCM be tested for **rationality,** and that outputs to powertrain components from the PCM be tested for **functionality.** Both inputs and outputs are to be checked *electrically.* Rationality checks refer to a PCM comparison of input values to values from other sensors to determine if they make sense and are normal (rational).

Example:

TPS	3 V
MAP	18 in./Hg
RPM	700 RPM
PRNDL	Park

NOTE: Comprehensive component monitors are continuous. Therefore enabling conditions do not apply.

- Monitor runs continuously
- Monitor includes sensors, switches, relays, solenoids, and PCM hardware
- All are checked for opens, shorts-to-ground, and shorts-to-voltage
- Inputs are checked for rationality
- Outputs are checked for functionality
- Most are one-trip DTCs
- Freeze-frame is priority 3
- Three consecutive good trips are used to extinguish the MIL
- Forty warm-up cycles are necessary to self erase the DTC and freeze frame
- Two minutes run time without reoccurrence of the fault constitutes a "good trip"

CONTINUOUS RUNNING MONITORS

Continuous monitors run continuously and only stop if they fail and include:

- Fuel system: rich/lean
- Misfire: catalyst damaging/FTP (emissions)
- Two-trip faults (except early generation catalyst damaging misfire)
- MIL, DTC, freeze-frame after two consecutive faults
- Freeze-frame is priority 2 on first trip
- Freeze-frame is priority 4 on maturing trip
- Three consecutive good trips in a similar condition window are used to extinguish the MIL
- Forty warm-up cycles are used to erase DTC and freeze-frame (80 to erase one-trip failure if similar conditions cannot be met)

ONCE PER TRIP MONITORS

- Monitor runs once per trip, pass or fail
- O_2 response, O_2 heaters, EGR, purge flow EVAP leak, secondary air, catalyst
- Two-trip DTCs
- MIL, DTC, freeze-frame after two consecutive faults
- Freeze-frame is priority 1 on first trip
- Freeze-frame is priority 3 on maturing trip
- Three consecutive good trips are used to extinguish the MIL
- Forty warm-up cycles are used to erase DTC and freeze-frame

EXPONENTIALLY WEIGHTED MOVING AVERAGE (EWMA) MONITORS

The **exponentially weighted moving average (EWMA) monitor** is a mathematical method used to determine performance.

This method smooths out any variables in the readings over time and results in a running average. This method is used by some vehicle manufacturers for two monitors.

1. Catalyst monitor
2. EGR monitor

ENABLING CRITERIA

With so many different tests (monitors) to run, the PCM needs an internal director to keep track of when each monitor should run. As mentioned, different manufacturers have different names for this director, such as the diagnostic executive or the task manager. Each monitor has enabling criteria. These criteria are a set of conditions that must be met before the task manager will give the go-ahead for each monitor to run. Most enabling criteria follow simple logic, for example:

- The task manager will not authorize the start of the O2S monitor until the engine has reached operating temperature and the system has entered closed loop.
- The task manager will not authorize the start of the EGR monitor when the engine is at idle, because the EGR is always closed at this time.

Because each monitor is responsible for testing a different part of the system, the enabling criteria can differ greatly from one monitor to the next. The task manager must decide when each monitor should run, and in what order, to avoid confusion.

There may be a conflict if two monitors were to run at the same time. The results of one monitor might also be tainted if a second monitor were to run simultaneously. In such cases, the task manager decides which monitor has a higher priority. Some monitors also depend on the results of other monitors before they can run.

A monitor may be classified as pending if a failed sensor or other system fault is keeping it from running on schedule.

The task manager may suspend a monitor if the conditions are not correct to continue. For example, if the catalyst monitor is running during a road test and the PCM detects a misfire, the catalyst monitor will be suspended for the duration of the misfire.

TRIP

A trip is defined as a key-on condition that contains the necessary conditions for a particular test to be performed followed by a key-off. These conditions are called the **enable criteria.** For example, for the EGR test to be performed, the engine must be at normal operating temperature and decelerating for a minimum amount of time. Some tests are performed when the engine is cold, whereas others require that the vehicle be cruising at a steady highway speed.

WARM-UP CYCLE

Once a MIL is deactivated, the original code will remain in memory until 40 warm-up cycles are completed without the fault reappearing. A warm-up cycle is defined as a trip with an engine temperature increase of at least 40°F and where engine temperature reaches at least 160°F (71°C).

MIL CONDITION: OFF

This condition indicates that the PCM has not detected any faults in an emissions-related component or system, or that the MIL circuit is not working.

FREQUENTLY ASKED QUESTION

What is a Drive Cycle?

A drive cycle is a vehicle being driven under specified speed and times that will allow all monitors to run. In other words, the powertrain control module (PCM) is looking at a series of data points representing speed and time and determines from these data points when the conditions are right to perform a monitor or a test of a component. These data points and therefore the drive cycle are vehicle specific and are not the same for each vehicle. Some common conditions for a drive cycle to successfully run all of the monitors include:

1. Cold start with intake air temperature (IAT) and engine coolant temperature (ECT) close to each other indicating that the engine has cooled to the temperature of the surrounding air temperature.
2. Fuel level within a certain range usually between 15% and 85%.
3. Vehicle speed within a certain speed range for an certain amount of time usually 4 to 12 minutes.
4. Stop and idle for a certain time.

Each monitor requires its own set of parameters needed to run the test and sometimes these conditions cannot be met. For example, some evaporate emissions control (EVAP) systems require a temperature that may not be possible in winter months in a cold climatic area.

A typical universal drive cycle that works for many vehicles includes the following steps.

MIL must be off.
No DTCs present.
Fuel fill between 15% and 85%.
Cold start—Preferred = 8-hour soak at 68°F to 86°F.
Alternative = ECT below 86°F.

STEP 1 With the ignition off, connect scan tool.
STEP 2 Start engine and drive between 20 and 30 mph for 22 minutes, allowing speed to vary.
STEP 3 Stop and idle for 40 seconds, gradually accelerate to 55 mph.
STEP 4 Maintain 55 mph for 4 minutes using a steady throttle input.
STEP 5 Stop and idle for 30 seconds, then accelerate to 30 mph.
STEP 6 Maintain 30 mph for 12 minutes.
STEP 7 Repeat steps 4 and 5 four times.

Using scan tool, check readiness. Always check service information for the exact drive cycle conditions for the vehicle being serviced for best results.

MIL CONDITION: ON STEADY This condition indicates a fault in an emissions-related component or system that could affect the vehicle emission levels.

MIL CONDITION: FLASHING This condition indicates a misfire or fuel control system fault that could damage the catalytic converter.

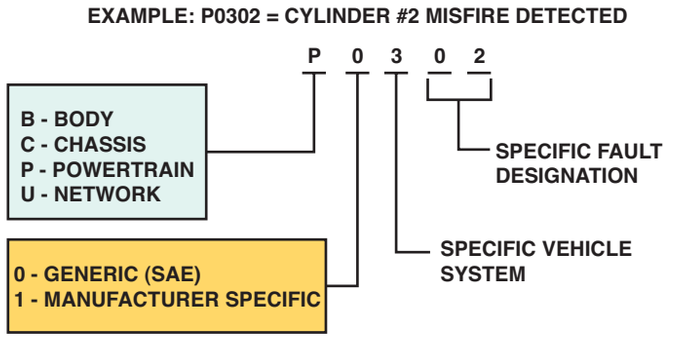


FIGURE 87–2 OBD-II DTC identification format.

NOTE: In a misfire condition with the MIL on steady, if the driver reaches a vehicle speed and load condition with the engine misfiring at a level that could cause catalyst damage, the MIL would start flashing. It would continue to flash until engine speed and load conditions caused the level of misfire to subside. Then the MIL would go back to the on-steady condition. This situation might result in a customer complaint of a MIL with an intermittent flashing condition.

MIL: OFF The PCM will turn off the MIL if any of the following actions or conditions occur:

- The codes are cleared with a scan tool.
- Power to the PCM is removed at the battery or with the PCM power fuse for an extended period of time (may be up to several hours or longer).
- A vehicle is driven on three consecutive trips with a warm-up cycle and meets all code set conditions without the PCM detecting any faults.

The PCM will set a code if a fault is detected that could cause tailpipe emissions to exceed 1.5 times the FTP standard; however, the PCM will not deactivate the MIL until the vehicle has been driven on three consecutive trips with vehicle conditions similar to actual conditions present when the fault was detected. This is not merely three vehicle start-ups and trips. It means three trips during which certain engine operating conditions are met so that the OBD-II monitor that found the fault can run again and pass the diagnostic test.

OBD-II DTC NUMBERING DESIGNATION

A scan tool is required to retrieve DTCs from an OBD-II vehicle. Every OBD-II scan tool will be able to read all generic **Society of Automotive Engineers (SAE)** DTCs from any vehicle. ● **SEE FIGURE 87–2** for definitions and explanations of OBD alphanumeric DTCs. The diagnostic trouble codes (DTCs) are grouped into major categories, depending on the location of the fault on the system involved.

Pxxx codes—powertrain DTCs (engine, transmission-related faults)

Bxxx codes—body DTCs (accessories, interior-related faults)

Cxxx codes—chassis DTCs (suspension and steering-related faults)

Uxxx codes—network DTCs (module communication-related faults)

DTC NUMBERING EXPLANATION The number in the hundredth position indicates the specific vehicle system or subgroup that failed. This position should be consistent for P0xxx and P1xxx type codes. The following numbers and systems were established by SAE:

- P0100—Air metering and fuel system fault
- P0200—Fuel system (fuel injector only) fault
- P0300—Ignition system or misfire fault
- P0400—Emission control system fault
- P0500—Idle speed control, vehicle speed (VS) sensor fault
- P0600—Computer output circuit (relay, solenoid, etc.) fault
- P0700—Transaxle, transmission faults

NOTE: The tens and ones numbers indicate the part of the system at fault.

TYPES OF DTCS Not all OBD-II DTCs are of the same importance for exhaust emissions. Each type of DTC has different requirements for it to set, and the computer will only turn on the MIL for emissions-related DTCs.

TYPE A CODES. A type A DTC is emission-related and will cause the MIL to be turned on the first trip if the computer has detected a problem. Engine misfire or a very rich or lean air–fuel ratio, for example, would cause a type A DTC. These codes alert the driver to an emission problem that may cause damage to the catalytic converter.

TYPE B CODES. A type B code will be stored and the MIL will be turned on during the second consecutive trip, alerting the driver to the fact that a diagnostic test was performed and failed.

NOTE: Type A and B codes are emission-related codes that will cause the lighting of the malfunction indicator lamp (MIL), usually labeled "check engine" or "service engine soon."

TYPE C AND D CODES. Type C and D codes are for use with non-emission-related diagnostic tests; they will cause the lighting of a "service" lamp (if the vehicle is so equipped). Type C codes are also called type C1 codes and D codes are also called type C0 codes.

DIAGNOSTIC TROUBLE CODE PRIORITY CARB has also mandated that all diagnostic trouble codes (DTCs) be stored according to individual priority. DTCs with a higher priority overwrite those with a lower priority. The OBD-II System DTC Priority is listed below.

Priority 0—Non-emission-related codes

Priority 1—One-trip failure of two-trip fault for non-fuel, non-misfire codes

Priority 2—One-trip failure of two-trip fault for fuel or misfire codes

Priority 3—Two-trip failure or matured fault of non-fuel, non-misfire codes

Priority 4—Two-trip failure or matured fault for fuel or misfire codes

OBD-II FREEZE-FRAME

To assist the service technician, OBD II requires the computer to take a "snapshot" or freeze-frame of all data at the instant an emission-related DTC is set. A scan tool is required to retrieve this data.

? FREQUENTLY ASKED QUESTION

What Are Pending Codes?

Pending codes are set when operating conditions are met and the component or circuit is not within the normal range, yet the conditions have not yet been met to set a DTC. For example, a sensor may require two consecutive faults before a DTC is set. If a scan tool displays a pending code or a failure, a driveability concern could also be present. The pending code can help the technician to determine the root cause before the customer complains of a check engine light indication.

NOTE: Although OBD II requires that just one freeze-frame of data be stored, the instant an emission-related DTC is set, vehicle manufacturers usually provide expanded data about the DTC beyond that required. However, retrieving this enhanced data usually requires the use of the vehicle-specific scan tool.

Freeze-frame items include:

- Calculated load value
- Engine speed (RPM)
- Short-term and long-term fuel trim percent
- Fuel system pressure (on some vehicles)
- Vehicle speed (mph)
- Engine coolant temperature
- Intake manifold pressure
- Closed-open-loop status
- Fault code that triggered the freeze-frame
- If a misfire code is set, identify which cylinder is misfiring

A DTC should not be cleared from the vehicle computer memory unless the fault has been corrected and the technician is so directed by the diagnostic procedure. If the problem that caused the DTC to be set has been corrected, the computer will automatically clear the DTC after 40 consecutive warm-up cycles with no further faults detected. It requires 80 warm-up cycles to erase the pending fault if similar conditions cannot be met. The codes can also be erased by using a scan tool. ● **SEE CHART 87–1.**

NOTE: Disconnecting the battery may not erase OBD-II DTCs or freeze-frame data. Most vehicle manufacturers recommend using a scan tool to erase DTCs rather than disconnecting the battery, because the memory for the radio, seats, and learned engine operating parameters is lost if the battery is disconnected.

ENABLING CONDITIONS

These are the exact engine operating conditions required for a diagnostic monitor to run.

Example:

Specific RPM

Specific ECT, MAP, run time, etc.

MONITOR NAME	MONITOR TYPE (HOW OFTEN IT COMPLETES)	NUMBER OF FAULTS ON SEPARATE TRIPS TO SET A PENDING DTC	NUMBER OF SEPARATE CONSECUTIVE TRIPS TO LIGHT MIL, STORE A DTC	NUMBER OF TRIPS WITH NO FAULTS TO ERASE A MATURING DTC	NUMBER OF TRIPS WITH NO FAULT TO TURN THE MIL OFF	NUMBER OF WARM-UP CYCLES TO ERASE DTC AFTER MIL IS TURNED OFF
CCM	Continuous (when trip conditions allow it)	1	2	1–Trip	3–Trips	40
Catalyst	Once per drive cycle	1	3	1	3–OBD-II drive cycle	40
Misfire Type A	Continuous		1		3–Similar conditions	80
Misfire Type B	Continuous	1	2	1	3–Similar conditions	80
Fuel System	Continuous	1	2	1	3–Similar conditions	80
Oxygen Sensor	Once per trip	1	2	1–Trip	3–Trips	40
EGR	Once per trip	1	2	1–Trip	3–Trips	40
EVAP	Once per trip	1	1	1–Trip	3–Trips	40
AIR	Once per trip	1	2	1–Trip	3–Trips	40

CHART 87–1

PCM Determination of Faults Chart

PENDING Under some situations the PCM will not run a monitor if the MIL is illuminated and a fault is stored from another monitor. In these situations, the PCM postpones monitors pending a resolution of the original fault. The PCM does not run the test until the problem is remedied.

For example, when the MIL is illuminated for an oxygen sensor fault, the PCM does not run the catalyst monitor until the oxygen sensor fault is remedied. Since the catalyst monitor is based on signals from the oxygen sensor, running the test would produce inaccurate results.

CONFLICT There are also situations when the PCM does not run a monitor if another monitor is in progress. In these situations, the effects of another monitor running could result in an erroneous failure. If this conflict is present, the monitor is not run until the conflicting condition passes. Most likely, the monitor will run later after the conflicting monitor has passed.

For example, if the fuel system monitor is in progress, the PCM does not run the EGR monitor. Since both tests monitor changes in air–fuel ratio and adaptive fuel compensation, the monitors conflict with each other.

SUSPEND Occasionally, the PCM may not allow a two-trip fault to mature. The PCM will suspend the maturing fault if a condition exists that may induce erroneous failure. This prevents illuminating the MIL for the wrong fault and allows more precise diagnosis.

For example, if the PCM is storing a one-trip fault for the oxygen sensor and the EGR monitor, the PCM may still run the EGR monitor but will suspend the results until the oxygen sensor monitor either passes or fails. At that point, the PCM can determine if the EGR system is actually failing or if an oxygen sensor is failing.

PCM TESTS

RATIONALITY TEST While input signals to the PCM are constantly being monitored for electrical opens and shorts, they are also tested for rationality. This means that the input signal is compared against other inputs and information to see if it makes sense under the current conditions.

PCM sensor inputs that are checked for rationality include:

- MAP sensor
- O_2 sensor
- ECT
- Camshaft position sensor (CMP)
- VS sensor
- Crankshaft position sensor (CKP)
- IAT sensor
- TP sensor
- Ambient air temperature sensor
- Power steering switch
- O_2 sensor heater
- Engine controller
- Brake switch
- P/N switch (range switch)
- Transmission controls

FUNCTIONALITY TEST A functionality test refers to PCM inputs checking the operation of the outputs.

Example:

PCM commands the IAC open; expected change in engine RPM is not seen
IAC 60 counts
RPM 700 RPM

PCM outputs that are checked for functionality include:

- EVAP canister purge solenoid
- EVAP purge vent solenoid
- Cooling fan
- Idle air control solenoid
- Ignition control system
- Transmission torque converter clutch solenoid
- Transmission shift solenoids (A, B, 1–2, etc.)

ELECTRICAL TEST Refers to the PCM check of both input and outputs for the following:

- Open
- Shorts
- Ground

Example:

ECT

Shorted high (input to PCM) above capable voltage, i.e., 5-volt sensor with 12-volt input to PCM would indicate a short to voltage.

Monitor Type	Conditions to Set DTC and Illuminate MIL	Extinguish MIL	Clear DTC Criteria	Applicable DTC
Continuous 1-trip monitor	(See note below) Input and output failure—rationally, functionally, electrically	3 consecutive pass trips	40 warm-up cycles	P0123

NOTE: The number of times the comprehensive component monitor must detect a fault depends on the vehicle manufacturer. On some vehicles, the comprehensive component monitor will activate the MIL as soon as it detects a fault. On other vehicles, the comprehensive component monitor must fail two times in a row.

- Freeze-frame captured on first-trip failure.
- Enabling conditions: Many PCM sensors and output devices are tested at key-on or immediately after engine start-up. However, some devices (ECT, idle speed control) are only tested by the comprehensive component monitor after the engine meets particular engine conditions.
- Pending: No pending condition
- Conflict: No conflict conditions
- Suspend: No suspend conditions

GLOBAL OBD-II

All OBD-II vehicles must be able to display data on a global (also called *generic*) scan tool under nine different modes of operation. These modes include:

Mode One	Current powertrain data (**parameter identification** display or **PID**)
Mode Two	Freeze-frame data
Mode Three	Diagnostic trouble codes
Mode Four	Clear and reset diagnostic trouble codes (DTCs), freeze-frame data, and readiness status monitors for noncontinuous monitors only
Mode Five	Oxygen sensor monitor test results
Mode Six	Onboard monitoring of test results for noncontinuously monitored systems

FREQUENTLY ASKED QUESTION

How Can You Tell Generic from Factory?

When using a scan tool on an OBD-II-equipped vehicle, if the display asks for make, model, and year, then the factory or enhanced part of the PCM is being accessed. If the generic or global part of the PCM is being scanned, then there is no need to know the vehicle identification details.

Mode Seven	Onboard monitoring of test results for continuously monitored systems
Mode Eight	Bidirectional control of onboard systems
Mode Nine	Module identification

The global (generic) data is used by most state emission programs. Global OBD-II displays often use hexadecimal numbers, which use 16 numbers instead of 10. The numbers 0 to 9 (zero counts as a number) make up the first 10 and then capital letters A to F complete the 16 numbers. To help identify the number as being in a hexadecimal format, a dollar sign ($) is used in front of the number or letter. See the conversion chart below:

Decimal Number	Hexadecimal Code
0	$0
1	$1
2	$2
3	$3
4	$4
5	$5
6	$6
7	$7
8	$8
9	$9
10	$A
11	$B
12	$C
13	$D
14	$E
15	$F

Hexadecimal coding is also used to identify tests (**test identification [TID]** and **component identification [CID]**).

DIAGNOSING PROBLEMS USING MODE SIX

Mode six information can be used to diagnose faults by following three steps:

1. Check the monitor status before starting repairs. This step will show how the system failed.
2. Look at the component or parameter that triggered the fault. This step will help pin down the root cause of the failure.
3. Look to the monitor enable criteria, which will show what it takes to fail or pass the monitor.

REVIEW QUESTIONS

1. What does the PCM do during a trip to test emission-related components?
2. What is the difference between a type A and type B OBD-II DTC?
3. What is the difference between a trip and a warm-up cycle?
4. What could cause the MIL to flash?

CHAPTER QUIZ

1. A freeze-frame is generated on an OBD-II vehicle _____.
   a. When a type C or D diagnostic trouble code is set
   b. When a type A or B diagnostic trouble code is set
   c. Every other trip
   d. When the PCM detects a problem with the O2S
2. An ignition misfire or fuel mixture problem is an example of what type of DTC?
   a. Type A **c.** Type C
   b. Type B **d.** Type D
3. The comprehensive component monitor checks computer-controlled devices for _____.
   a. opens **c.** shorts-to-ground
   b. rationality **d.** All of the above
4. OBD II has been on all passenger vehicles in the United States since _____.
   a. 1986 **c.** 1996
   b. 1991 **d.** 2000
5. Which is a continuous monitor?
   a. Fuel system monitor **c.** Oxygen sensor monitor
   b. EGR monitor **d.** Catalyst monitor
6. DTC P0302 is a _____.
   a. Generic DTC
   b. Vehicle manufacturer-specific DTC
   c. Idle speed-related DTC
   d. Transmission/transaxle-related DTC
7. Global (generic) OBD II contains some data in what format?
   a. Plain English **c.** Roman numerals
   b. Hexadecimal **d.** All of the above
8. By looking at the way diagnostic trouble codes are formatted, which DTC could indicate that the gas cap is loose or defective?
   a. P0221 **c.** P0442
   b. P1301 **d.** P1603
9. The computer will automatically clear a DTC if there are no additional detected faults after _____.
   a. Forty consecutive warm-up cycles
   b. Eighty warm-up cycles
   c. Two consecutive trips
   d. Four key-on/key-off cycles
10. A pending code is set when a fault is detected on _____.
    a. A one-trip fault item
    b. The first fault of a two-trip failure
    c. The catalytic converter efficiency
    d. Thermostat problem (too long to closed-loop status)

chapter 88

SCAN TOOLS AND ENGINE PERFORMANCE DIAGNOSIS

OBJECTIVES: After studying Chapter 88, the reader will be able to: • Prepare for the ASE computerized engine controls diagnosis (A8) certification test content area "E". • List the steps of the diagnostic process. • Describe the simple preliminary tests that should be performed at the start of the diagnostic process. • List six items to check as part of a thorough visual inspection. • Explain the troubleshooting procedures to follow if a diagnostic trouble code has been set. • Explain the troubleshooting procedures to follow if no diagnostic trouble code has been set. • Discuss the type of scan tools that are used to assess vehicle components. • Describe the methods that can be used to reprogram (reflash) a vehicle computer.

KEY TERMS: Data link connector (DLC) 969 • Drive cycle 981 • Flash code retrieval 973 • Key-on—engine off test (KOEO) 974 • Key-on—engine running test (KOER) 974 • Paper test 968 • Pending code 969 • Self-test automatic readout (STAR) 973 • Smoke machine 968 • Technical service bulletin (TSB) 969 • Trip 977

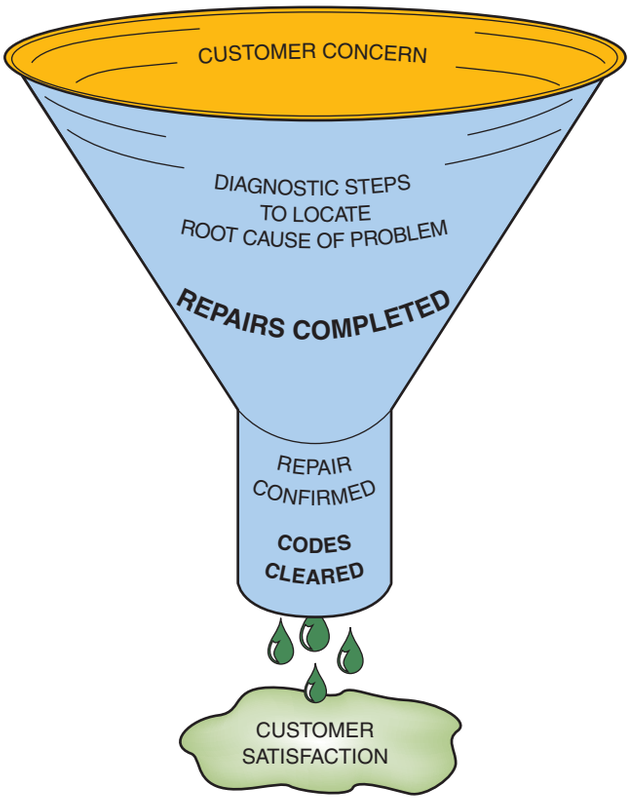


FIGURE 88–1 A funnel is one way to visualize the diagnostic process. The purpose is to narrow the possible causes of a concern until the root cause is determined and corrected.

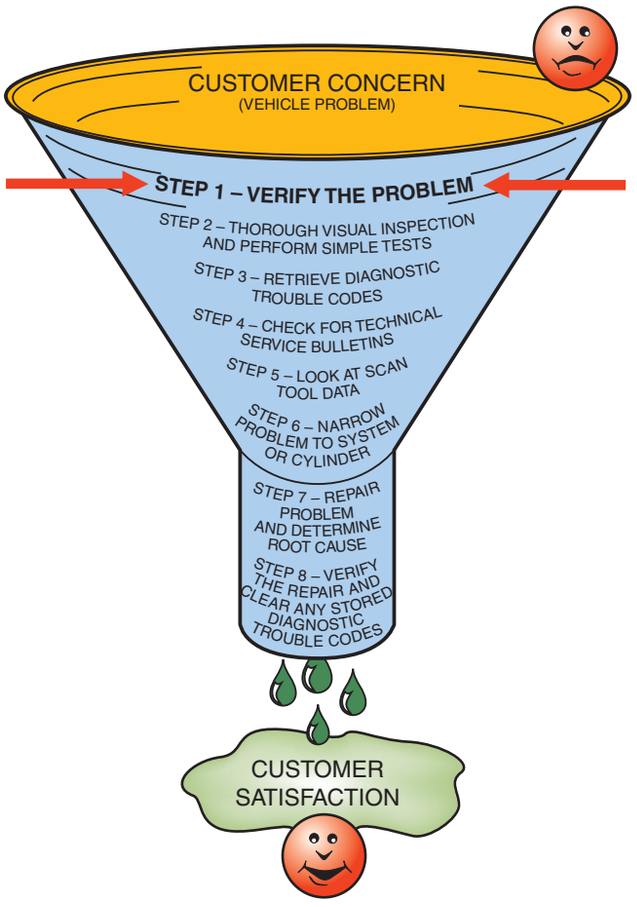


FIGURE 88–2 Step #1 is to verify the customer concern or problem. If the problem cannot be verified, then the repair cannot be verified.

THE EIGHT-STEP DIAGNOSTIC PROCEDURE

It is important that all automotive service technicians know how to diagnose and troubleshoot engine computer systems. The diagnostic process is a strategy that eliminates known-good components or systems in order to find the root cause of automotive engine performance problems. All vehicle manufacturers recommend a diagnostic procedure, and the plan suggested in this chapter combines most of the features of these plans plus additional steps developed over years of real-world problem solving.

Many different things can cause an engine performance problem or concern. The service technician has to narrow the possibilities to find the cause of the problem and correct it. A funnel is a way of visualizing a diagnostic procedure. ● **SEE FIGURE 88–1.** At the wide top are the symptoms of the problem; the funnel narrows as possible causes are eliminated until the root cause is found and corrected at the bottom of the funnel.

All problem diagnosis deals with symptoms that could be the result of many different causes. The wide range of possible solutions must be narrowed to the most likely and these must eventually be further narrowed to the actual cause. The following section describes eight steps the service technician can take to narrow the possibilities to one cause.

STEP 1 VERIFY THE PROBLEM (CONCERN) Before a minute is spent on diagnosis, be certain that a problem exists. If the problem cannot be verified, it cannot be solved or tested to verify that the repair was complete. ● **SEE FIGURE 88–2.**

The driver of the vehicle knows much about the vehicle and how it is driven. *Before* diagnosis, always ask the following questions:

- Is the malfunction indicator light (check engine) on?
- What was the temperature outside?
- Was the engine warm or cold?
- Was the problem during starting, acceleration, cruise, or some other condition?
- How far had the vehicle been driven?
- Were any dash warning lights on? If so, which one(s)?
- Has there been any service or repair work performed on the vehicle lately?

NOTE: This last question is very important. Many engine performance faults are often the result of something being knocked loose or a hose falling off during repair work. Knowing that the vehicle was just serviced before the problem began may be an indicator as to where to look for the solution to a problem.

After the nature and scope of the problem are determined, the complaint should be verified before further diagnostic tests are performed. A sample form that customers could fill out with details of the problem is shown in ● **FIGURE 88–3.**

NOTE: Because drivers differ, it is sometimes the best policy to take the customer on the test drive to verify the concern.

STEP 2 PERFORM A THOROUGH VISUAL INSPECTION AND BASIC TESTS The visual inspection is the most important aspect of diagnosis! Most experts agree that between 10%

ENGINE PERFORMANCE DIAGNOSIS WORKSHEET

(To Be Filled Out By the Vehicle Owner)

Name: _____ Mileage: _____ Date: _____

Make: _____ Model: _____ Year: _____ Engine: _____

(Please Circle All That Apply in All Categories)	
Describe Problem:	
When Did the Problem First Occur?	• Just Started • Last Week • Last Month • Other _____
List Previous Repairs in the Last 6 Months:	
Starting Problems	• Will Not Crank • Cranks, but Will Not Start • Starts, but Takes a Long Time
Engine Quits or Stalls	• Right after Starting • When Put into Gear • During Steady Speed Driving • Right after Vehicle Comes to a Stop • While Idling • During Acceleration • When Parking
Poor Idling Conditions	• Is Too Slow at All Times • Is Too Fast • Intermittently Too Fast or Too Slow • Is Rough or Uneven • Fluctuates Up and Down
Poor Running Conditions	• Runs Rough • Lacks Power • Bucks and Jerks • Poor Fuel Economy • Hesitates or Stumbles on Acceleration • Backfires • Misfires or Cuts Out • Engine Knocks, Pings, Rattles • Surges • Dieseling or Run-On
Auto. Transmission Problems	• Improper Shifting (Early/Late) • Changes Gear Incorrectly • Vehicle Does Not Move when in Gear • Jerks or Bucks
Usually Occurs	• Morning • Afternoon • Anytime
Engine Temperature	• Cold • Warm • Hot
Driving Conditions During Occurrence	• Short—Less Than 2 Miles • 2–10 Miles • Long—More Than 10 Miles • Stop and Go • While Turning • While Braking • At Gear Engagement • With A/C Operating • With Headlights On • During Acceleration • During Deceleration • Mostly Downhill • Mostly Uphill • Mostly Level • Mostly Curvy • Rough Road
Driving Habits	• Mostly City Driving • Highway • Park Vehicle Inside • Park Vehicle Outside Drive Per Day: • Less Than 10 Miles • 10–50 • More Than 50
Gasoline Used	Fuel Octane: • 87 • 89 • 91 • More Than 91 Brand: _____
Temperature when Problem Occurs	• 32–55° F • Below Freezing (32° F) • Above 55° F
Check Engine Light/ Dash Warning Light	• Light on Sometimes • Light on Always • Light Never On
Smells	• "Hot" • Gasoline • Oil Burning • Electrical
Noises	• Rattle • Knock • Squeak • Other

FIGURE 88–3 A form that the customer should fill out if there is a driveablilty concern to help the service technician more quickly find the root cause.

and 30% of all engine performance problems can be found simply by performing a *thorough* visual inspection. The inspection should include the following:

- **Check for obvious problems (basics, basics, basics).**
  Fuel leaks
  Vacuum hoses that are disconnected or split
  Corroded connectors
  Unusual noises, smoke, or smell
  Check the air cleaner and air duct (squirrels and other small animals can build nests or store dog food in them). ● **SEE FIGURE 88–4.**
- **Check everything that does and does not work.** This step involves turning things on and observing that everything is working properly.



FIGURE 88–4 This is what was found when removing an air filter from a vehicle that had a lack-of-power concern. Obviously the nuts were deposited by squirrels or some other animal, blocking a lot of the airflow into the engine.



FIGURE 88–5 Using a bright light makes seeing where the smoke is coming from easier. In this case, smoke was added to the intake manifold with the inlet blocked with a yellow plastic cap and smoke was seen escaping past a gasket at the idle air control.

TECH TIP

"Original Equipment" Is Not a Four-Letter Word

To many service technicians, an original-equipment part is considered to be only marginal and to get the really "good stuff" an aftermarket (renewal market) part has to be purchased. However, many problems can be traced to the use of an aftermarket part that has failed early in its service life. Technicians who work at dealerships usually begin their diagnosis with an aftermarket part identified during a visual inspection. It has been their experience that simply replacing the aftermarket part with the factory original-equipment (OE) part often solves the problem.

Original equipment parts are *required* to pass quality and durability standards and tests at a level not required of aftermarket parts. The technician should be aware that the presence of a new part does not necessarily mean that the part is good.

TECH TIP

Smoke Machine Testing

Vacuum (air) leaks can cause a variety of driveability problems and are often difficult to locate. One good method is to use a machine that generates a stream of smoke. Connecting the outlet of the **smoke machine** to the hose that was removed from the vacuum brake booster allows smoke to enter the intake manifold. Any vacuum leaks will be spotted by observing smoke coming out of the leak. ● **SEE FIGURE 88–5.**

- **Look for evidence of previous repairs.** Any time work is performed on a vehicle, there is always a risk that something will be disturbed, knocked off, or left disconnected.
- **Check oil level and condition.** Another area for visual inspection is oil level and condition.

  Oil level. Oil should be to the proper level.

  Oil condition. Using a match or lighter, try to light the oil on the dipstick; if the oil flames up, gasoline is present in the engine oil. Drip some engine oil from the dipstick onto the hot exhaust manifold. If the oil bubbles or boils, coolant (water) is present in the oil. Check for grittiness by rubbing the oil between your fingers.

NOTE: Gasoline in the oil will cause the engine to run rich by drawing fuel through the positive crankcase ventilation (PCV) system.

- **Check coolant level and condition.** Many mechanical engine problems are caused by overheating. The proper operation of the cooling system is critical to the life of any engine.

NOTE: Check the coolant level in the radiator only if the radiator is cool. If the radiator is hot and the radiator cap is removed, the drop in pressure above the coolant will cause the coolant to boil immediately, which can cause severe burns because the coolant expands explosively upward and outward from the radiator opening.

- **Use the paper test.** A sound engine should produce even and steady exhaust flow at the tailpipe when running. For the paper test, hold a piece of paper (even a dollar bill works) or a 3-by-5-inch card within 1 inch (2.5 centimeters) of the tailpipe with the engine running at idle. The paper should blow evenly away from the end of the tailpipe without "puffing" or being drawn inward toward the end of the tailpipe. If the paper is at times drawn *toward* the tailpipe, the valves in one or more cylinders could be burned. Other reasons why the paper might be drawn toward the tailpipe include the following:

  1. The engine could be misfiring because of a lean condition that could occur normally when the engine is cold.
  2. Pulsing of the paper toward the tailpipe could also be caused by a hole in the exhaust system. If exhaust escapes through a hole in the exhaust system, air could be drawn—in the intervals between the exhaust puffs—from the tailpipe to the hole in the exhaust, causing the paper to be drawn toward the tailpipe.

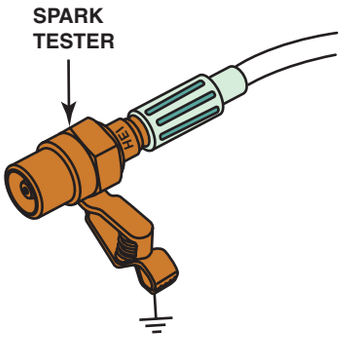


FIGURE 88–6 A spark tester connected to a spark plug wire or coil output. A typical spark tester will only fire if at least 25,000 volts is available from the coil, making a spark tester a very useful tool. Do not use one that just lights when a spark is present, because they do not require more than about 2,000 volts to light.

- **Ensure adequate fuel level.** Make certain that the fuel tank is at least one-fourth to one-half full; if the fuel level is low it is possible that any water or alcohol at the bottom of the fuel tank is more concentrated and can be drawn into the fuel system.
- **Check the battery voltage.** The voltage of the battery should be at least 12.4 volts and the charging voltage (engine running) should be 13.5 to 15.0 volts at 2,000 RPM. Low battery voltage can cause a variety of problems including reduced fuel economy and incorrect (usually too high) idle speed. Higher-than-normal battery voltage can also cause the PCM problems and could cause damage to electronic modules.
- **Check the spark using a spark tester.** Remove one spark plug wire and attach the removed plug wire to the spark tester. Attach the grounding clip of the spark tester to a good clean engine ground, start or crank the engine, and observe the spark tester. ● **SEE FIGURE 88–6.** The spark at the spark tester should be steady and consistent. If an intermittent spark occurs, then this condition should be treated as a no-spark condition. If this test does not show satisfactory spark, carefully inspect and test all components of the primary and secondary ignition systems.

  NOTE: Do not use a standard spark plug to check for proper ignition system voltage. An electronic ignition spark tester is designed to force the spark to jump about 0.75 inch (19 mm). This amount of gap requires between 25,000 and 30,000 volts (25 to 30 kV) at atmospheric pressure, which is enough voltage to ensure that a spark can occur under compression inside an engine.

- **Check the fuel-pump pressure.** Checking the fuel-pump pressure is relatively easy on many port-fuel-injected engines. Often the cause of intermittent engine performance is due to a weak electric fuel pump or clogged fuel filter. Checking fuel pump pressure early in the diagnostic process eliminates low fuel pressure as a possibility.

STEP 3 RETRIEVE THE DIAGNOSTIC TROUBLE CODES (DTCs)

If a diagnostic trouble code (DTC) is present in the computer memory, it may be signaled by illuminating a malfunction indicator lamp (MIL), commonly labeled "check engine" or "service engine soon." ● **SEE FIGURE 88–7.** Any code(s) that is displayed on a scan tool when the MIL is *not* on is called a **pending code.** Because the MIL is not on, this indicates that the fault has not repeated to cause the PCM to turn on the MIL. Although this pending code is helpful to the technician to know that a fault has, in the past, been detected, further testing will be needed to find the root cause of the problem.

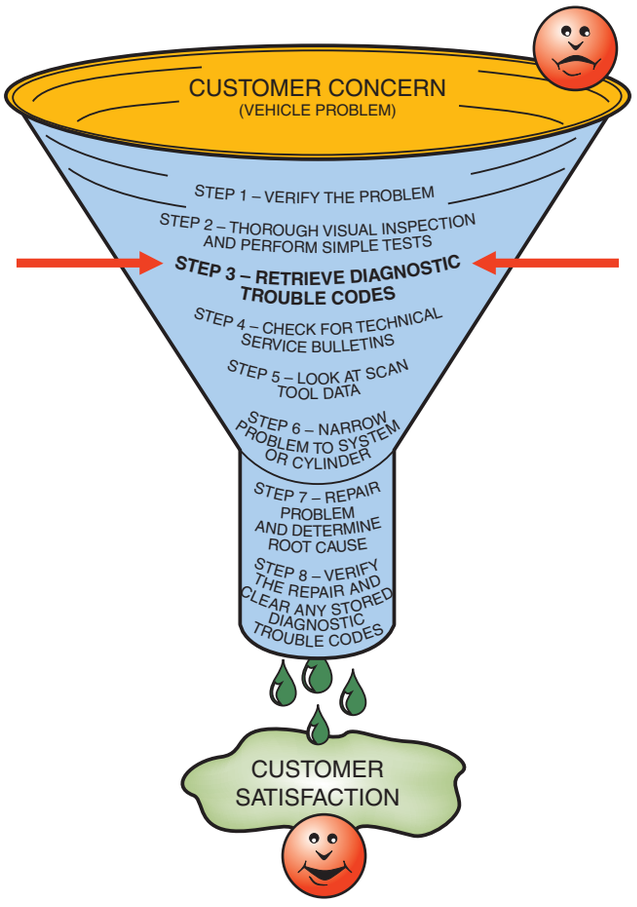


FIGURE 88–7 Step 3 in the diagnostic process is to retrieve any stored diagnostic trouble codes.

STEP 4 CHECK FOR TECHNICAL SERVICE BULLETINS (TSBs)

Check for corrections or repair procedures in **technical service bulletins (TSBs)** that match the symptoms. ● **SEE FIGURE 88–8.** According to studies performed by automobile manufacturers, as many as 30% of vehicles can be repaired following the information, suggestions, or replacement parts found in a service bulletin. DTCs must be known before searching for service bulletins, because bulletins often include information on solving problems that involve a stored diagnostic trouble code.

STEP 5 LOOK CAREFULLY AT SCAN TOOL DATA

Vehicle manufacturers have been giving the technician more and more data on a scan tool connected to the **data link connector (DLC).** ● **SEE FIGURE 88–9.** Beginning technicians are often observed scrolling through scan data without a real clue about what they are looking for. When asked, they usually reply that they are looking for something unusual, as if the screen will flash a big message "LOOK HERE—THIS IS NOT CORRECT." That statement does not appear on scan tool displays. The best way to look at scan data is in a definite sequence and with specific, selected bits of data that can tell the most about the operation of the engine, such as the following:

- Engine coolant temperature (ECT) is the same as intake air temperature (IAT) after the vehicle sits for several hours.
- Idle air control (IAC) valve is being commanded to an acceptable range.



FIGURE 88–8 After checking for stored diagnostic trouble codes (DTCs), the wise technician checks service information for any technical service bulletins that may relate to the vehicle being serviced.

- Oxygen sensor (O_2S) is operating properly:
  1. Readings below 200 mV at times
  2. Readings above 800 mV at times
  3. Rapid transitions between rich and lean

STEP 6 NARROW THE PROBLEM TO A SYSTEM OR CYLINDER Narrowing the focus to a system or individual cylinder is the hardest part of the entire diagnostic process.

- Perform a cylinder power balance test.
- If a weak cylinder is detected, perform a compression and a cylinder leakage test to determine the probable cause.

STEP 7 REPAIR THE PROBLEM AND DETERMINE THE ROOT CAUSE The repair or part replacement must be performed following vehicle manufacturer's recommendations and be certain that the root cause of the problem has been found. Also follow the manufacturer's recommended repair procedures and methods.

STEP 8 VERIFY THE REPAIR AND CLEAR ANY STORED DTCs ● **SEE FIGURE 88–10.**

- Test drive to verify that the original problem (concern) is fixed.
- Verify that no additional problems have occurred during the repair process.
- Check for and then clear all diagnostic trouble codes. (This step ensures that the computer will not make any changes based on a stored DTC, but should not be performed if the vehicle is going to be tested for emissions because all of the monitors will need to be run and pass.)
- Return the vehicle to the customer and double-check the following:
  1. The vehicle is clean.
  2. The radio is turned off.
  3. The clock is set to the right time and the radio stations have been restored if the battery was disconnected during the repair procedure.

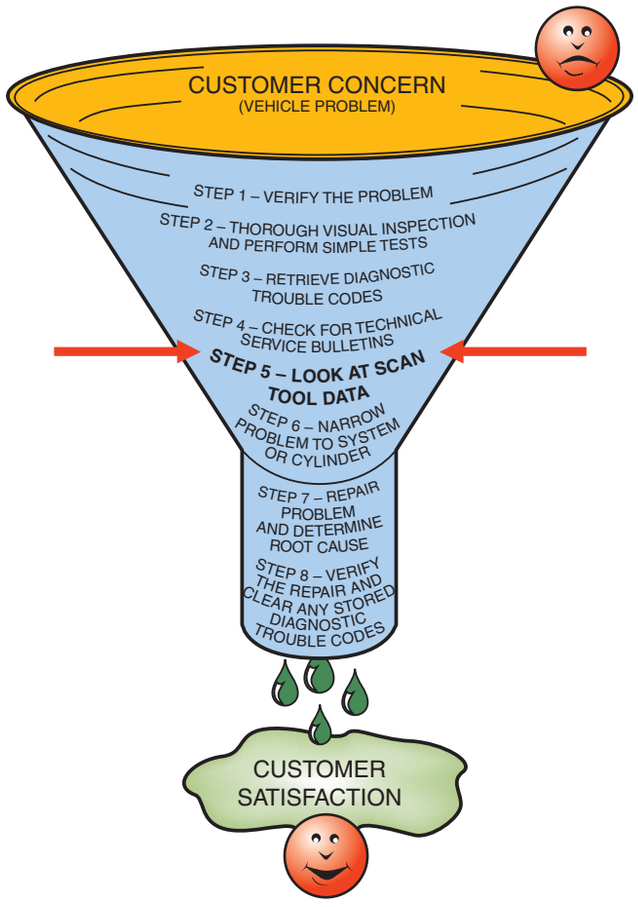


FIGURE 88–9 Looking carefully at the scan tool data is very helpful in locating the source of a problem.

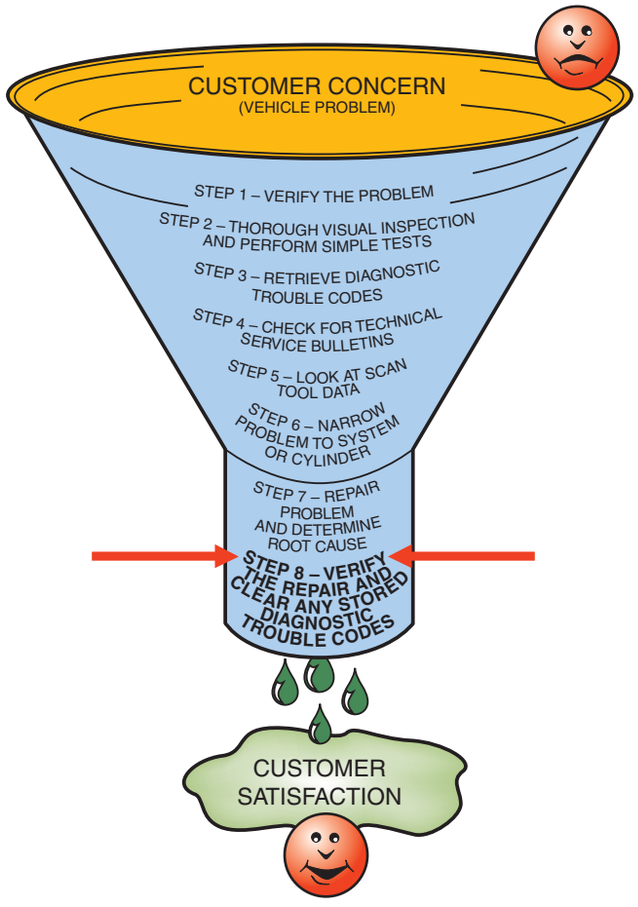


FIGURE 88–10 Step 8 is very important. Be sure that the customer's concern has been corrected.



FIGURE 88–11 A TECH 2 scan tool is the factory scan tool used on General Motors vehicles.



FIGURE 88–12 Some scan tools use pocket PCs which make it very convenient to use.

TECH TIP

One Test Is Worth 1,000 "Expert" Opinions

Whenever any vehicle has an engine performance or driveability concern, certain people always say:

"Sounds like it's a bad injector."
"I'll bet you it's a bad computer."
"I had a problem just like yours yesterday and it was a bad EGR valve."

Regardless of the skills and talents of those people, it is still more accurate to perform tests on the vehicle than to rely on feelings or opinions of others who have not even seen the vehicle. Even your own opinion should not sway your thinking. Follow a plan, perform tests, and the test results will lead to the root cause.

SCAN TOOLS

Scan tools are the workhorse for any diagnostic work on all vehicles. Scan tools can be divided into two basic groups:

1. **Factory scan tools.** These are the scan tools required by all dealers that sell and service the brand of vehicle. Examples of factory scan tools include:
   - **General Motors**—Tech 2. ● **SEE FIGURE 88–11.**
   - **Ford**—New Generation Star (NGS) and IDS (Integrated Diagnostic Software).
   - **Chrysler**—DRB-III or Star Scan (CAN-equipped vehicles)
   - **Honda**—HDS or Master Tech
   - **Toyota**—Master Tech

   All factory scan tools are designed to provide bidirectional capability which allows the service technician the opportunity to operate components using the scan tool thereby confirming that the component is able to work when commanded. Also all factory scan tools are capable of displaying all factory parameters.

2. **Aftermarket scan tools.** These scan tools are designed to function on more than one brand of vehicle. Examples of aftermarket scan tools include:
   - **Snap-on** (various models including the MT2500 and Modis)
   - **OTC** (various models including Pegasus, Genisys and Task Master)
   - **AutoEnginuity** and other programs that use a laptop or handheld computer for the display

While many aftermarket scan tools can display most if not all of the parameters of the factory scan tool, there can be a difference when trying to troubleshoot some faults. ● **SEE FIGURE 88–12.**

RETRIEVAL OF DIAGNOSTIC INFORMATION

To retrieve diagnostic information from the powertrain control module (PCM), a scan tool is needed. If a factory or factory-level scan tool is used, then all of the data can be retrieved. If a global (generic) only type scan tool is used, only the emissions-related data can be retrieved. To retrieve diagnostic information from the PCM, use the following steps:

STEP 1 Locate and gain access to the data link connector (DLC).

STEP 2 Connect the scan tool to the DLC and establish communication.

NOTE: If no communication is established, follow the vehicle manufacturer's specified instructions.

STEP 3 Follow the on-screen instructions of the scan tool to correctly identify the vehicle.

STEP 4 Observe the scan data, as well as any diagnostic trouble codes.

STEP 5 Follow vehicle manufacturer's instructions if any DTCs are stored. If no DTCs are stored, compare all sensor values with a factory acceptable range chart to see if any sensor values are out-of-range.

Parameter Identification (PID)

Scan Tool Parameter	Units Displayed	Typical Data Value
Engine Idling/Radiator Hose Hot/Closed Throttle/ Park or Neutral/Closed Loop/Accessories Off/ Brake Pedal Released		
3X Crank Sensor	RPM	Varies
24X Crank Sensor	RPM	Varies
Actual EGR Position	Percent	0
BARO	kPa/Volts	65–110 kPa/ 3.5–4.5 Volts
CMP Sensor Signal Present	Yes/No	Yes
Commanded Fuel Pump	On/Off	On
Cycles of Misfire Data	Counts	0–99
Desired EGR Position	Percent	0
ECT	°C/°F	Varies
EGR Duty Cycle	Percent	0
Engine Run Time	Hr: Min: Sec	Varies
EVAP Canister Purge	Percent	Low and Varying
EVAP Fault History	No Fault/ Excess Vacuum/ Purge Valve Leak/ Small Leak/ Weak Vacuum	No Fault
Fuel Tank Pressure	Inches of H_2O/ Volts	Varies
HO_2S Sensor 1	Ready/Not Ready	Ready
HO_2S Sensor 1	Millivolts	0–1,000 and Varying
HO_2S Sensor 2	Millivolts	0–1,000 and Varying
HO_2S X Counts	Counts	Varies
IAC Position	Counts	15–25 preferred
IAT	°C/°F	Varies
Knock Retard	Degrees	0
Long Term FT	Percent	0–10
MAF	Grams per second	3–7
MAF Frequency	Hz	1,200–3,000 (depends on altitude and engine load)
MAP	kPa/Volts	20–48 kPa/ 0.75–2 Volts (depends on altitude)
Misfire Current Cyl. 1–10	Counts	0
Misfire History Cyl. 1–10	Counts	0
Short Term FT	Percent	0–10
Start Up ECT	°C/°F	Varies
Start Up IAT	°C/°F	Varies
Total Misfire Current Count	Counts	0
Total Misfire Failures	Counts	0
Total Misfire Passes	Counts	0
TP Angle	Percent	0
TP Sensor	Volts	0.20–0.74
Vehicle Speed	MPH/Km/h	0

Note: Viewing the PID screen on the scanner is useful in determining if a problem is occurring at the present time

TROUBLESHOOTING USING DIAGNOSTIC TROUBLE CODES

Pinning down causes of the actual problem can be accomplished by trying to set the opposite code. For example, if a code indicates an open throttle position (TP) sensor (high resistance), clear the code and create a shorted (low-resistance) condition. This can be accomplished by using a jumper wire and connecting the signal terminal to the 5-volt reference terminal. This should set a diagnostic trouble code.

- **If the opposite code sets,** this indicates that the wiring and connector for the sensor is okay and the sensor itself is defective (open).
- **If the same code sets,** this indicates that the wiring or electrical connection is open (has high resistance) and is the cause of the setting of the DTC.

METHODS FOR CLEARING DIAGNOSTIC TROUBLE CODES

Clearing diagnostic trouble codes from a vehicle computer sometimes needs to be performed. There are three methods that can be used to clear stored diagnostic trouble codes.

CAUTION: Clearing diagnostic trouble codes (DTCs) also will clear all of the noncontinuous monitors.

- **Clearing codes—Method 1.** The preferred method of clearing codes is by using a scan tool. This is the method recommended by most vehicle manufacturers if the procedure can be performed on the vehicle. The computer of some vehicles cannot be cleared with a scan tool.
- **Clearing codes—Method 2.** If a scan tool is not available or a scan tool cannot be used on the vehicle being serviced, the power to the computer can be disconnected.
  1. Disconnect the fusible link (if so equipped) that feeds the computer.
  2. Disconnect the fuse or fuses that feed the computer.

  NOTE: The fuse may not be labeled as a computer fuse. For example, many Toyotas can be cleared by disconnecting the fuel-injection fuse. Some vehicles require that two fuses be disconnected to clear any stored codes.
- **Clearing codes—Method 3.** If the other two methods cannot be used, the negative battery cable can be disconnected to clear stored diagnostic trouble codes.

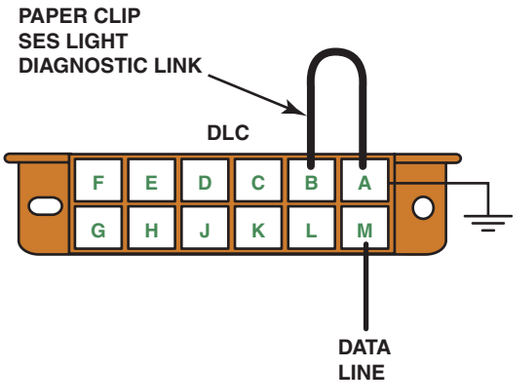


FIGURE 88–13 To retrieve flash codes from an OBD-I General Motors vehicle, without a scan tool, connect terminals A and B with the ignition on–engine off. The M terminal is used to retrieve data from the sensors to a scan tool.

NOTE: Because of the adaptive learning capacity of the computer, a vehicle may fail an exhaust emissions test if the vehicle is not driven enough to allow the computer to run all of the monitors.

CAUTION: By disconnecting the battery, the radio presets and clock information will be lost. They should be reset before returning the vehicle to the customer. If the radio has a security code, the code must be entered before the radio will function. Before disconnecting the battery, always check with the vehicle owner to be sure that the code is available.

FLASH CODE RETRIEVAL ON OBD-I GENERAL MOTORS VEHICLES

The GM system uses a "check engine" or "check engine soon" MIL to notify the driver of possible system failure. Under the dash (on most GM vehicles) is a data link connector (DLC) previously called an assembly line communications link (ALCL) or assembly line diagnostic link (ALDL).

Most General Motors diagnostic trouble codes can be retrieved by using a metal tool and contacting terminals A and B of the 12-pin DLC. ● **SEE FIGURE 88–13.** This method is called **flash code retrieval** because the MIL will flash to indicate diagnostic trouble codes. The steps are as follows:

1. Turn the ignition switch to on (engine off). The "check engine" light or "service engine soon" light should be on. If the amber malfunction indicator light (MIL) is not on, a problem exists within the light circuit.
2. Connect terminals A and B at the DLC.
3. Observe the MIL. A code 12 (one flash, then a pause, then two flashes) reveals that there is no engine speed indication to the computer. Because the engine is not running, this simply indicates that the computer diagnostic system is working correctly.

TECH TIP

Do Not Lie to a Scan Tool!

Because computer calibration may vary from year to year, using the incorrect year for the vehicle while using a scan tool can cause the data retrieved to be incorrect or inaccurate.

NOTE: Refer to service manual diagnostic procedures if the MIL is on and does not flash a code 12 when terminals A and B are connected.

4. After code 12 is displayed three times, the MIL will flash any other stored DTCs in numeric order starting with the lowest-number code. If only code 12 is displayed another three times, the computer has not detected any other faults.

NOTE: Trouble codes can vary according to year, make, model, and engine. Always consult the service literature or service manual for the exact vehicle being serviced. Check service information for the meaning and recommended steps to follow if a diagnostic trouble code is retrieved.

RETRIEVING FORD DIAGNOSTIC CODES

The best tool to use during troubleshooting of a Ford vehicle is a **self-test automatic readout (STAR)** tester, new generation STAR (NGS), WDS (Worldwide Diagnostic System), or another scan tool with Ford capabilities. If a STAR tester or scan tool is not available, a needle (analog) type of voltmeter can be used for all OBD-I (prior to 1996) systems. See the Tech Tip "Put a Wire in the Attic and a Light in the Basement!" to obtain flash codes. The test connector is usually located under the hood on the driver's side. ● **SEE FIGURE 88–14.**

KEY ON–ENGINE OFF TEST (ON-DEMAND CODES OR HARD FAULTS)

With the ignition key on (engine off), watch the voltmeter pulses, which should appear within 5 to 30 seconds. (Ignore any initial surge of voltage when the ignition is turned on.)

The computer will send a two-digit code that will cause the voltmeter to pulse or move from left to right. For example, if the voltmeter needle pulses two times, then pauses for 2 seconds, and then pulses three times, the code is 23. There is normally a 4-second pause between codes.

SEPARATOR PULSE. After all the codes have been reported, the computer will pause for about 6 to 9 seconds, then cause the voltmeter needle to pulse once, and then pause for another 6 to 9 seconds. This is the normal separation between current trouble codes and continuous memory codes (for intermittent problems). Code 11 is the normal pass code, which means that no fault has been stored in memory. Therefore, normal operation of the diagnostic procedure using a voltmeter should indicate the following if no codes are set: 1 pulse (2-second pause), 1 pulse (6- to 9-second pause), 1 pulse (6- to 9-second pause), 1 pulse (2-second pause), and finally, 1 pulse. These last two pulses that are separated by a 2-second interval represent a code 11, which is the code used between current and intermittent trouble codes.

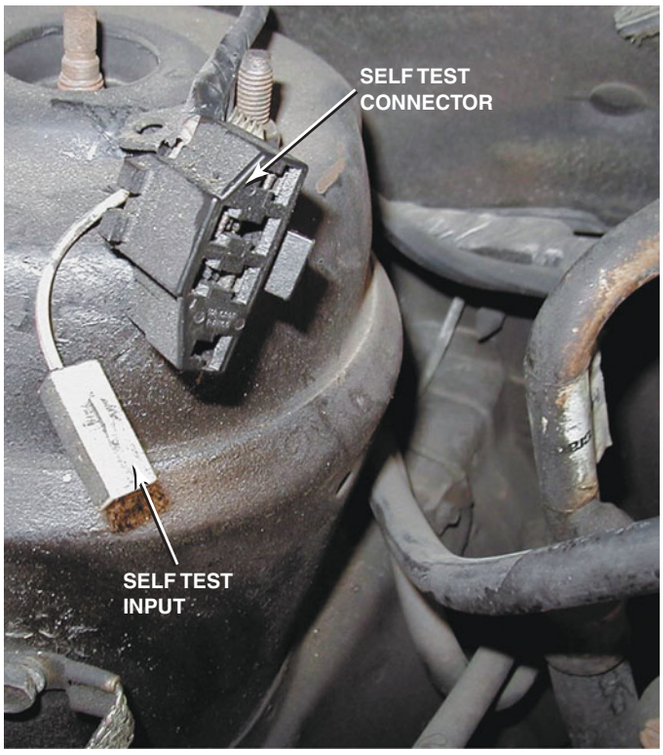


FIGURE 88–14 A Ford OBD-I self-test connector. The location of this connector can vary with model and year of vehicle.

TECH TIP

Put a Wire in the Attic and a Light in the Basement!

Retrieving DTCs from a Ford using low-cost test equipment is easier when you remember the following: "*Put a wire in the attic and a light in the basement.*"

After warming the engine to operating temperature, perform these simple steps:

1. Locate the data link connector (DLC) under the hood. Connect a jumper wire from the single-wire pigtail called the self-test input to terminal #2 at the top (attic) of the connector.
2. To read DTCs, connect a standard 12-volt test light (not a self-powered continuity light) to the positive battery terminal and the lower (basement) terminal (#4) of the DLC. ● **SEE FIGURE 88–15.** Turn the ignition to on (engine off). The DTCs will be displayed by means of the flashes of the test light.

To clear stored Ford DTCs, simply disconnect the jumper wire from the self-test input while the codes are being flashed. This interruption is the signal to the computer to clear any stored DTCs.

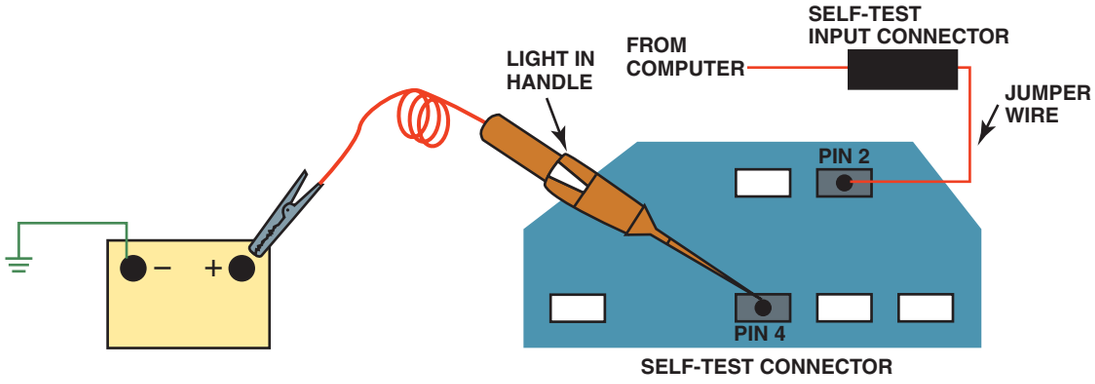


FIGURE 88–15 To retrieve Ford DTCs using a test light and a jumper wire, turn the ignition switch on (engine off) and make the connections shown. The test light will blink out the diagnostic trouble codes.

CONTINUOUS MEMORY CODES (SOFT CODES)

Continuous memory codes are set based on information stored while the vehicle was in normal operation. These codes represent an intermittent problem and should only be used for diagnosis if the **KOEO** test results in code 11 (no faults detected). Therefore, any codes displayed after the separation pulse represent failures that have been detected but may no longer be present.

KEY ON–ENGINE RUNNING (KOER) TEST

During the **KOER** self-test, the sensors are checked by the computer under actual operating conditions and the output devices (actuators) are operated and checked for expected results. Start the engine and raise the speed to 2500 to 3000 RPM to warm the oxygen sensor within 20 seconds of starting. Hold a steady high engine speed until the initial pulses appear (2 pulses for a four-cylinder engine, 3 pulses for a six-cylinder, and 4 pulses for an eight-cylinder). These codes are used to verify the proper processor (computer) is in the vehicle and that the self-test has been entered. Continue to hold a high engine speed until the code pulses begin (10 to 14 seconds).

STEERING, BRAKE, AND OVERDRIVE SWITCH TEST

To test the power steering pressure switch, the technician must turn the steering wheel one-half turn after the ID code has been displayed. The brake pedal and the overdrive cancel switch must also be cycled after the ID code to allow the system to detect a change of state of these switches.

DYNAMIC RESPONSE CHECK. The dynamic response test checks the throttle position (TP) mass air flow (MAF) and manifold absolute pressure (MAP) sensors during a brief wide-open throttle (WOT) test performed by the technician. The signal for the technician to depress the throttle briefly to wide open is a single pulse or a code 10 on a STAR tester.

If any hard (on-demand) faults appear, these should be repaired first and then any soft (continuous) codes next. Use the factory "pinpoint tests" to trace the problem. Refer to service information for a description of Ford-specific alphanumeric DTCs.

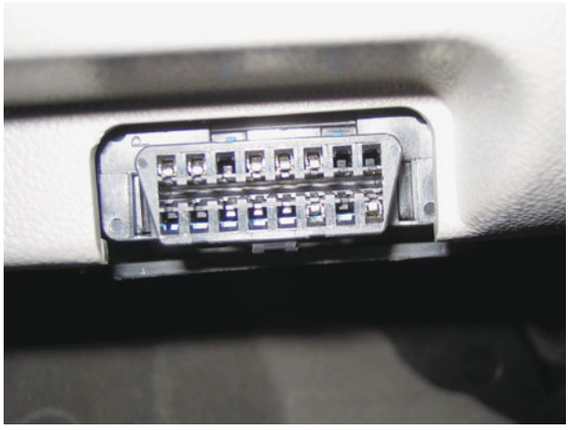


FIGURE 88–16 A typical OBD-II data link connector (DLC). The location varies with make and model and may even be covered, but a tool is not needed to gain access. Check service information for the exact location if needed.

FLASH CODE RETRIEVAL ON CHRYSLER VEHICLES

To put the computer into the self-diagnostic mode, the ignition switch must be turned on and off three times within a 5-second period (on-off-on-off-on). The computer will flash a series of fault codes. Older Chrysler brand products flash the "check engine" lamp on the dash.

NOTE: Unlike other manufacturers, most Chrysler brand vehicles equipped with OBD II will display the P-codes on the odometer display by cycling the ignition key as previously performed on older vehicles.

OBD-II DIAGNOSIS

Starting with the 1996 model year, all vehicles sold in the United States must use the same type of 16-pin data link connector (DLC) and must monitor emission-related components. ● **SEE FIGURE 88–16.**

RETRIEVING OBD-II CODES A scan tool is required to retrieve diagnostic trouble codes from most OBD-II vehicles. Every OBD-II scan tool will be able to read all generic Society of Automotive Engineers (SAE) DTCs from any vehicle.

Fuel and Air Metering System

P0100 Mass or Volume Airflow Circuit Problem
P0101 Mass or Volume Airflow Circuit Range or Performance Problem
P0102 Mass or Volume Airflow Circuit Low Input
P0103 Mass or Volume Airflow Circuit High Input
P0105 Manifold Absolute Pressure or Barometric Pressure Circuit Problem
P0106 Manifold Absolute Pressure or Barometric Pressure Circuit Range or Performance Problem
P0107 Manifold Absolute Pressure or Barometric Pressure Circuit Low Input
P0108 Manifold Absolute Pressure or Barometric Pressure Circuit High Input
P0110 Intake Air Temperature Circuit Problem
P0111 Intake Air Temperature Circuit Range or Performance Problem
P0112 Intake Air Temperature Circuit Low Input
P0113 Intake Air Temperature Circuit High Input
P0115 Engine Coolant Temperature Circuit Problem
P0116 Engine Coolant Temperature Circuit Range or Performance Problem
P0117 Engine Coolant Temperature Circuit Low Input
P0118 Engine Coolant Temperature Circuit High Input
P0120 Throttle Position Circuit Problem
P0121 Throttle Position Circuit Range or Performance Problem
P0122 Throttle Position Circuit Low Input
P0123 Throttle Position Circuit High Input
P0125 Excessive Time to Enter Closed-Loop Fuel Control
P0128 Coolant Temperature Below Thermostat Regulating Temperature
P0130 O2 Sensor Circuit Problem (Bank 1* Sensor 1)
P0131 O2 Sensor Circuit Low Voltage (Bank 1* Sensor 1)
P0132 O2 Sensor Circuit High Voltage (Bank 1* Sensor 1)
P0133 O2 Sensor Circuit Slow Response (Bank 1* Sensor 1)
P0134 O2 Sensor Circuit No Activity Detected (Bank 1* Sensor 1)
P0135 O2 Sensor Heater Circuit Problem (Bank 1* Sensor 1)
P0136 O2 Sensor Circuit Problem (Bank 1* Sensor 2)
P0137 O2 Sensor Circuit Low Voltage (Bank 1* Sensor 2)
P0138 O2 Sensor Circuit High Voltage (Bank 1* Sensor 2)
P0139 O2 Sensor Circuit Slow Response (Bank 1* Sensor 2)
P0140 O2 Sensor Circuit No Activity Detected (Bank 1* Sensor 2)
P0141 O2 Sensor Heater Circuit Problem (Bank 1* Sensor 2)
P0142 O2 Sensor Circuit Problem (Bank 1* Sensor 3)
P0143 O2 Sensor Circuit Low Voltage (Bank 1* Sensor 3)
P0144 O2 Sensor Circuit High Voltage (Bank 1* Sensor 3)
P0145 O2 Sensor Circuit Slow Response (Bank 1* Sensor 3)
P0146 O2 Sensor Circuit No Activity Detected (Bank 1* Sensor 3)
P0147 O2 Sensor Heater Circuit Problem (Bank 1* Sensor 3)
P0150 O2 Sensor Circuit Problem (Bank 2 Sensor 1)
P0151 O2 Sensor Circuit Low Voltage (Bank 2 Sensor 1)
P0152 O2 Sensor Circuit High Voltage (Bank 2 Sensor 1)
P0153 O2 Sensor Circuit Slow Response (Bank 2 Sensor 1)
P0154 O2 Sensor Circuit No Activity Detected (Bank 2 Sensor 1)
P0155 O2 Sensor Heater Circuit Problem (Bank 2 Sensor 1)
P0156 O2 Sensor Circuit Problem (Bank 2 Sensor 2)
P0157 O2 Sensor Circuit Low Voltage (Bank 2 Sensor 2)
P0158 O2 Sensor Circuit High Voltage (Bank 2 Sensor 2)
P0159 O2 Sensor Circuit Slow Response (Bank 2 Sensor 2)
P0160 O2 Sensor Circuit No Activity Detected (Bank 2 Sensor 2)
P0161 O2 Sensor Heater Circuit Problem (Bank 2 Sensor 2)
P0162 O2 Sensor Circuit Problem (Bank 2 Sensor 3)
P0163 O2 Sensor Circuit Low Voltage (Bank 2 Sensor 3)
P0164 O2 Sensor Circuit High Voltage (Bank 2 Sensor 3)

(*continued*)

P0165 O2 Sensor Circuit Slow Response (Bank 2 Sensor 3)
P0166 O2 Sensor Circuit No Activity Detected (Bank 2 Sensor 3)
P0167 O2 Sensor Heater Circuit Problem (Bank 2 Sensor 3)
P0170 Fuel Trim Problem (Bank 1*)
P0171 System Too Lean (Bank 1*)
P0172 System Too Rich (Bank 1*)
P0173 Fuel Trim Problem (Bank 2)
P0174 System Too Lean (Bank 2)
P0175 System Too Rich (Bank 2)
P0176 Fuel Composition Sensor Circuit Problem
P0177 Fuel Composition Sensor Circuit Range or Performance
P0178 Fuel Composition Sensor Circuit Low Input
P0179 Fuel Composition Sensor Circuit High Input
P0180 Fuel Temperature Sensor Problem
P0181 Fuel Temperature Sensor Circuit Range or Performance
P0182 Fuel Temperature Sensor Circuit Low Input
P0183 Fuel Temperature Sensor Circuit High Input

Fuel and Air Metering (Injector Circuit)

P0201 Injector Circuit Problem—Cylinder 1
P0202 Injector Circuit Problem—Cylinder 2
P0203 Injector Circuit Problem—Cylinder 3
P0204 Injector Circuit Problem—Cylinder 4
P0205 Injector Circuit Problem—Cylinder 5
P0206 Injector Circuit Problem—Cylinder 6
P0207 Injector Circuit Problem—Cylinder 7
P0208 Injector Circuit Problem—Cylinder 8
P0209 Injector Circuit Problem—Cylinder 9
P0210 Injector Circuit Problem—Cylinder 10
P0211 Injector Circuit Problem—Cylinder 11
P0212 Injector Circuit Problem—Cylinder 12
P0213 Cold Start Injector 1 Problem
P0214 Cold Start Injector 2 Problem

Ignition System or Misfire

P0300 Random Misfire Detected
P0301 Cylinder 1 Misfire Detected
P0302 Cylinder 2 Misfire Detected
P0303 Cylinder 3 Misfire Detected
P0304 Cylinder 4 Misfire Detected
P0305 Cylinder 5 Misfire Detected
P0306 Cylinder 6 Misfire Detected
P0307 Cylinder 7 Misfire Detected
P0308 Cylinder 8 Misfire Detected
P0309 Cylinder 9 Misfire Detected
P0310 Cylinder 10 Misfire Detected
P0311 Cylinder 11 Misfire Detected
P0312 Cylinder 12 Misfire Detected
P0320 Ignition or Distributor Engine Speed Input Circuit Problem
P0321 Ignition or Distributor Engine Speed Input Circuit Range or Performance
P0322 Ignition or Distributor Engine Speed Input Circuit No Signal
P0325 Knock Sensor 1 Circuit Problem
P0326 Knock Sensor 1 Circuit Range or Performance
P0327 Knock Sensor 1 Circuit Low Input
P0328 Knock Sensor 1 Circuit High Input
P0330 Knock Sensor 2 Circuit Problem
P0331 Knock Sensor 2 Circuit Range or Performance
P0332 Knock Sensor 2 Circuit Low Input
P0333 Knock Sensor 2 Circuit High Input
P0335 Crankshaft Position Sensor Circuit Problem
P0336 Crankshaft Position Sensor Circuit Range or Performance
P0337 Crankshaft Position Sensor Circuit Low Input
P0338 Crankshaft Position Sensor Circuit High Input

Auxiliary Emission Controls

P0400 Exhaust Gas Recirculation Flow Problem
P0401 Exhaust Gas Recirculation Flow Insufficient Detected
P0402 Exhaust Gas Recirculation Flow Excessive Detected
P0405 Air Conditioner Refrigerant Charge Loss
P0410 Secondary Air Injection System Problem
P0411 Secondary Air Injection System Insufficient Flow Detected
P0412 Secondary Air Injection System Switching Valve or Circuit Problem
P0413 Secondary Air Injection System Switching Valve or Circuit Open
P0414 Secondary Air Injection System Switching Valve or Circuit Shorted
P0420 Catalyst System Efficiency below Threshold (Bank 1*)
P0421 Warm Up Catalyst Efficiency below Threshold (Bank 1*)
P0422 Main Catalyst Efficiency below Threshold (Bank 1*)
P0423 Heated Catalyst Efficiency below Threshold (Bank 1*)
P0424 Heated Catalyst Temperature below Threshold (Bank 1*)
P0430 Catalyst System Efficiency below Threshold (Bank 2)
P0431 Warm Up Catalyst Efficiency below Threshold (Bank 2)
P0432 Main Catalyst Efficiency below Threshold (Bank 2)
P0433 Heated Catalyst Efficiency below Threshold (Bank 2)
P0434 Heated Catalyst Temperature below Threshold (Bank 2)
P0440 Evaporative Emission Control System Problem
P0441 Evaporative Emission Control System Insufficient Purge Flow
P0442 Evaporative Emission Control System Leak Detected
P0443 Evaporative Emission Control System Purge Control Valve Circuit Problem
P0444 Evaporative Emission Control System Purge Control Valve Circuit Open
P0445 Evaporative Emission Control System Purge Control Valve Circuit Shorted
P0446 Evaporative Emission Control System Vent Control Problem
P0447 Evaporative Emission Control System Vent Control Open
P0448 Evaporative Emission Control System Vent Control Shorted
P0450 Evaporative Emission Control System Pressure Sensor Problem

P0451 Evaporative Emission Control System Pressure Sensor Range or Performance
P0452 Evaporative Emission Control System Pressure Sensor Low Input
P0453 Evaporative Emission Control System Pressure Sensor High Input

Vehicle Speed Control and Idle Control

P0500 Vehicle Speed Sensor Problem
P0501 Vehicle Speed Sensor Range or Performance
P0502 Vehicle Speed Sensor Low Input
P0505 Idle Control System Problem
P0506 Idle Control System RPM Lower Than Expected
P0507 Idle Control System RPM Higher Than Expected
P0510 Closed Throttle Position Switch Problem

Computer Output Circuit

P0600 Serial Communication Link Problem
P0605 Internal Control Module (Module Identification Defined by J1979)

Transmission

P0703 Brake Switch Input Problem
P0705 Transmission Range Sensor Circuit Problem (PRNDL Input)
P0706 Transmission Range Sensor Circuit Range or Performance
P0707 Transmission Range Sensor Circuit Low Input
P0708 Transmission Range Sensor Circuit High Input
P0710 Transmission Fluid Temperature Sensor Problem
P0711 Transmission Fluid Temperature Sensor Range or Performance
P0712 Transmission Fluid Temperature Sensor Low Input
P0713 Transmission Fluid Temperature Sensor High Input
P0715 Input or Turbine Speed Sensor Circuit Problem
P0716 Input or Turbine Speed Sensor Circuit Range or Performance
P0717 Input or Turbine Speed Sensor Circuit No Signal
P0720 Output Speed Sensor Circuit Problem
P0721 Output Speed Sensor Circuit Range or Performance
P0722 Output Speed Sensor Circuit No Signal
P0725 Engine Speed Input Circuit Problem
P0726 Engine Speed Input Circuit Range or Performance
P0727 Engine Speed Input Circuit No Signal
P0730 Incorrect Gear Ratio
P0731 Gear 1 Incorrect Ratio
P0732 Gear 2 Incorrect Ratio
P0733 Gear 3 Incorrect Ratio
P0734 Gear 4 Incorrect Ratio
P0735 Gear 5 Incorrect Ratio
P0736 Reverse Incorrect Ratio
P0740 Torque Converter Clutch System Problem
P0741 Torque Converter Clutch System Performance or Stuck Off
P0742 Torque Converter Clutch System Stuck On
P0743 Torque Converter Clutch System Electrical
P0745 Pressure Control Solenoid Problem
P0746 Pressure Control Solenoid Performance or Stuck Off
P0747 Pressure Control Solenoid Stuck On
P0748 Pressure Control Solenoid Electrical
P0750 Shift Solenoid A Problem
P0751 Shift Solenoid A Performance or Stuck Off
P0752 Shift Solenoid A Stuck On
P0753 Shift Solenoid A Electrical
P0755 Shift Solenoid B Problem
P0756 Shift Solenoid B Performance or Stuck Off
P0757 Shift Solenoid B Stuck On
P0758 Shift Solenoid B Electrical
P0760 Shift Solenoid C Problem
P0761 Shift Solenoid C Performance or Stuck Off
P0762 Shift Solenoid C Stuck On
P0763 Shift Solenoid C Electrical
P0765 Shift Solenoid D Problem
P0766 Shift Solenoid D Performance or Stuck Off
P0767 Shift Solenoid D Stuck On
P0768 Shift Solenoid D Electrical
P0770 Shift Solenoid E Problem
P0771 Shift Solenoid E Performance or Stuck Off
P0772 Shift Solenoid E Stuck On
P0773 Shift Solenoid E Electrical

* The side of the engine where number one cylinder is located.

OBD-II ACTIVE TESTS

The vehicle computer must run tests on the various emission-related components and turn on the malfunction indicator lamp (MIL) if faults are detected. OBD II is an *active* computer analysis system because it actually tests the operation of the oxygen sensors, exhaust gas recirculation system, and so forth whenever conditions permit. It is the purpose and function of the powertrain control module (PCM) to monitor these components and perform these active tests.

For example, the PCM may open the EGR valve momentarily to check its operation while the vehicle is decelerating. A change in the manifold absolute pressure (MAP) sensor signal will indicate to the computer that the exhaust gas is, in fact, being introduced into the engine. Because these tests are active and certain conditions must be present before these tests can be run, the computer uses its internal diagnostic program to keep track of all the various conditions and to schedule active tests so that they will not interfere with each other.

OBD-II DRIVE CYCLE The vehicle must be driven under a variety of operating conditions for all active tests to be performed. A **trip** is defined as an engine-operating drive cycle that contains the necessary conditions for a particular test to be performed. For example, for the EGR test to be performed, the engine has to be at normal operating temperature and decelerating for a minimum amount of time. Some tests are performed when the engine is cold, whereas others require that the vehicle be cruising at a steady highway speed.

TYPES OF OBD-II CODES

Not all OBD-II diagnostic trouble codes are of the same importance for exhaust emissions. Each type of DTC has different requirements for it to set, and the computer will only turn on the MIL for emissions-related DTCs.

TYPE A CODES. A type A diagnostic trouble code is emission related and will cause the MIL to be turned on at the *first trip* if the computer has detected a problem. Engine misfire or a very rich or lean air–fuel ratio, for example, would cause a type A diagnostic trouble code. These codes alert the driver to an emissions problem that may cause damage to the catalytic converter.

TYPE B CODES. A type B code will be stored as a pending code in the PCM and the MIL will be turned on only after the second consecutive trip, alerting the driver to the fact that a diagnostic test was performed and failed.

NOTE: Type A and Type B codes are emission related and will cause the lighting of the malfunction indicator lamp, usually labeled "check engine" or "service engine soon."

TYPE C AND D CODES. Type C and type D codes are for use with non-emission-related diagnostic tests. They will cause the lighting of a "service" lamp (if the vehicle is so equipped).

OBD-II FREEZE-FRAME

To assist the service technician, OBD II requires the computer to take a "snapshot" or freeze-frame of all data at the instant an emission-related DTC is set. A scan tool is required to retrieve this data. CARB and EPA regulations require that the controller store specific freeze-frame (engine-related) data when the first emission related fault is detected. The data stored in freeze-frame can only be replaced by data from a trouble code with a higher priority such as a trouble related to a fuel system or misfire monitor fault.

NOTE: Although OBD II requires that just one freeze-frame of data be stored, the instant an emission-related DTC is set, vehicle manufacturers usually provide expanded data about the DTC beyond that required. However, retrieving enhanced data usually requires the use of an enhanced or factory level scan tool.

The freeze-frame has to contain data values that occurred at the time the code was set (these values are provided in standard units of measurement). Freeze-frame data is recorded during the first trip on a two-trip fault. As a result, OBD-II systems record the data present at the time an emission-related code is recorded and the MIL activated. This data can be accessed and displayed on a scan tool. Freeze-frame data is one frame or one instant in time. Freeze-frame data is not updated (refreshed) if the same monitor test fails a second time.

REQUIRED FREEZE-FRAME DATA ITEMS.

- Code that triggered the freeze-frame
- A/F ratio, airflow rate, and calculated engine load
- Base fuel injector pulse width
- ECT, IAT, MAF, MAP, TP, and VS sensor data
- Engine speed and amount of ignition spark advance
- Open- or closed-loop status
- Short-term and long-term fuel trim values
- For misfire codes—identify the cylinder that misfired

NOTE: All freeze-frame data will be lost if the battery is disconnected, power to the PCM is removed, or the scan tool is used to erase or clear trouble codes.

DIAGNOSING INTERMITTENT MALFUNCTIONS

Of all the different types of conditions that you will see, the hardest to accurately diagnose and repair are intermittent malfunctions. These conditions may be temperature related (only occur when the vehicle is hot or cold), or humidity related (only occur when it is raining). Regardless of the conditions that will cause the malfunction to occur, you must diagnose and correct the condition.

When dealing with an intermittent concern, you should determine the conditions when the malfunction occurs, and then try to duplicate those conditions. If a cause is not readily apparent to you, ask the customer when the symptom occurs. Ask if there are any conditions that seem to be related to, or cause the concern.

Another consideration when working on an OBD-II-equipped vehicle is whether a concern is intermittent, or if it only occurs when a specific diagnostic test is performed by the PCM. Since OBD-II systems conduct diagnostic tests only under very precise conditions, some tests may only be run once during an ignition cycle. Additionally, if the requirements needed to perform the test are not met, the test will not run during an ignition cycle. This type of onboard diagnostics could be mistaken as "intermittent" when, in fact, the tests are only infrequent (depending on how the vehicle is driven). Examples of this type of diagnostic test are HO_2S heaters, evaporative canister purge, catalyst efficiency, and EGR flow. When diagnosing intermittent concerns on an OBD-II-equipped vehicle, a logical diagnostic strategy is essential. The use of stored freeze-frame information can also be very useful when diagnosing an intermittent malfunction if a code has been stored.

SERVICE/FLASH PROGRAMMING

Designing a program that allows an engine to meet strict air quality and fuel economy standards while providing excellent performance is no small feat. However, this is only part of the challenge facing engineers assigned with the task of developing OBD-II software. The reason for this is the countless variables involved with running the diagnostic monitors. Although programmers do their best to factor in any and all operating conditions when writing this complex code, periodic revisions are often required.

Reprogramming consists of downloading new calibration files from a scan tool, personal computer, or modem into the PCM's electronically erasable programmable read-only memory (EEPROM). This can be done on or off the vehicle using the appropriate equipment. Since reprogramming is not an OBD-II requirement however, many vehicles will need a new PCM in the event software changes become necessary. Physically removing and replacing the PROM chip is no longer possible.

The following are three industry-standard methods used to reprogram the EEPROM:

- Remote programming
- Direct programming
- Off-board programming

REMOTE PROGRAMMING. Remote programming uses the scan tool to transfer data from the manufacturer's shop PC to the vehicle's PCM. This is accomplished by performing the following steps:

- Connect the scan tool to the vehicle's DLC. ● **SEE FIGURE 88–17.**



FIGURE 88–17 The first step in the reprogramming procedure is to determine the current software installed using a scan tool. Not all scan tools can be used. In most cases using the factory scan tool is needed for reprogramming unless the scan tool is equipped to handle reprogramming.

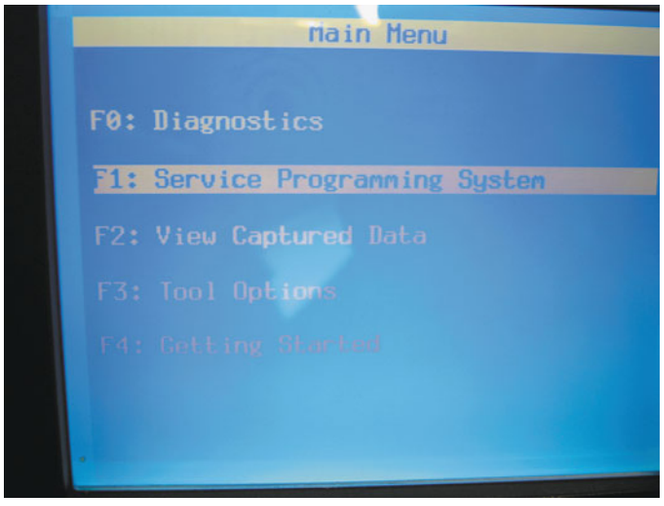


FIGURE 88–18 Follow the on-screen instructions.

- Enter the vehicle information into the scan tool through the programming application software incorporated in the scan tool. ● **SEE FIGURE 88–18.**
- Download VIN and current EEPROM calibration using a scan tool.
- Disconnect the scan tool from the DLC and connect the tool to the shop PC.
- Download the new calibration from the PC to the scan tool. ● **SEE FIGURE 88–19.**
- Reconnect the scan tool to the vehicle's DLC and download the new calibration into the PCM.

CAUTION: Before programming, the vehicle's battery must be between 11 and 14 volts. Do not attempt to program while charging the battery unless using a special battery charger which does not produce excessive ripple voltage such as the Midtronics PSC-300 (30 amp) or PSC-550 (55 amp) or similar as specified by the vehicle manufacturer.

DIRECT PROGRAMMING. Direct programming does utilize a connection between the shop PC and the vehicle DLC.

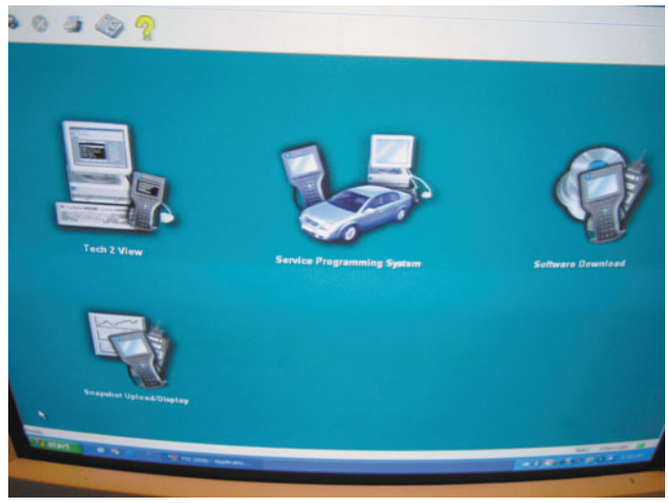


FIGURE 88–19 An Internet connection is usually needed to perform updates although some vehicle manufacturers use CDs which are updated regularly at a cost to the shop.



FIGURE 88–20 Connecting cables and a computer to perform off-board programming.

OFF-BOARD PROGRAMMING. Off-board programming is used if the PCM must be programmed away from the vehicle. This is performed using the off-board programming adapter. ● **SEE FIGURE 88–20.**

J2534 REPROGRAMMING

Legislation has mandated that vehicle manufacturers meet the SAE J2534 standards for all emissions-related systems on all new vehicles starting with model year 2004. This standard enables independent service repair operators to program or reprogram emissions-related ECMs from a wide variety of vehicle manufacturers with a single tool. ● **SEE FIGURE 88–21.** A J2534 compliant pass-through system is a standardized programming and diagnostic system. It uses a personal computer (PC) plus a standard interface to a software device driver, and a hardware vehicle communication interface. The interface connects to a PC, and to a programmable ECM on a vehicle through the J1962 data link connector (DLC). This system allows programming of all vehicle manufacturer ECMs using a single set of programming hardware. Programming software made available by the vehicle manufacturer must be functional with a J2534 compliant pass-through system.

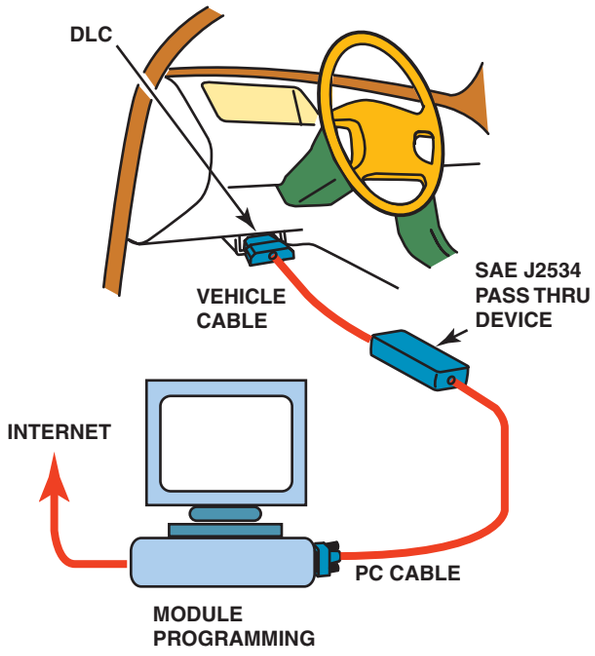


FIGURE 88–21 The J2534 pass-through reprogramming system does not need a scan tool to reflash the PCM on most 2004 and newer vehicles.

The software for a typical pass-through application consists of two major components including:

- The part delivered by the company that furnishes the hardware for J2534 enables the pass-through vehicle communication interface to communicate with the PC and provides for all Vehicle Communication Protocols as required by SAE J2534. It also provides for the software interface to work with the software applications as provided for by the vehicle manufacturers. ● **SEE FIGURE 88–22.**
- The second part of the pass-through enabling software is provided for by the vehicle manufacturers. This is normally a subset of the software used with their original equipment manufacturer (OEM) tools and their website will indicate how to obtain this software and under what conditions it can be used. Refer to the National Automotive Service Task Force (NASTF) website for the addresses for all vehicle manufacturers' service information and cost, *www.NASTF.org*.

Since the majority of vehicle manufacturers make this software available in downloadable form, having an Internet browser (Explorer/Netscape) and connection is a must.

MANUFACTURER'S DIAGNOSTIC ROUTINES

Each vehicle manufacturer has established their own diagnostic routines and they should be followed. Most include the following steps:

STEP 1 Retrieve diagnostic trouble codes.

STEP 2 Check for all technical service bulletins that could be related to the stored DTC.

STEP 3 If there are multiple DTCs, the diagnostic routine may include checking different components or systems instead of when only one DTC was stored.



FIGURE 88–22 A typical J2534 universal reprogrammer that uses the J2534 standards.

TECH TIP

The Brake Pedal Trick

If the vehicle manufacturer recommends that battery power be disconnected, first disconnect the negative battery cable and then depress the brake pedal. Because the brake lights are connected to battery power, depressing the brake pedal causes all of the capacitors in the electrical system and computer(s) to discharge through the brake lights.

STEP 4 Perform system checks.

STEP 5 Perform the necessary service or repair.

STEP 6 Perform a road test matching the parameters recorded in the freeze-frame to check that the repair has corrected the malfunction.

STEP 7 Repeat the road test to cause the MIL to be extinguished.

NOTE: Do not clear codes (DTCs) unless instructed by the service information.

Following the vehicle manufacturer's specific diagnostic routines will ensure that the root cause is found and the repair verified. This is important for customer satisfaction.

COMPLETING SYSTEM REPAIRS

After the repair has been successfully completed, the vehicle should be driven under similar conditions that caused the original concern. Verify that the problem has been corrected. To perform this test drive, it is helpful to have a copy of the freeze-frame parameters that were present when the DTC was set. By driving under similar conditions, the PCM may perform a test of the system and automatically extinguish the MIL. This is the method preferred by most vehicle manufacturers. The DTC can be cleared using a scan tool, but then that means that monitors will have to be run and the vehicle may fail an emission inspection if driven directly to the testing station.

PROCEDURES FOR RESETTING THE PCM

The PCM can be reset or cleared of previously set DTCs and freeze-frame data in the following ways:

1. **Driving the Vehicle.** Drive the vehicle under similar conditions that were present when the fault occurred. If the conditions are similar and the PCM performed the noncontinuous monitor test and it passed three times, then the PCM will extinguish the MIL. This is the method preferred by most vehicle manufacturers, however, this method could be time consuming. If three passes cannot be achieved, the owner of the vehicle will have to be told that even though the check engine light (MIL) is on, the problem has been corrected and the MIL should go out in a few days of normal driving.
2. **Clear DTCs Using a Scan Tool.** A scan tool can be used to clear the diagnostic trouble code (DTC), which will also delete all of the freeze-frame data. The advantage of using a scan tool is that the check engine (MIL) will be out and the customer will be happy that the problem (MIL on) has been corrected. Do not use a scan tool to clear a DTC if the vehicle is going to be checked soon at a test station for state-mandated emission tests.
3. **Battery Disconnect.** Disconnecting the negative battery cable will clear the DTCs and freeze-frame on many vehicles but not all. Besides clearing the DTCs, disconnecting the battery for about 20 minutes will also erase radio station presets and other memory items in many cases. Most vehicle manufacturers do not recommend that the battery be disconnected to clear DTCs and it may not work on some vehicles.

TECH TIP

Drive the Light Out

If working on a vehicle that is subject to state emission testing, it is best to not clear codes. When diagnostic trouble codes are cleared, all of the monitors have to be rerun and this can be a time consuming job. Instead of clearing the code, simply drive the vehicle until the PCM clears the code. This will likely take less time compared to trying to drive the vehicle under varying conditions to run all of the monitors.

ROAD TEST (DRIVE CYCLE)

Use the freeze-frame data and test-drive the vehicle so that the vehicle is driven to match the conditions displayed on the freeze-frame. If the battery has been disconnected, then the vehicle may have to be driven under conditions that allow the PCM to conduct monitor tests. This drive pattern is called a **drive cycle.** The drive cycle is different for each vehicle manufacturer but a universal drive cycle may work in many cases. In many cases performing a universal drive cycle will reset most monitors in most vehicles.

UNIVERSAL DRIVE CYCLE

PRECONDITIONING: Phase 1.

MIL must be off.

No DTCs present.

Fuel fill between 15% and 85%.

Cold start—Preferred = 8-hour soak at 68°F to 86°F.

Alternative = ECT below 86°F.

1. With the ignition off, connect scan tool.
2. Start engine and drive between 20 and 30 mph for 22 minutes, allowing speed to vary.
3. Stop and idle for 40 seconds, gradually accelerate to 55 mph.
4. Maintain 55 mph for 4 minutes using a steady throttle input.
5. Stop and idle for 30 seconds, then accelerate to 30 mph.
6. Maintain 30 mph for 12 minutes.
7. Repeat steps 4 and 5 four times.

Using scan tool, check readiness. If insufficient readiness set, continue to universal drive trace phase II.

Important: (Do not shut off engine between phases). Phase II:

1. Vehicle at a stop and idle for 45 seconds, then accelerate to 30 mph.
2. Maintain 30 mph for 22 minutes.
3. Repeat steps 1 and 2 three times.
4. Bring vehicle to a stop and idle for 45 seconds, then accelerate to 35 mph.
5. Maintain speed between 30 and 35 mph for 4 minutes.
6. Bring vehicle to a stop and idle for 45 seconds, then accelerate to 30 mph.
7. Maintain 30 mph for 22 minutes.
8. Repeat steps 6 and 7 five times.
9. Using scan tool, check readiness.

REVIEW QUESTIONS

1. Explain the procedure to follow when diagnosing a vehicle with stored DTCs using a scan tool.
2. Discuss what the PCM does during a drive cycle to test emission-related components.
3. Explain the difference between a type A and type B OBD-II diagnostic trouble code.
4. List three things that should be checked as part of a thorough visual inspection.
5. List the eight-step funnel diagnostic procedure.
6. Explain why a bulletin search should be performed after stored DTCs are retrieved.
7. List the three methods that can be used to reprogram a PCM.

CHAPTER QUIZ

1. Technician A says that the first step in the diagnostic process is to verify the problem (concern). Technician B says the second step is to perform a thorough visual inspection. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

2. Which item is *not* important to know before starting the diagnosis of an engine performance problem?
   a. List of previous repairs
   b. The brand of engine oil used
   c. The type of gasoline used
   d. The temperature of the engine when the problem occurs

3. A paper test can be used to check for a possible problem with _____.
   a. The ignition system (bad spark plug wire)
   b. A faulty injector on a multiport engine
   c. A burned valve
   d. All of the above

4. Which step should be performed *last* when diagnosing an engine performance problem?
   a. Checking for any stored diagnostic trouble codes
   b. Checking for any technical service bulletins (TSBs)
   c. Performing a thorough visual inspection
   d. Verify the repair

5. Technician A says that if the opposite DTC can be set, the problem is the component itself. Technician B says if the opposite DTC cannot be set, the problem is with the wiring or grounds. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

6. The preferred method to clear diagnostic trouble codes (DTCs) is to _____.
   a. Disconnect the negative battery cable for 10 seconds
   b. Use a scan tool
   c. Remove the computer (PCM) power feed fuse
   d. Cycle the ignition key on and off 40 times

7. Which is the factory scan tool for Chrysler brand vehicles equipped with CAN?
   a. Star Scan
   b. Tech 2
   c. NGS
   d. Master Tech

8. Technician A says that reprogramming a PCM using the J2534 system requires a factory scan tool. Technician B says that reprogramming a PCM using the J2534 system requires Internet access. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

9. Technician A says that knowing if there are any stored diagnostic trouble codes (DTCs) may be helpful when checking for related technical service bulletins (TSBs). Technician B says that only a factory scan tool should be used to retrieve DTCs. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

10. Which method can be used to reprogram a PCM?
    a. Remote
    b. Direct
    c. Off-board
    d. All of the above

SECTION X

Hybrid and Fuel Cell Vehicles

89 Introduction to Hybrid Vehicles
90 Hybrid Safety and Service Procedures
91 Fuel Cells and Advanced Technologies

chapter 89

INTRODUCTION TO HYBRID VEHICLES

OBJECTIVES: After studying Chapter 89, the reader will be able to: • Describe the different types of hybrid electric vehicles. • Explain how a hybrid vehicle is able to achieve an improvement in fuel economy compared to a conventional vehicle design. • Discuss the advantages and disadvantages of the various hybrid designs. • Describe HEV components, including motors, energy sources, and motor controllers. • Discuss the operation of a typical hybrid electric vehicle.

KEY TERMS: Assist hybrid 990 • BAS 987 • BEV 983 • EV 983 • Full hybrid 990 • HEV 983 • HOV lane 989 • Hybrid 989 • ICE 983 • Idle stop mode 989 • Medium hybrid 989 • Micro-hybrid drive 989 • Mild hybrid 989 • Motoring mode 987 • Parallel-hybrid design 986 • Power-assist mode 989 • Quiet mode 990 • Series-hybrid 985 • Series-parallel hybrid 987 • Strong hybrid 990 • ZEV 984

HYBRID VEHICLE

DEFINITION OF TERMS

A hybrid vehicle is one that uses two different methods to propel the vehicle. A hybrid electric vehicle, abbreviated **HEV** uses both an internal combustion engine and an electric motor to propel the vehicle. Most hybrid vehicles use a high-voltage battery pack and a combination electric motor and generator to help or assist a gasoline engine. The **internal combustion engine (ICE)** used in a hybrid vehicle can be either gasoline or diesel, although only gasoline-powered engines are currently used in hybrid vehicles. An electric motor is used to help propel the vehicle, and in some designs, is capable of propelling the vehicle alone without having to start the internal combustion engine.

BACKGROUND

In the early years of vehicle development, many different types of propulsion systems were used, including:

- steam engine powered
- gasoline engine powered
- electric motor powered

Early electric vehicles (**EVs**) were also called **battery electric vehicles (BEV).** These early electric vehicles used lead–acid batteries, an electric traction motor, and a mechanical controller. A traction motor is an electric motor used to rotate the drive wheels and propel vehicle. The vehicle moves as a result of the traction between the wheel and the road surface to transmit the torque needed to move the vehicle.

ELECTRIC VEHICLES

EARLY ELECTRIC VEHICLES

The controller was operated by the driver and allowed different voltages to be applied to the electric motor, depending on the needs of the driver. For an example, assume that an early electric vehicle used six 6-volt batteries. If the batteries are connected in series, the negative terminal of one battery is connected to the positive terminal of the second battery. Two 6-volt batteries connected in series result in 12 volts, but the same current as one of the batteries. If two 6-volt 500-amp hour batteries were connected in series, then the output would be 12 volts and 500-amp hours. If the batteries were connected in parallel, the current of each battery is increased, but the voltage remains the

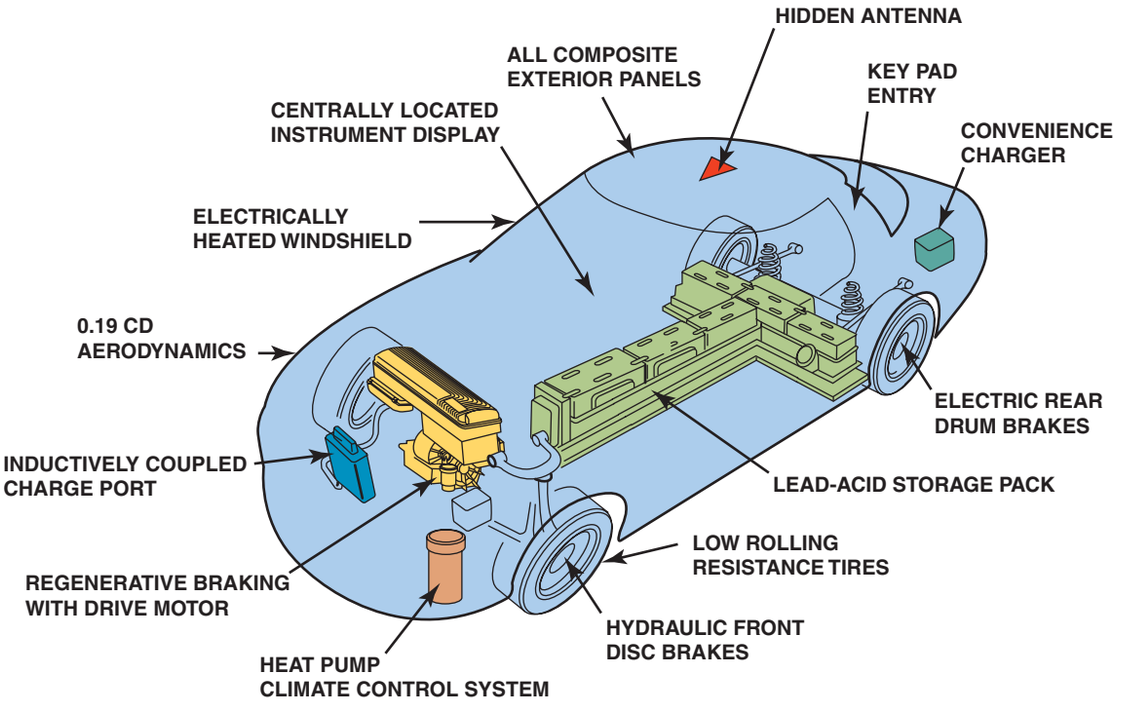


FIGURE 89–1 View of the components of the General Motors electric vehicle (EV1). Many of the features of this vehicle, such as regenerative braking, currently used on hybrid vehicles were first put into production on this vehicle.

same. If two 6-volt 500-amp hour batteries were connected in parallel, then the voltage would be six volts, but the capacity would be 1,000 amp hours.

The old electric vehicle mechanical controller was able to switch all six batteries in various combinations of series and parallel configurations to achieve lower voltage for slow speeds and higher voltages for higher speeds.

Electric vehicles did not have a long range and needed to have the batteries charged regularly, which meant that electric vehicles could only be used for short distances. In fact electric vehicles were almost more popular than steam power in 1900 when steam had 40% of the sales and electric had 38% of the sales. The gasoline-powered cars represented only 22% of the vehicles sold.

NOTE: Due to the oil embargo of 1973 and increased demand for alternative energy sources, Congress enacted Public Law 94-413, the *Electric and Hybrid Vehicle Research, Development, and Demonstration Act of 1976,* which was designed to promote new technologies.

NEWER ELECTRIC VEHICLES

In the late 1990s, several vehicle manufacturers produced electric vehicles, using electronic controllers to meet the demands for zero emission vehicles as specified by law in California at the time. Electric vehicles were produced by Ford, Toyota, Nissan, and General Motors. Legislation was passed in California that included the following revisions within the **zero emissions vehicle (ZEV)** mandate.

As a direct result of the California zero-emission vehicle mandate originally calling for 10% ZEV, General Motors developed the Electric Vehicle 1, known as EV1, and it was leased to customers in California and Arizona. ● **SEE FIGURE 89–1.**

By 2010, there were several electric vehicles for sale although often in limited parts of the country and in limited numbers. Electric vehicles include the Tesla, Nissan Leaf, and Chevrolet VOLT as well as plug-in hybrid electric vehicles such as the Toyota Prius. ● **SEE FIGURE 89–2.**

DRIVING AND OWNING A HYBRID ELECTRIC VEHICLE

DRIVING A HYBRID VEHICLE

Driving a hybrid electric vehicle is the same as driving any other conventional vehicle. In fact, many drivers and passengers are often not aware they are driving or riding in a hybrid electric vehicle. Some unique characteristics that the driver may or may not notice include:

- After the internal combustion engine has achieved normal operating temperature and other conditions are met, the engine will stop when the vehicle slows down and stops. This condition may cause some concern to some drivers who may think that the engine has stalled and then may try to restart it.
- The brake pedal may feel different, especially at slow speeds of about 5 mph and 15 mph when slowing to a stop. It is at about these speeds that the brake system switches from regenerative braking to actually applying brake force to the mechanical brakes. A slight surge or pulsation may be felt at this time. This may or may not be felt and is often not a concern to drivers.
- The power steering works even when the engine stops because all hybrid electric vehicles use an electric power steering system.
- Some hybrid electric vehicles are able to propel the vehicle using the electric motor alone, resulting in quiet, almost eerie operation.
- If a hybrid electric vehicle is being driven aggressively and at a high rate of acceleration, there is often a feeling that the vehicle is not going to slow down when the accelerator pedal is first released. This is caused by two factors:
  1. The inertia of the rotor of the electric motor attached to the crankshaft of the ICE results in the engine continuing to rotate after the throttle has been closed.

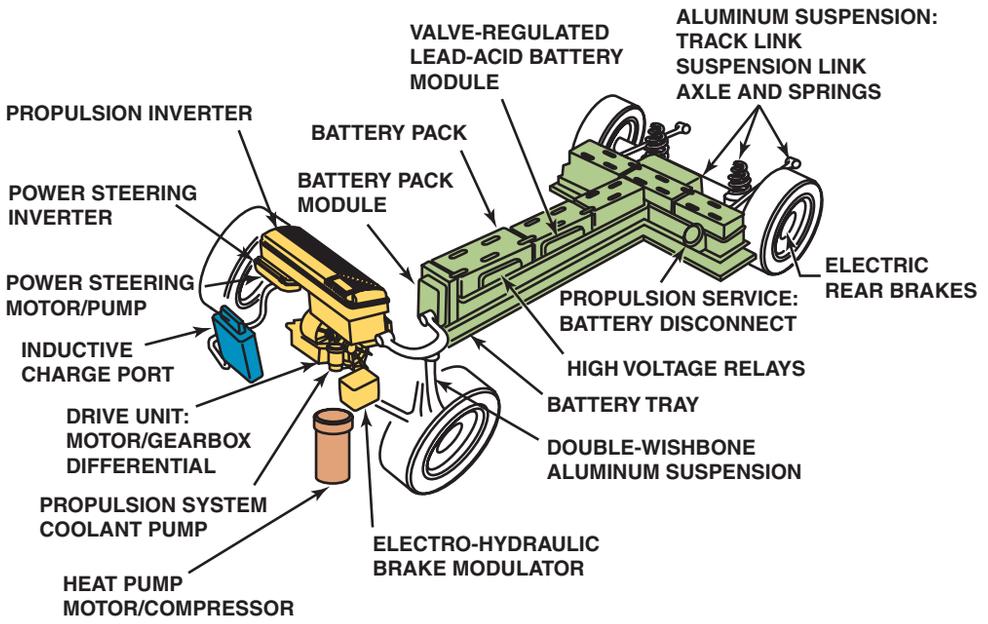


FIGURE 89–2 Using a standardized plug to recharge an electric vehicle or a plug-in hybrid electric vehicle such as this Toyota Prius takes many hours depending on the voltage of the charger.

2. The slight delay that occurs when the system switches the electric motor from powering the vehicle to generating (regenerative braking). While this delay would rarely be experienced, and is not at all dangerous, for a fraction of a second it gives a feeling that the accelerator pedal did not react to a closed throttle.

OWNING A HYBRID ELECTRIC VEHICLE

- The fuel economy will be higher compared to a similar-type vehicle, especially if driven in city-type driving conditions where engine stop and regenerative braking really add to the efficiency of a hybrid electric vehicle. However, the range of the hybrid version may be about the same as the conventional version of the same vehicle because the hybrid version usually has a smaller fuel tank capacity.
- A hybrid electric vehicle will cost and weigh more than a conventional vehicle. The increased cost is due to the batteries, electric motor(s), and controllers used plus the additional components needed to allow operation of the heating and air conditioning systems during idle stop periods. The cost is offset in part by returning improved fuel economy as well as government energy credits awarded at the time of purchase for some new-technology vehicles. It may take many years of operation before the extra cost is offset by cost savings from the improved fuel economy. However, many owners purchase a hybrid electric vehicle for other reasons besides fuel savings, including a feeling that they are helping the environment and love of the high technology involved.

CLASSIFICATIONS OF HYBRID ELECTRIC VEHICLES

SERIES HYBRID The types of hybrid electric vehicles include series, parallel, and series-parallel designs. In a **series-hybrid design,** sole propulsion is by a battery-powered electric motor, but the electric energy for the batteries comes from another on-board energy source, such as an internal combustion engine. In this design, the engine turns a generator and the generator can either charge the batteries or power an electric motor that drives the transmission. The internal combustion engine never powers the vehicle directly. **SEE FIGURES 89–3 AND 89–4.**

The engine is only operated to keep the batteries charged. Therefore, the vehicle could be moving with or without the internal combustion engine running. Series-hybrid vehicles also use regeneration braking to help keep the batteries charged. The Chevrolet VOLT is an example of a series-hybrid design.

The engine is designed to just keep the batteries charged, and therefore, is designed to operate at its most efficient speed and load. An advantage of a series-hybrid design is that no transmission, clutch, or torque converter is needed.

A disadvantage of a series-hybrid design is the added weight of the internal combustion engine to what is basically an electric

? FREQUENTLY ASKED QUESTION

How Fast Does the Motor-Generator Turn the Engine When Starting?

The typical starter motor used on a conventional gasoline or diesel engine rotates the engine from 100 to 300 revolutions per minute (RPM). Because the typical engine idles at about 600 to 700 RPM, the starter motor is rotating the engine at a speed slower than it operates. This makes it very noticeable when starting because the sound is different when cranking compared to when the engine actually starts and runs.

However, when the motor-generator of a hybrid electric vehicle rotates the engine to start it, the engine is rotated about 1,000 RPM, which is about the same speed as when it is running. As a result, engine cranking is just barely heard or felt. The engine is either running or not running, which is a truly unique sensation to those not familiar with the operation of hybrid electric vehicles (HEVs).

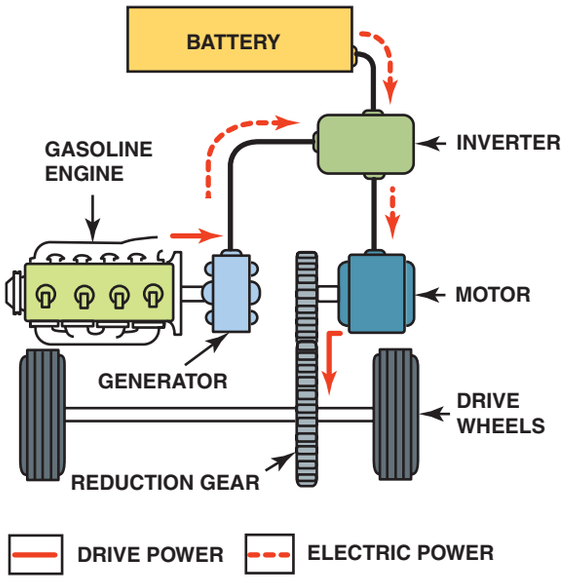


FIGURE 89–3 A drawing of the power flow in a typical series-hybrid vehicle.

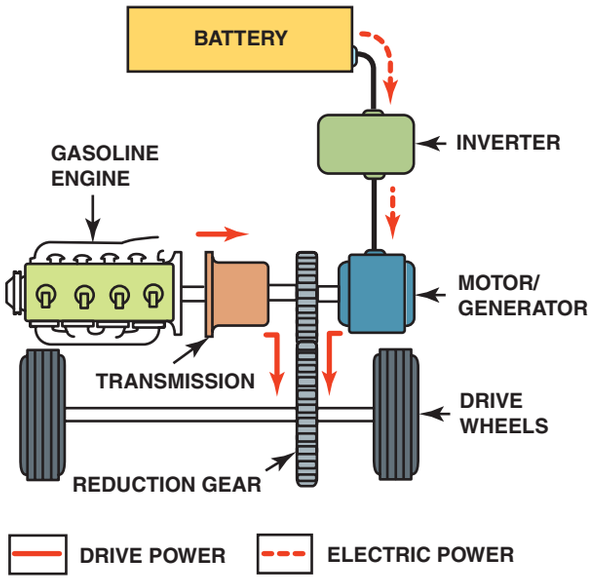


FIGURE 89–5 The power flow in a typical parallel-hybrid vehicle.

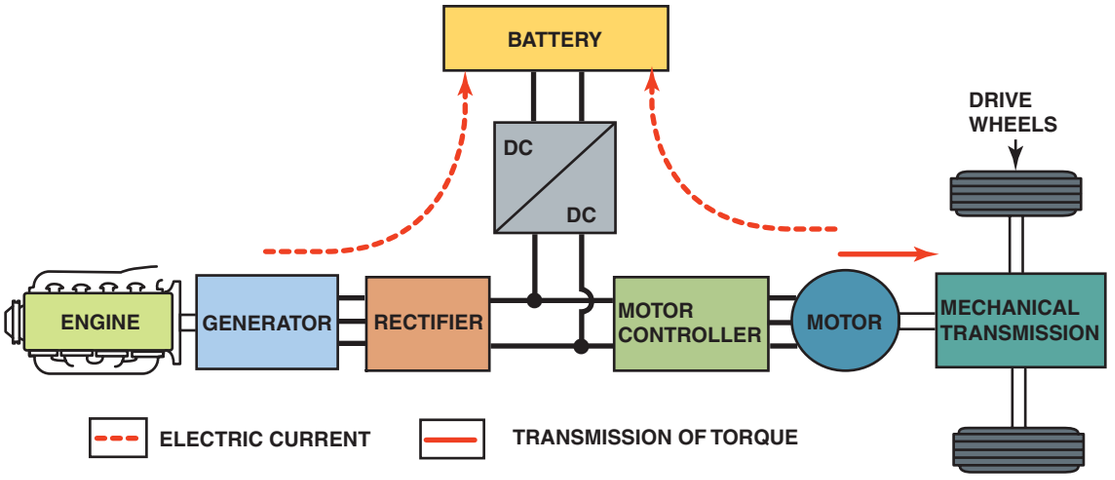


FIGURE 89–4 This diagram shows the components included in a typical series-hybrid design. The solid-line arrow indicates the transmission of torque to the drive wheels. The dotted-line arrows indicate the flow of electrical current.

vehicle. The engine is actually a heavy on-board battery charger. Also, the electric motor and battery capacity have to be large enough to power the vehicle under all operating conditions, including climbing hills.

All power needed for heating and cooling must also come from the batteries so using the air conditioning in hot weather and the heater in cold weather reduces the range that the vehicle can travel on battery power alone.

PARALLEL HYBRID

In a **parallel-hybrid design,** multiple propulsion sources can be combined, or one of the energy sources alone can drive the vehicle. In this design, the battery and engine are both connected to the transmission.

The vehicle using a parallel-hybrid design can be powered by the internal combustion engine alone, by the electric motor alone (full hybrids only), or by a combination of engine and electric motor propulsion. In most cases, the electric motor is used to assist the internal combustion engine. One of the advantages of using a parallel hybrid design is that by using an electric motor or motors to assist the internal combustion engine, the engine itself can be smaller than would normally be needed. ● **SEE FIGURES 89–5 AND 89–6.**

? FREQUENTLY ASKED QUESTION

Is a Diesel-Hybrid Electric Vehicle Possible?

Yes, using a diesel engine instead of a gasoline engine in a hybrid electric vehicle is possible. While the increased efficiency of a diesel engine would increase fuel economy, the extra cost of the diesel engine is the major reason this combination is not currently in production.

NOTE: A parallel-hybrid design could include additional batteries to allow for plug-in capability, which could extend the distance the vehicle can travel using battery power alone.

One disadvantage of a parallel-hybrid design is that complex software is needed to seamlessly blend electric and ICE power. Another concern about the parallel-hybrid design is that it had to be engineered to provide proper heating and air-conditioning system operation when the ICE stops at idle.

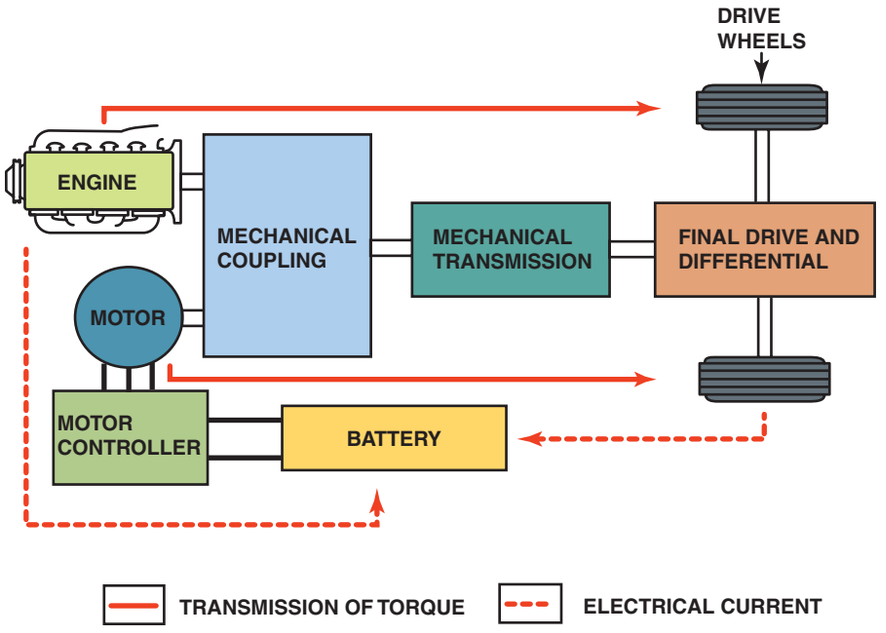


FIGURE 89–6 Diagram showing the components involved in a typical parallel-hybrid vehicle. The solid-line arrows indicate the transmission of torque to the drive wheels, and the dotted-line arrows indicate the flow of electrical current.

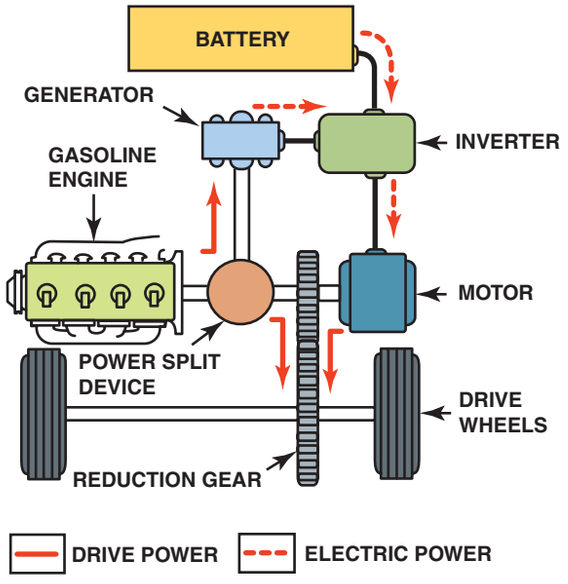


FIGURE 89–7 A series-parallel hybrid design allows the vehicle to operate in electric motor mode only or in combination with the internal combustion engine.

SERIES-PARALLEL HYBRID

The Toyota and Ford hybrids are classified as **series-parallel hybrids** because they can operate using electric motor power alone or with the assist of the ICE. Series-parallel hybrids combine the functions of both a series and a parallel design.

The internal combustion engine may be operating even though the vehicle is stopped if the electronic controller has detected that the batteries need to be charged. ● **SEE FIGURE 89–7.**

NOTE: The internal combustion engine may or may not start when the driver starts the vehicle depending on the temperature of the engine and other conditions. This can be confusing to some who are driving a hybrid electric vehicle for the first time and sense that the engine did not start when they tried to start the engine.

BELT ALTERNATOR STARTER SYSTEMS

PARTS AND OPERATION

The belt system, commonly called the **belt alternator starter (BAS),** is the least expensive system that can be used and still claim that the vehicle is a hybrid. For many buyers, cost is a major concern and the BAS system allows certain hybrid features without the cost associated with an entire redesign of the engine and powertrain. Consumers will be able to upgrade from conventional models to BAS hybrids at a reasonable cost and will get slightly better fuel economy.

The BAS concept is to replace the belt-driven alternator with an electric motor that serves as a generator and a motor. When the engine is running the motor, acting as a generator, it will charge a separate 36-volt battery (42-volt charging voltage). When the engine needs to be started again after the engine has been stopped at idle to save fuel (idle stop), the BAS motor is used to crank the engine by taking electrical power from the 36-volt battery pack and applies its torque via the accessory belt, and cranks the engine instead of using the starter motor.

NOTE: A BAS system uses a conventional starter motor for starting the ICE the first time, and only uses the high-voltage motor-generator to start the ICE when leaving idle stop mode.

The motor-generator is larger than a standard starter motor so more torque can be generated in the cranking mode, also referred to as the **motoring mode.** The fast rotation of the BAS allows for quicker starts of the engine, and makes the start/stop operation possible. Having the engine shut off when the vehicle is at a stop saves fuel. Of course, the stopping of the engine does create a sense that the engine has stalled, which is a common concern to drivers unfamiliar with the operation of hybrid vehicles.

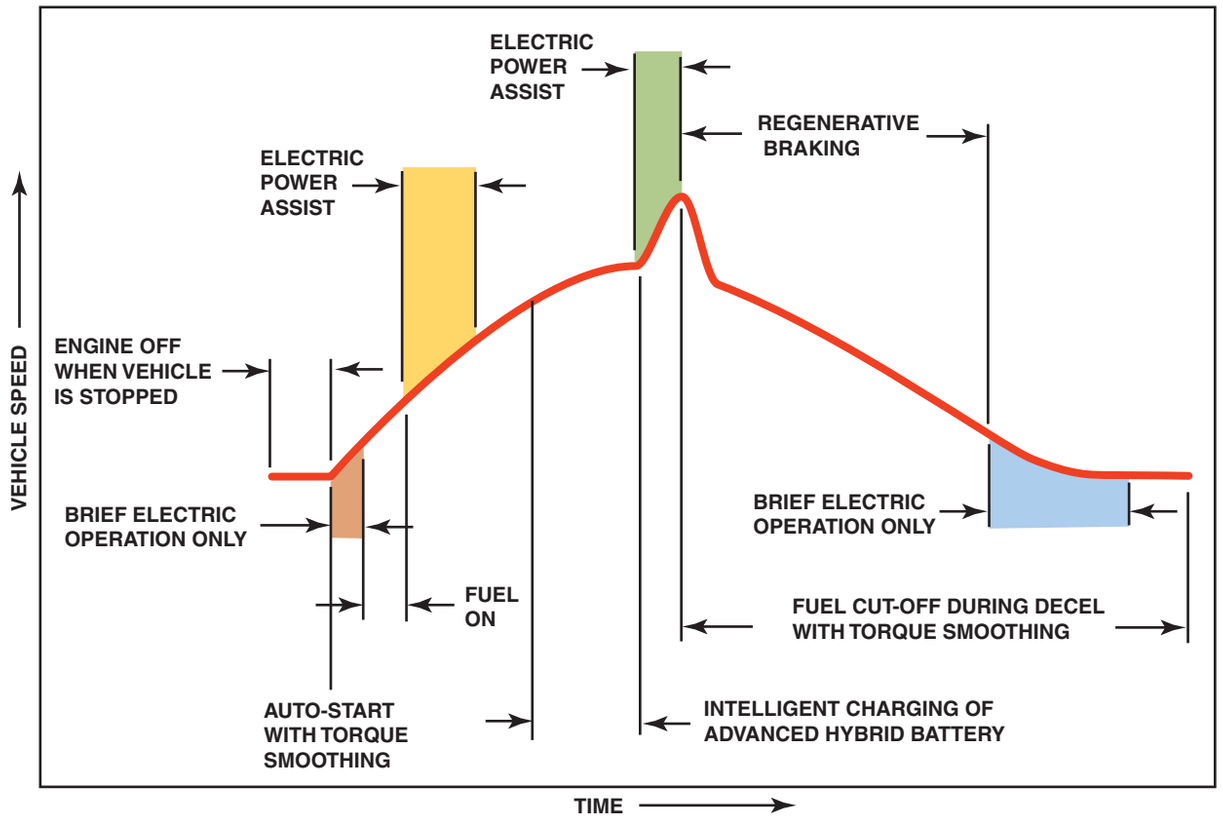


FIGURE 89–8 This chart shows what is occurring during various driving conditions in a BAS-type hybrid.

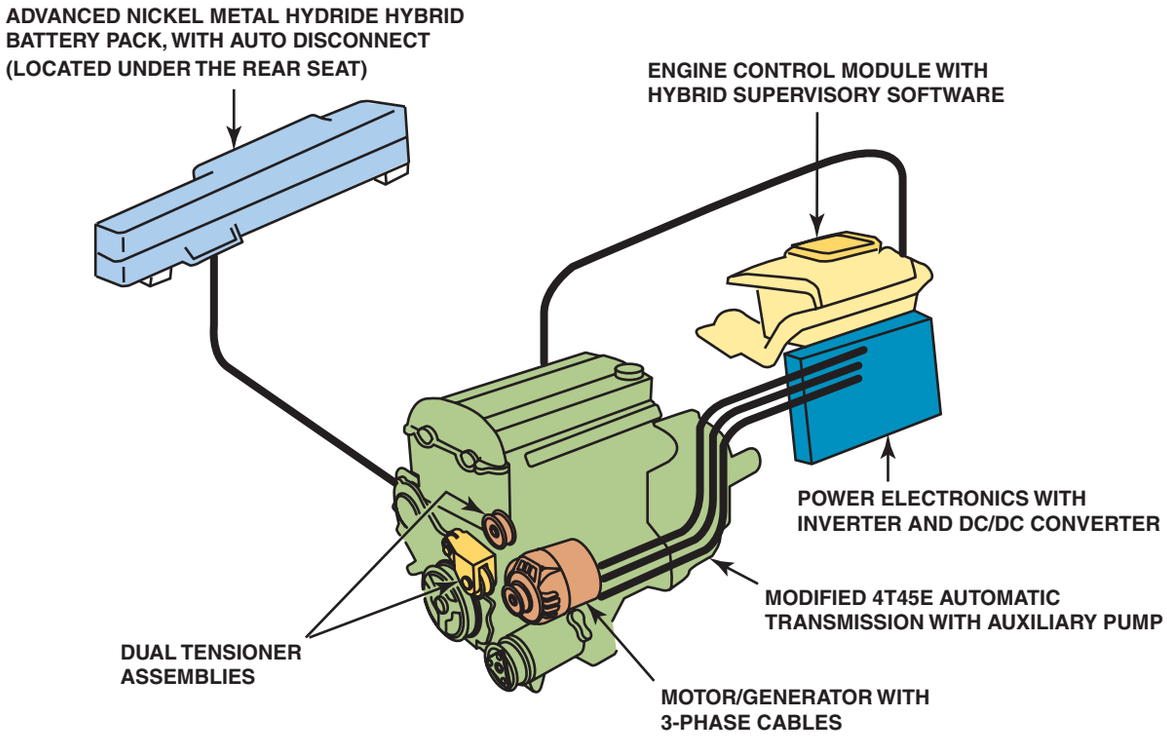


FIGURE 89–9 The components of a typical belt alternator-starter (BAS) system.

A typical BAS system will achieve a 8% to 15% increase in fuel economy, mostly affecting the city mileage with little, if any, effect on the highway mileage. On extremely small vehicles, the belt alternator starter might nudge a vehicle into the mild hybrid category. The BAS system is the type used in the Saturn VUE hybrid SUV. ● **SEE FIGURES 89–8 AND 89–9.**

MICRO-HYBRID DRIVE SYSTEM One of the major fuel-saving features of a hybrid electric vehicle is the idle stop mode, in which the internal combustion engine is stopped, instead of idling, while in traffic.

One simple system developed by Valeo uses a starter/alternator that is used as a conventional alternator when the engine is running,



FIGURE 89–10 This sticker on a hybrid vehicle allows the driver to use the high-occupancy vehicle (HOV) lanes even if there is only one person in the vehicle as a way to increase demand for hybrid vehicles in California.

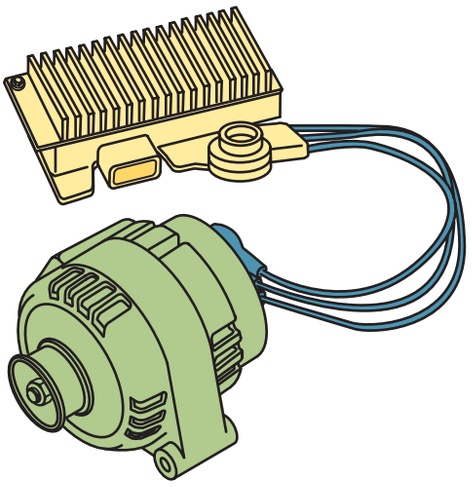


FIGURE 89–11 A combination starter/alternator is used to provide idle stop function to conventional vehicles. This very limited and low cost system is called a micro-hybrid drive.

? **FREQUENTLY ASKED QUESTION**

Can Hybrids Use the HOV Lane?

In most locations the answer is yes, but it depends on the type of hybrid vehicle. The **high-occupancy vehicle (HOV) lane** in many cities is reserved for use by vehicles that are carrying more than one occupant as a way to encourage carpooling and the use of public transportation. In California, only those hybrids classified as being high-fuel-economy models and those meeting certain emission ratings qualify. Those that do qualify, such as the Toyota Prius, are issued stickers that show that they are entitled to be in the HOV lane even if there is just the driver in the vehicle. High-performance hybrids, such as the Honda Accord hybrid, do not meet the specified fuel economy rating to allow the owners to be issued HOV stickers, which are also limited as to how many in the entire state can be issued.

● **SEE FIGURE 89–10.**

and as a starter to start the engine by transmitting power through the drive belt system. This type of system is often called a **micro-hybrid-drive system.** ● **SEE FIGURE 89–11.**

The only mechanical addition needed is a special belt tensioner that allows two-directional belt travel and can be fitted to almost any existing gasoline or diesel engine. The fuel and exhaust emission savings are proportional to the amount of idle time and can save up to 6% during city driving conditions.

COMMON FEATURES OF MOST HYBRIDS

The following are the most common features of hybrids that improve fuel economy:

Idle stop. The **idle stop mode** turns off the engine when the vehicle is stopped. When the brake is released, the engine immediately starts. This ensures that the vehicle is not using fuel, nor creating CO_2 emissions, when the engine is not required to propel the vehicle.

Regenerative braking. When decelerating, the braking system captures the energy from the vehicle's inertia and converts it to electrical energy which is stored in the battery or other device for later use. Regenerative braking helps keep the batteries charged.

Power assist. The electric motor provides extra power using electrical current drawn from the battery to assist the internal combustion engine during acceleration. This **power-assist mode** enables the vehicle to use a smaller, more fuel-efficient engine without giving up vehicle performance.

Engine-off drive-electric vehicle mode. The electric motor propels the vehicle at lower speeds. This mode is often called the motoring mode. Because the internal combustion engine is not being used during acceleration, no fuel is being used and no emissions are being released. When the hybrid is in this mode, it is essentially an electric vehicle.

LEVELS OF HYBRID VEHICLES

The term **hybrid** refers to a type of vehicle. However, there are different levels of "hybridization" among hybrids on the market. Different vehicle manufacturers use various hybrid technologies.

MILD HYBRID A **mild hybrid** will incorporate idle stop and regenerative braking but is not capable of using the electric motor to propel the vehicle on its own without help from the internal combustion engine. A mild hybrid system has the advantage of costing less, but saves less fuel compared to a full hybrid vehicle and usually uses a 42-volt electrical motor and battery package (36-volt batteries, 42-volt charging). An example of this type of hybrid is the General Motors Silverado pickup truck and the Saturn VUE. The fuel savings for a mild type of hybrid design is about 8% to 15%.

MEDIUM HYBRID A **medium hybrid** uses 144- to 158-volt batteries that provide for engine stop/start, regenerative braking, and power assist. Like a mild hybrid, a typical medium hybrid is not capable of propelling the vehicle from a stop using battery power alone. Examples of a medium hybrid vehicle include the Honda Insight, Civic, and Accord. The fuel economy savings are about 20% to 25% for medium hybrid systems.

TECH TIP

Watch Out for Motoring Mode

When a hybrid electric vehicle is operating at low speeds, it is often being propelled by the electric motor alone, sometimes called motoring mode. As a result, the vehicle is very quiet and is said to be operating in **quiet mode.**

During this time, the driver should be aware that the vehicle is not making any sound and should be careful when driving in congested areas. Service technicians should also be extremely careful when moving a hybrid electric vehicle around the shop due to the silence of the vehicle.

Hybrid Features by Make/Model

Make/Model	Idle Stop	Regenerative Braking	Motor Assist	Engine-Off Drive— EV Mode
Chevrolet Silverado 1500/GMC Sierra Hybrid	✓	✓		
Ford Escape and Mercury Mariner Hybrid	✓	✓	✓	✓
Honda Accord Civic Hybrid	✓	✓	✓	
Honda Insight	✓	✓	✓	
Toyota Prius	✓	✓	✓	✓
Saturn VUE	✓	✓	✓	
Toyota Highlander/ Lexus RX hybrids.	✓	✓	✓	✓

FULL HYBRID A **full hybrid,** also called a **strong hybrid,** uses idle stop regenerative braking, and is able to propel the vehicle using the electric motor(s) alone.

Each vehicle manufacturer has made its decision on which hybrid type to implement based on its assessment of the market niche for a particular model. Examples of a full or strong hybrid include the Ford Escape SUV, Toyota Highlander, Lexus RX400h, Lexus GS450h, Toyota Prius, and Toyota Camry. The fuel economy savings are about 30% to 50% for full hybrid systems.

FREQUENTLY ASKED QUESTION

What Is an Assist Hybrid?

An **assist hybrid**-electric vehicle is a term used to describe a vehicle where the electric motor is not able to start moving the vehicle on electric power alone. This type of hybrid would include all mild hybrids (36 to 42 volts), as well as the medium hybrids that use 144- to 158-volt systems.

EFFICIENCIES OF ELECTRIC MOTORS AND INTERNAL COMBUSTION ENGINES

- An electric motor can have efficiency (including controller) of over 90%, while a gasoline engine only has efficiency of 35% or less.
- An ICE does not have the overload capability of an electric motor. That is why the rated power of an internal combustion engine is usually much higher than required for highway cruising. Operating smoothly at idle speed produces a much lower efficiency than operating at a higher speed.
- Maximum torque of an internal combustion engine is reached at intermediate speed and the torque declines as speed increases further.
- There is a maximum fuel efficiency point in the speed range for the ICE, and this speed is optimized by many hybrid vehicle manufacturers by using a transmission that keeps the engine speed within the most efficient range.

ELECTRIC MOTORS Electric motors offer ideal characteristics for use in a vehicle because of the following factors:

- Constant power over all speed ranges
- Constant torque at low speeds needed for acceleration and hill-climbing capability
- Constant torque below base speed
- Constant power above base speed
- Only single gear or fixed gear is needed in the electric motor transmission

REVIEW QUESTIONS

1. What are the advantages and disadvantages of a series-hybrid design?
2. What type of hybrid electrical vehicle is a Toyota Prius and Ford Escape hybrid?
3. What are the advantages and disadvantages of mild, medium, and full hybrid vehicles?
4. Why does a BAS system cost less than the other types of hybrid vehicles?
5. What are the four modes of operation of a typical hybrid vehicle?

CHAPTER QUIZ

1. The GM EV1 was what type of vehicle?
   a. Totally electric powered
   b. A first-generation hybrid electric vehicle (HEV)
   c. A series-type HEV
   d. A parallel-type HEV
2. Which type of hybrid uses 36 to 42 volts?
   a. Mild hybrid **c.** Full hybrid
   b. Medium hybrid **d.** Strong hybrid
3. Which type of hybrid is capable of propelling the vehicle using just the electric motor?
   a. BAS type **c.** Medium hybrid
   b. Strong (full) hybrid **d.** Mild hybrid
4. About how fast does a motor-generator crank the internal combustion engine?
   a. About 1000 RPM **c.** About 150–300 RPM
   b. About 2000 RPM **d.** About 400–600 RPM
5. Which type of hybrid electric design costs the least?
   a. Strong hybrid design **c.** Parallel-hybrid design
   b. Series-hybrid design **d.** BAS design
6. Which type of hybrid electric vehicle has idle stop operation?
   a. Strong hybrids only
   b. Strong, mild, and medium hybrids
   c. Mild hybrids only
   d. Medium hybrids only
7. Technician A says that most hybrids require that they be plugged into an electrical outlet at night to provide the electrical power to help propel the vehicle. Technician B says that the internal combustion engine in an HEV will often stop running when the vehicle is stopped. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
8. Technician A says that most hybrids use the series hybrid design. Technician B says that some hybrids have 42-volt batteries. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
9. Electric motors are better than an internal combustion engine to propel a vehicle because _____.
   a. They produce high torque at low speeds
   b. They do not burn fuel and therefore do not release carbon dioxide into the environment
   c. They are quiet
   d. All of the above are correct
10. All of the following are characteristic of a hybrid electric vehicle (HEV), ***except*** _____.
    a. High voltages (safety issue)
    b. Lower fuel economy
    c. Lower amount of carbon dioxide released to the atmosphere
    d. Quiet

chapter 90

HYBRID SAFETY AND SERVICE PROCEDURES

OBJECTIVES: **After studying Chapter 90, the reader will be able to:** • Safely de-power a hybrid electric vehicle. • Safely perform high-voltage disconnects. • Understand the unique service issues related to HEV high-voltage systems. • Correctly use appropriate personal protective equipment (PPE). • Perform routine vehicle service procedure on a hybrid electric vehicle. • Explain hazards while driving, moving, and hoisting a hybrid electric vehicle.

KEY TERMS: ANSI 992 • ASTM 992 • CAT III 993 • DMM 992 • Floating ground 994 • HV 991 • HV cables 991 • IEC 992 • Lineman's gloves 992 • NiMH 996 • OSHA 992 • Service plug 995

HIGH-VOLTAGE SAFETY

NEED FOR CAUTION There have been electrical systems on vehicles for over 100 years. Technicians have been repairing vehicle electrical systems without fear of serious injury or electrocution. However, when working with hybrid electric vehicles, this is no longer true. It is now possible to be seriously injured or electrocuted (killed) if proper safety procedures are not followed.

Hybrid electric vehicles and all electric vehicles use **high-voltage (HV)** circuits that if touched with an unprotected hand could cause serious burns or even death.

IDENTIFYING HIGH-VOLTAGE CIRCUITS **High-voltage cables** are identified by color of the plastic conduit and include:

- **Blue or yellow.** 42 volts (not a shock hazard but an arc will be maintained if a circuit is opened)
- **Orange.** 144 to 600 volts or higher



FIGURE 90–1 Rubber lineman's gloves protect the wearer from a shock hazard.



FIGURE 90–2 Wearing leather gloves over the lineman's gloves helps protect the rubber gloves from damage.



FIGURE 90–3 Checking rubber lineman's gloves for pinhole leaks.

carefully before each use. High voltage and current (amperes) in combination is fatal. ● **SEE FIGURES 90–1 AND 90–2.**

NOTE: The high-voltage insulated safety gloves must be recertified every six months to remain within Occupational Safety and Health Administration (OSHA) guidelines.

Before using the rubber gloves, they should be tested for leaks using the following procedure:

1. Roll the glove up from the open end until the lower portion of the glove begins to balloon from the resulting air pressure. Be sure to "lean" into the sealed glove to raise the internal air pressure. If the glove leaks any air, discard the gloves. ● **SEE FIGURE 90–3.**
2. The gloves should not be used if they show any signs of wear and tear.

WARNING

Touching circuits or wires containing high voltage can cause severe burns or death.

WARNING

Cables and wiring are orange in color. High-voltage insulated safety gloves and a face shield must be worn when carrying out any diagnostics involving the high-voltage systems or components.

HIGH-VOLTAGE SAFETY EQUIPMENT

RUBBER GLOVES

Before working on the high-voltage system of a hybrid electric vehicle, be sure that high-voltage **lineman's gloves** are available. Be sure that the gloves are rated at least 1,000 volts and class "0" by ANSI/ASTM. The **American National Standards Institute (ANSI)** is a private, nonprofit organization that administers and coordinates the U.S. voluntary standardization and conformity assessment system. ASTM International, originally known as the **American Society for Testing and Materials (ASTM),** was formed over a century ago, to address the need for component testing in industry. The **Occupational Safety and Health Administration (OSHA)** requirements specify that the HV gloves get inspected every six months by a qualified glove inspection laboratory. Use an outer leather glove to protect the HV rubber gloves. Inspect the gloves

CAT III-RATED DIGITAL MULTIMETER

Hybrid electric vehicles are equipped with electrical systems whose voltages can exceed 600 volts DC. A CAT III-certified **digital multimeter (DMM)** is required for making measurements on these high-voltage systems.

The **International Electrotechnical Commission (IEC)** has several categories of voltage standards for meter and meter leads. These categories are ratings for over-voltage protection and are rated CAT I, CAT II, CAT III, and CAT IV. The higher the category (CAT) rating, the greater the protection to the technician when measuring high-energy voltage. Under each category there are various voltage ratings.

CAT I Typically a CAT I meter is used for low-voltage measurements, such as voltage measurements at wall outlets in the home. Meters with a CAT I rating are usually rated at 300 to 800 volts. CAT I is for relatively low-energy levels, and while the voltage level to be high enough for use when working on a hybrid electric vehicle, the protective energy level is lower than what is needed.



FIGURE 90–4 Be sure to only use a meter that is CAT III-rated when taking electrical voltage measurements on a hybrid electric or electric vehicle.

? FREQUENTLY ASKED QUESTION

Is It the Voltage Rating that Determines the CAT Rating?

Yes and no. The voltages stated for the various CAT ratings are important but the potential harm to a technician due to the energy level is what is most important. For example some CAT II rated meters may have a stated voltage higher than a meter that has a CAT III rating. Always use a meter that has a CAT III rating when working on a hybrid electric vehicle. ● **SEE FIGURES 90–4 AND 90–5.**

CAT II A higher-rated meter that would be typically used for checking voltages at the circuit-breaker panel in the home. Meters with a CAT II rating are usually rated at 300 to 600 volts. CAT II rated meters have similar voltage ratings as the other CAT ratings, but the energy level of protection is higher with a CAT II compared to a CAT I.

CAT III **CAT III** is the minimum-rated meter that should be used for hybrid vehicles. Meters with a CAT III rating are usually rated at 600 to 1,000 volts and the highest energy level which is needed to protect the service technician.

CAT IV CAT IV meters are for clamp-on meters only. A clamp-on meter is used to measure current (amperes) in a circuit by placing the clamp around the wire carrying the current. If a clamp-on meter also has meter leads for voltage measurements, that part of the meter will be rated as CAT III.

INSULATION TESTER An electrical insulation tester, such as the Fluke 1587, is used to test for electrical continuity between the high-voltage wires or components and the body of the vehicle. If a hybrid electric vehicle has been involved in any type of collision or any other incident where damage could occur to the insulation, the high-voltage system should be checked. An insulation tester is more expensive than a digital meter. This means that an individual service technician often does not purchase one, but any technician or service shop that works on hybrid electric vehicles should have one available.



FIGURE 90–5 The meter leads should also be CAT III-rated when checking voltages on a hybrid electric vehicle.

EYE PROTECTION Eye protection should be worn when testing for high voltage, which is considered by many experts to be over 60 volts. Eye protection should include the following features:

1. Plastic frames (avoid metal frames as these are conductive and could cause a shock hazard)
2. Side shields
3. Meet the standard ANSI Z87.1

Most hybrid electric systems use voltages higher than this threshold. If the system has not been powered down or has not had the high-voltage system disabled, a shock hazard is always possible. Even when the high-voltage system has been disconnected, there is still high voltage in the HV battery box.

NOTE: Some vehicle manufacturers specify that full face shields be worn instead of safety glasses when working with high voltage circuits or components.

SAFETY CONES Ford requires that cones be placed at the four corners of any hybrid electric vehicle when service work on the high voltage system is being performed. They are used to establish a safety zone around the vehicles so that other technicians will know that a possible shock hazard may be present.

FIBERGLASS POLE Ford requires that a ten foot insulated fiberglass pole be available outside the safety zone to be used to pull a technician away from the vehicle in the unlikely event of an accident where the technician is shocked or electrocuted.

ELECTRIC SHOCK POTENTIAL

LOCATIONS WHERE SHOCKS CAN OCCUR Accidental and unprotected contact with any electrically charged ("hot" or "live") high-voltage component can cause serious injury or death. However, receiving an electric shock from a hybrid vehicle is highly unlikely because of the following:

1. Contact with the battery module or other components inside the battery box can occur only if the box is damaged and the contents are exposed, or the box is opened without following proper precautions.
2. Contact with the electric motor can occur only after one or more components are removed.

3. The high-voltage cables can be easily identified by their distinctive orange color, and contact with them can be avoided.
4. The system main relays (SMRs) disconnect power from the cables the moment the ignition is turned off.

LOCATIONS OF AUXILIARY BATTERIES

● SEE CHART 90–1 for a summary of the locations of auxiliary batteries.

As a rule of thumb, the auxiliary battery is usually a flood-type if it is located under the hood and an AGM-type if it is in the trunk area.

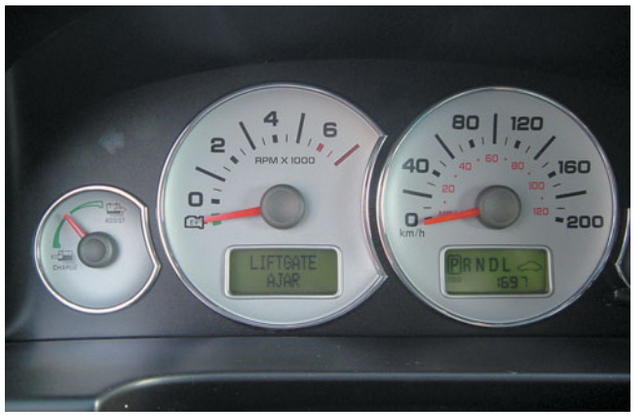


FIGURE 90–6 The Ford Escape Hybrid instrument panel showing the vehicle in park and the tachometer on "EV" instead of 0 RPM. This means that the gasoline engine could start at any time depending on the state-of-charge of the high-voltage batteries and other factors.

WARNING

Power remains in the high-voltage electrical system for up to 10 minutes after the HV battery pack is shut off. Never touch, cut, or open any orange high-voltage power cable or high-voltage component without confirming that the high-voltage has been completely discharged.

TECH TIP

Silence Is NOT Golden

Never assume the vehicle is shut off just because the engine is off. When working with a Toyota or Lexus hybrid electric vehicle, always look for the **READY** indicator status on the dash display. The vehicle is shut off when the **READY** indicator is off.

The vehicle may be powered by:

1. The electric motor only.
2. The gasoline engine only.
3. A combination of both the electric motor and the gasoline engine.

The vehicle computer determines the mode in which the vehicle operates to improve fuel economy and reduce emissions. The driver cannot manually select the mode.

● SEE FIGURE 90–6.

TECH TIP

High Voltage Is Insulated from the Vehicle Body

Both positive and negative high-voltage power cables are isolated from the metal chassis, so there is no possibility of shock by touching the metal chassis. This design is called a **floating ground.**

A ground fault monitor continuously monitors for high-voltage leakage to the metal chassis while the vehicle is running. If a malfunction is detected, the vehicle computer will illuminate the master warning light in the instrument cluster and the hybrid warning light in the LCD display. The HV battery pack relays will automatically open to stop electricity flow in a collision sufficient to activate the SRS airbags.

HYBRID VEHICLE AUXILIARY BATTERY CHART

VEHICLE	AUXILIARY BATTERY TYPE	AUXILIARY BATTERY LOCATION
Honda Insight Hybrid	Flooded lead acid	Underhood; center near bulkhead
Honda Civic Hybrid	Flooded lead acid	Underhood; driver's side
Honda Accord Hybrid	Flooded lead acid	Underhood; driver's side
Ford Escape Hybrid	Flooded lead acid	Underhood; driver's side
Toyota Prius Hybrid (2001–2003)	Absorbed glass mat (AGM)	Trunk; driver's side
Toyota Prius Hybrid (2004–2007)	Absorbed glass mat (AGM)	Trunk; passenger side
Toyota Highlander Hybrid	Flooded lead acid	Underhood; passenger side
Toyota Camry Hybrid	Absorbed glass mat (AGM)	Trunk; passenger side
Lexus RX 400h Hybrid	Flooded lead acid	Underhood; passenger side
Lexus GS 450h Hybrid	Absorbed glass mat (AGM)	Trunk; driver's side
Chevrolet/GMC Hybrid Pickup Truck	Flooded lead acid	Underhood; driver's side

CHART 90–1

As a rule of thumb, the auxiliary battery is usually a flood-type if it is located under the hood and an AGM-type if it is in the trunk area.

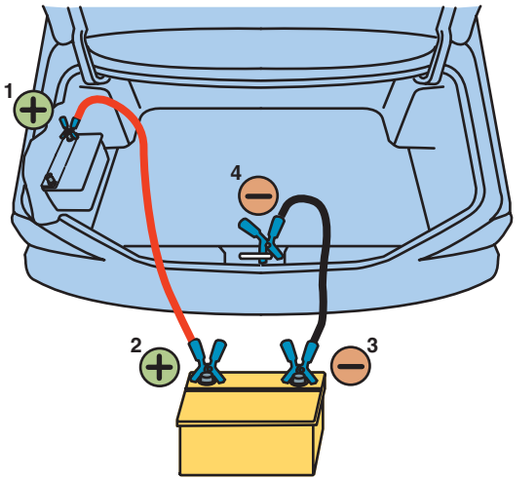


FIGURE 90–7 Jump starting a 2001–2003 Toyota Prius using a 12-volt supply to boost the 12-volt auxiliary battery in the trunk.

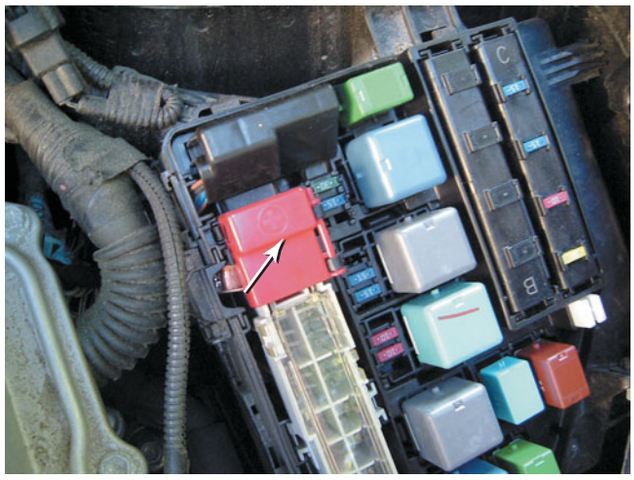


FIGURE 90–8 The underhood 12-volt jump-start terminal on this 2004+ Toyota Prius has a red plastic cover with a "+" sign. The positive booster cable clamp will attach directly to the vertical metal bracket.

DE-POWERING THE HIGH-VOLTAGE SYSTEM

THE NEED TO DE-POWER THE HV SYSTEM

During routine vehicle service work there is no need to go through any procedures needed to de-power or to shut off the high-voltage circuits. However, if work is going to be performed on any of the following components then service information procedures must be followed to prevent possible electrical shock and personal injury.

- The high-voltage (HV) battery pack
- Any of the electronic controllers that use orange cables such as the inverter and converters
- The air-conditioning compressor if electrically driven and has orange cables attached

To safely de-power the vehicle always follow the instructions found in service information for the exact vehicle being serviced. The steps usually include:

STEP 1 Turn the ignition off and remove the key (if equipped) from the ignition.

CAUTION: If a push-button start is used, remove the key fob at least 15 feet (5 meters) from the vehicle to prevent the vehicle from being powered up.

STEP 2 Remove the 12-volt power source to the HV controller. This step could involve:

- Removing a fuse or a relay
- Disconnecting the negative battery cable from the auxiliary 12-volt battery

STEP 3 Remove the high-voltage (HV) fuse or **service plug** or switch.

WARNING

Even if all of the above steps are followed, there is still a risk for electrical shock at the high-voltage batteries. Always follow the vehicle manufacturer's instructions exactly and wear high-voltage gloves and other specified personal protective equipment (PPE).

FREQUENTLY ASKED QUESTION

When Do I Need to De-Power the High-Voltage System?

During routine service work, there is no need for a technician to de-power the high-voltage system. The only time when this process is needed is if service repairs or testing is being performed on any circuit that has an orange cable attached. These include:

- AC compressor if electrically powered
- High-voltage battery pack or electronic controllers

The electric power steering system usually operates on 12 volts or 42 volts and neither is a shock hazard. However, an arc will be maintained if a 42-volt circuit is opened. Always refer to service information if servicing the electric power steering system or any other system that may contain high voltage.

COLLISION AND REPAIR INDUSTRY ISSUES

JUMP STARTING

The 12-volt auxiliary battery may be jump started if the vehicle does not start. The 12-volt auxiliary battery is located under the hood or in the cargo (trunk) area of some HEVs. Using a jump box or jumper cable from another vehicle, make the connections to the positive and negative battery terminals. ● **SEE FIGURE 90–7.**

On the 2004+ Toyota Prius vehicles, there is a stud located under the hood that can be used to jump start the auxiliary battery, which is located in the truck. ● **SEE FIGURE 90–8.**

NOTE: The high-voltage HV battery pack cannot be jump started on most HEVs. One exception is the Ford Escape/Mercury Mariner hybrids that use a special "jump-start" button located behind the left kick panel. When this button is pushed, the auxiliary battery is used to boost the HV battery through a DC-DC converter.



FIGURE 90–9 Using a warning cover over the steering wheel helps others realize that work is being performed on the high-voltage system and that no one is to attempt to start or move the vehicle.



FIGURE 90–10 A lock box is a safe location to keep the ignition keys of a hybrid electric vehicle while it is being serviced.



FIGURE 90–11 Insulated tools, such as this socket set, would provide an additional margin of safety to the service technician when working around high-voltage components and systems.

FREQUENTLY ASKED QUESTION

Will the Heat from Paint Ovens Hurt the High-Voltage Batteries?

Nickel-metal hydride (NiMH) batteries may be damaged if exposed to high temperatures, such as in a paint oven. The warning labels on hybrid vehicles specify that the battery temperature not exceed 146°F (63°C). Therefore be sure to check the temperature of any paint oven before allowing a hybrid electric vehicle into one that may be hotter than specified. Check service information for details on the vehicle being repaired.

MOVING AND TOWING A HYBRID

TOWING If a disabled vehicle needs to be moved a short distance (to the side of the road, for example) and the vehicle can still roll on the ground, the easiest way is to shift the transmission into neutral and manually push the vehicle. To transport a vehicle away from an emergency location, a flatbed truck should be used if the vehicle might be repaired. If a flatbed is not available, the vehicle should be towed by wheel-lift equipment with the front wheels off the ground (FWD hybrid electric vehicles only). Do not use sling-type towing equipment. In the case of 4WD HEVs such as the Toyota Highlander, only a flatbed vehicle should be used.

MOVING THE HYBRID VEHICLE IN THE SHOP After an HEV has been serviced, it may be necessary to push the vehicle to another part of the shop or outside as parts are ordered. Make sure to tape any orange cable ends that were disconnected during the repair procedure. Permanent magnets are used in all the drive motors and generators and it is possible that a high-voltage arc could occur as the wheels turn and produce voltage. Another way to prevent this is to use wheel dollies. A sign that says "HIGH VOLTAGE—DO NOT TOUCH" could also be added to the roof of the vehicle. Remove the keys from the vehicle and keep in a safe location. ● **SEE FIGURES 90–9 AND 90–10.**

REMOVING THE HIGH-VOLTAGE BATTERIES

PRECAUTIONS The HV battery box should always be removed as an assembly, placed on a rubber-covered work bench, and handled carefully. Every other part, especially the capacitors, should be checked for voltage reading while wearing HV rubber gloves. Always check for voltage as the components become accessible before proceeding. When removing high-voltage components, it is wise to use insulated tools. ● **SEE FIGURE 90–11.**

STORING THE HIGH-VOLTAGE BATTERIES If a hybrid is to be stored for any length of time, the state of charge of the HV batteries must be maintained. If possible, start the vehicle every month and run it for at least 30 minutes to help recharge the HV batteries. This is necessary because NiMH batteries suffer from self-discharge over time. High-voltage battery chargers



FIGURE 90–12 The high-voltage wiring on this Honda hybrid is colored orange for easy identification.

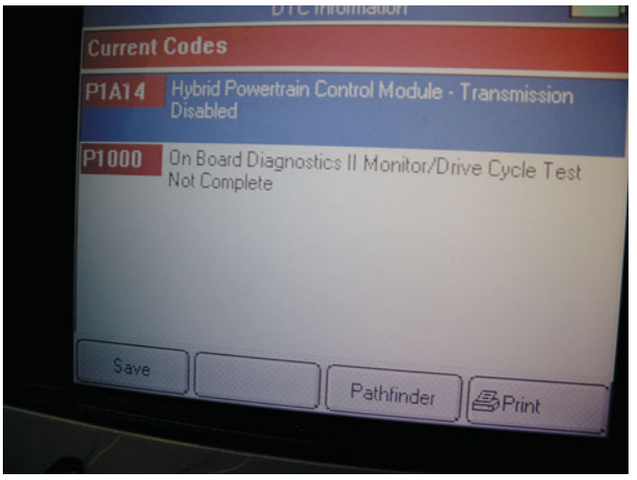


FIGURE 90–13 A scan tool display showing two hybrid-related faults in this Ford Escape hybrid.

TECH TIP

High-Voltage Battery SOC Considerations

NiMH batteries do not store well for long lengths of time. After a repair job, or when the HV system has been powered down by a technician and powered up again, do not be surprised if a warning lamp lights, diagnostic trouble codes are set, and the MIL are illuminated. If everything was done correctly, a couple road tests may be all that is required to reset the MIL. The HV battery indicator on the dash may also read zero charge level. After a road test, the HV battery level indicator will most likely display the proper voltage level.

are expensive and may be hard to find. If the HV battery SOC was over 60% when it was put into storage, the batteries may be stored for about a month without a problem. If, however, the SOC is less than 60%, a problem with a discharged HV battery may result.

HOISTING A HYBRID VEHICLE When hoisting or using a floor jack, pay attention to the lift points. Orange cables run under the vehicle just inside the fame rails on most hybrids. ● **SEE FIGURE 90–12.**

Some Honda hybrid vehicles use an aluminum pipe painted orange that includes three HV cables for the starter/generator and also three more cables for the HV air-conditioning compressor. If any damage occurs to any high-voltage cables, the MIL will light up and a no-start will result if the PCM senses a fault. The cables are not repairable and are expensive. The cables can be identified by an orange outer casing, but in some cases, the orange casing is not exposed until a black plastic underbelly shield is removed first.

HV BATTERY DISPOSAL The hybrid electric vehicle manufacturers are set up to ship NiMH battery packs to a recycling center. There is an 800 number located under the hood or on the HV battery pack that can be used to gain information on how to recycle these batteries.

Always follow the proper safety procedures, and then minor service to hybrid vehicles can be done with a reasonable level of safety.

ROUTINE SERVICE PROCEDURES

DIAGNOSIS PROCEDURES Hybrid electric vehicles should be diagnosed the same as any other type of vehicle. This means following a diagnostic routine, which usually includes the following steps:

STEP 1 Verify the customer concern.

STEP 2 Check for diagnostic trouble codes (DTCs). An enhanced or factory level scan tool may be needed to get access to codes and sub-codes.

STEP 3 Perform a thorough visual inspection. If a DTC is stored, carefully inspect those areas that might be the cause of the trouble code.

STEP 4 Check for technical service bulletins (TSBs) that may relate to the customer concern.

STEP 5 Follow service information specified steps and procedures. This could include checking scan tool data for sensors or values that are not within normal range.

STEP 6 Determine and repair the root cause of the problem.

STEP 7 Verify the repair and clear any stored diagnostic trouble codes unless in an emission testing area. If in an emission test area, drive the vehicle until the powertrain control module (PCM) passes the fault and turns off the malfunction indicator lamp (MIL) thereby allowing the vehicle to pass the inspection.

STEP 8 Complete the work order and record the "three Cs" (complaint, cause, and correction).

● **SEE FIGURE 90–13.**

OIL CHANGE Performing an oil change is similar to changing oil in any vehicle equipped with an internal combustion engine. However, there are several items to know when changing oil in a hybrid electric vehicle including:

- **Use vehicle manufacturer's recommended hoisting locations.** Use caution when hoisting a hybrid electric vehicle and avoid placing the pads on or close to the orange high-voltage cables that are usually located under the vehicle.



FIGURE 90–14 Always use the specified viscosity of oil in a hybrid electric vehicle not only for best fuel economy but also because of the need for fast lubrication because of the engine (idle) stop feature.

- **Always use the specified oil viscosity.** Most hybrid electric vehicles require either:

  SAE 0W-20
  SAE 5W-20

  Using the specified oil viscosity is important because the engine stops and starts many times and using the incorrect viscosity not only can cause a decrease in fuel economy but also could cause engine damage. ● **SEE FIGURE 90–14.**
- **Always follow the specified procedures.** Be sure that the internal combustion engine (ICE) is off and that the "READY" lamp is off. If there is a smart key or the vehicle has a push-button start, be sure that the key fob is at least 15 feet (5 meters) away from the vehicle to help prevent the engine from starting accidentally.

COOLING SYSTEM SERVICE

Performing cooling system service is similar to performing this service in any vehicle equipped with an internal combustion engine. However, there are several items to know when servicing the cooling system on a hybrid electric vehicle including:

- **Always check service information for the exact procedure to follow.** The procedure will include the following:
  1. **The specified coolant.** Most vehicle manufacturers will recommend using premixed coolant because using water (half of the coolant) that has minerals could cause corrosion issues.
  2. **The specified coolant replacement interval.** While this may be similar to the coolant replacement interval for a conventional vehicle, always check to be sure that this service is being performed at the specified time or mileage interval.
  3. **The specified precautions.** Some Toyota Prius HEVs use a coolant storage bottle that keeps the coolant hot for up to three days. Opening a coolant hose could cause the release of this hot coolant and can cause serious burns to the technician.
  4. Always read, understand, and follow all of the service information instructions when servicing the cooling system on a hybrid electric vehicle.

REAL WORLD FIX

A Bad Day Changing Oil

A shop owner was asked by a regular customer who had just bought a Prius if the oil could be changed there. The owner opened the hood, made sure the filter was in stock (it is a standard Toyota filter used on other models), and said yes. A technician with no prior knowledge of hybrids drove the warmed-up vehicle into the service bay. The internal combustion engine never started, as it was in electric (stealth) mode at the time. Not hearing the engine running, the technician hoisted the vehicle into the air, removed the drain bolt, and drained the oil into the oil drain unit. When the filter was removed, oil started to fly around the shop. The engine was in "standby" mode during the first part of the oil change. When the voltage level dropped, the onboard computer started the engine so that the HV battery could recharge. The technician should have removed the key to keep this from happening. Be sure that the "ready" light is off before changing the oil or doing any other service work that may cause personal harm or harm to the vehicle if the engine starts.

AIR FILTER SERVICE

Performing air filter service is similar to performing this service in any vehicle equipped with an internal combustion engine. However, there are several items to know when servicing the air filter on a hybrid electric vehicle including:

1. Always follow the service information recommended air filter replacement interval.
2. For best results use the factory type and quality air filter.
3. Double-check that all of the air ducts are securely fastened after checking or replacing the air filter.

AIR-CONDITIONING SERVICE

Performing air-conditioning system service is similar to performing this service in any vehicle equipped with an internal combustion engine. However, there are several items to know when servicing the air-conditioning system on a hybrid electric vehicle including:

1. Many hybrid electric vehicles use an air-conditioning compressor that uses high voltage from the high-voltage (HV) battery pack to operate the compressor either all of the time, such as many Toyota/Lexus models, or during idle stop periods, such as on Honda hybrids.
2. If the system is electrically driven, then special refrigerant oil is used that is nonconductive. This means that a separate recovery machine should be used to avoid the possibility of mixing regular refrigerant oils in with the oil used in hybrids.
3. Always read, understand, and follow all of the service information instructions when servicing the air-conditioning system on a hybrid electric vehicle.

STEERING SYSTEM SERVICE Performing steering system service is similar to performing this service in any vehicle equipped with an internal combustion engine. However, there are several items to know when servicing the steering system on a hybrid electric vehicle including:

1. Check service information for any precautions that are specified to be followed when servicing the steering system on a hybrid electric vehicle.
2. Most hybrid electric vehicles use an electric power steering system. These can be powered by one of two voltages:
   - **12 volts**—These systems can be identified by the red or black wiring conduit and often use an inverter that increases the voltage to operate the actuator motor (usually to 42 volts). While this higher voltage is contained in the controller and should not create a shock hazard, always follow the specified safety precautions and wear protective high-voltage gloves as needed.
   - **42 volts**—These systems use a yellow or blue plastic conduit over the wires to help identify the possible hazards from this voltage level. This voltage level is not a shock hazard but can maintain an arc if a circuit carrying 42 volts is opened.

BRAKING SYSTEM SERVICE Performing braking system service is similar to performing this service in any vehicle equipped with an internal combustion engine. However, there are several items to know when servicing the braking system on a hybrid electric vehicle including:

1. Check service information for any precautions that are specified to be followed when servicing the braking system on a hybrid electric vehicle.
2. All hybrid electric vehicles use a regenerative braking system, which captures the kinetic energy of the moving vehicle and converts it to electrical energy and is sent to the high-voltage battery pack. The amount of current produced during hard braking can exceed 100 amperes. This current is stored in the high-voltage battery pack and is then used as needed to help power the vehicle.
3. The base brakes used on hybrid electric vehicles are the same as any other conventional vehicle except for the master cylinder and related control systems. There is no high-voltage circuits associated with the braking system as the regeneration occurs inside the electric drive (traction) motors and is controlled by the motor controller.
4. The base brakes on many hybrid vehicles are often found to be stuck or not functioning correctly because the brakes are not doing much work and can rust.

NOTE: Always check the base brakes whenever there is a poor fuel economy complaint heard from an owner of a hybrid vehicle. Often when a disc brake caliper sticks, the brakes drag but the driver is not aware of any performance problems but the fuel economy drops.

TIRES Performing tire-related service is similar to performing this service in any vehicle equipped with an internal combustion engine. However, there are several items to know when servicing tires on a hybrid electric vehicle including:

1. Tire pressure is very important to not only the fuel economy but also on the life of the tire. Lower inflation pressure increases rolling resistance and reduces load carrying capacity and tire life. Always inflate the tires to the pressure indicated on the door jamb sticker or found in service information or the owner's manual.
2. All tires create less rolling resistance as they wear. This means that even if the same identical tire is used as a replacement, the owner may experience a drop in fuel economy.
3. Tires can have a big effect on fuel economy. It is best to warn the owner that replacement of the tires can and often will cause a drop in fuel economy, even if low rolling resistance tires are selected.
4. Try to avoid using tires that are larger than used from the factory. The larger the tire, the heavier it is and it takes more energy to rotate, resulting in a decrease in fuel economy.
5. Follow normal tire inspections and tire rotation intervals as specified by the vehicle manufacturer.

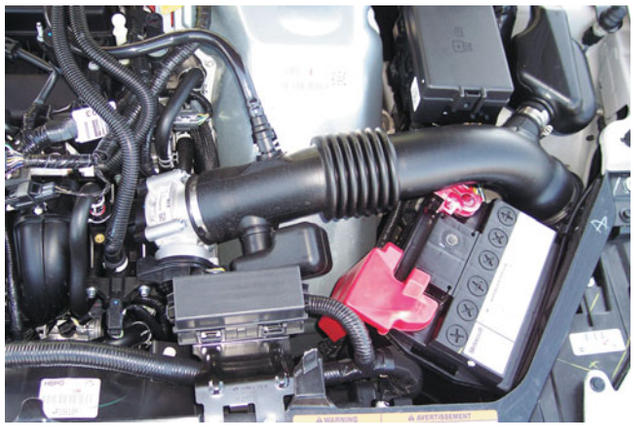


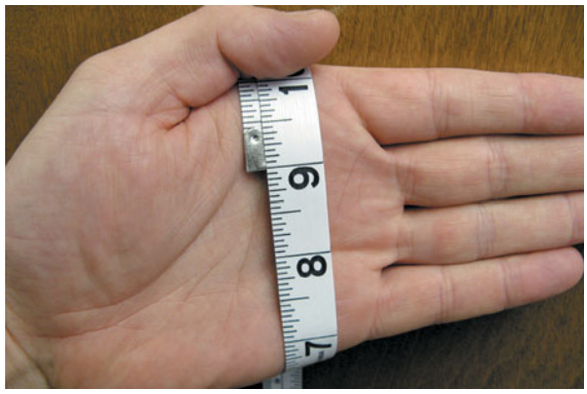
FIGURE 90–15 This 12 volt battery under the hood on a Ford Fusion hybrid is a flooded cell type auxiliary battery.

AUXILIARY BATTERY TESTING AND SERVICE Performing auxiliary battery service is similar to performing this service in any vehicle equipped with an internal combustion engine. However, there are several items to know when servicing the auxiliary battery on a hybrid electric vehicle including:

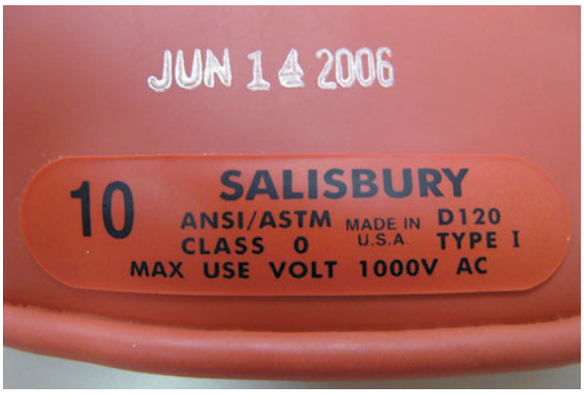
1. Auxiliary 12-volt batteries used in hybrid electric vehicles are located in one of two general locations.
   - **Under the hood**—If the 12-volt auxiliary battery is under the hood it is generally a flooded-type lead–acid battery and should be serviced the same as any conventional battery. ● **SEE FIGURE 90–15**.
   - **In the passenger or trunk area**—If the battery is located in the passenger or trunk area of the vehicle, it is usually of the absorbed glass mat (AGM) design. This type of battery requires that a special battery charger that limits the charging voltage be used.
2. The auxiliary 12-volt battery is usually smaller than a battery used in a conventional vehicle because it is not used to actually start the engine unless under extreme conditions on Honda hybrids only.
3. The 12-volt auxiliary battery can be tested and serviced the same as any battery used in a conventional vehicle.
4. Always read, understand, and follow all of the service information instructions when servicing the auxiliary battery on a hybrid electric vehicle.



1 The cuff of the rubber glove should extend at least 1/2 inch beyond the cuff of the leather protector.



2 To determine correct glove size, use a soft tape to measure around the palm of the hand. A measurement of 9 inches would correspond with a glove size of 9.



3 The glove rating and the date of the last test should be stamped on the glove cuff.



4 Start with a visual inspection of the glove fingertips, making sure that no cuts or other damage is present.



5 The damage on this glove was easily detected with a simple visual inspection. Note that the rubber glove material can be damaged by petroleum products, detergents, certain hand soaps, and talcum powder.



6 Manually inflate the glove to inspect for pinhole leaks. Starting at the cuff, roll up the glove and trap air at the finger end. Listen and watch carefully for deflation of the glove. If a leak is detected, the glove must be discarded.



7 Petroleum on the leather protector's surfaces will damage the rubber glove underneath.



8 Glove powder (glove dust) should be used to absorb moisture and reduce friction.



9 Put on the gloves and tighten the straps on the back of the leather protectors.



10 Technicians MUST wear HV gloves and leather protectors whenever working around the high-voltage areas of a hybrid electric vehicle.



11 HV gloves and leather protectors should be placed in a canvas storage bag when not in use. Note the ventilation hole at the bottom of this bag.



12 Make sure that the rubber gloves are not folded when placed in the canvas bag. Folding increases mechanical stress on the rubber and can lead to premature failure of the glove material.

REVIEW QUESTIONS

1. What are the recommended items that should be used when working with the high-voltage circuits of a hybrid electric vehicle?
2. What actions are needed to disable the high-voltage (HV) circuit?
3. What are the precautions that service technicians should adhere to when servicing hybrid electric vehicles?

CHAPTER QUIZ

1. Rubber gloves should be worn whenever working on or near the high-voltage circuits or components of a hybrid electric vehicle. Technician A says that the rubber gloves should be rated at 1,000 volts or higher. Technician B says that leather gloves should be worn over the high-voltage rubber gloves. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
2. A CAT-III certified DMM should be used whenever measuring high-voltage circuits or components. The CAT III rating relates to _____.
   a. High voltage **c.** High electrical resistance
   b. High energy **d.** Both a and b
3. All of the following will shut off the high voltage to components and circuits, except _____.
   a. Opening the driver's door
   b. Turning the ignition off
   c. Disconnecting the 12-volt auxiliary battery
   d. Removing the main fuse, relay, or HV plug
4. If the engine is not running, Technician A says that the high-voltage circuits are de-powered. Technician B says that all high-voltage wiring is orange-colored. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
5. Which statement is false about high-voltage wiring?
   a. Connects the battery pack to the electric controller
   b. Connects the controller to the motor/generator
   c. Is electrically grounded to the frame (body) of the vehicle
   d. Is controlled by a relay that opens if the ignition is off
6. What routine service procedure could result in lower fuel economy, which the owner may discover?
   a. Using the wrong viscosity engine oil
   b. Replacing tires
   c. Replacing the air filter
   d. Either a or b
7. Two technicians are discussing jump starting a hybrid electric vehicle. Technician A says that the high-voltage (HV) batteries can be jumped on some HEV models. Technician B says that the 12-volt auxiliary battery can be jumped using a conventional jump box or jumper Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. What can occur if a hybrid electric vehicle is pushed in the shop?
   a. The HV battery pack can be damaged
   b. The tires will be locked unless the ignition is on
   c. Damage to the electronic controller can occur
   d. High voltage will be generated by the motor/generator
9. Nickel-metal hydride (NiMH) batteries can be damaged if exposed to temperatures higher than about _____.
   a. 150°F (66°C) **c.** 200°F (93°C)
   b. 175°F (79°C) **d.** 225°F (107°C)
10. How should nickel-metal hydride (NiMH) batteries be disposed?
    a. In regular trash
    b. Call an 800 number shown under the hood of the vehicle for information
    c. Submerged in water and then disposed of in regular trash
    d. Burned at an EPA-certified plant

chapter 91

FUEL CELLS AND ADVANCED TECHNOLOGIES

OBJECTIVES: **After studying Chapter 91, the reader will be able to:** • Explain how a fuel cell generates electricity. • Discuss the advantages and disadvantages of fuel cells. • List the types of fuel cells. • Explain how ultracapacitors work. • Describe the advantages and disadvantages of electric vehicles. • Discuss alternative energy sources.

KEY TERMS: Double-layer technology 1007 • Electrolysis 1003 • Electrolyte 1004 • Energy carrier 1003 • Energy density 1005 • Farads 1007 • Fuel cell 1003 • Fuel cell hybrid vehicle (FCHV) 1003 • Fuel-cell stack 1004 • Fuel cell vehicle (FCV) 1003 • Homogeneous Charge Compression Ignition (HCCI) 1011 • Hydraulic Power Assist (HPA) 1010 • Inverter 1008 • Low-grade heat 1006 • Membrane Electrode Assembly (MEA) 1004 • NEDRA 1013 • Plug-in hybrid electric vehicle (PHEV) 1011 • Polymer Electrolyte Fuel Cell (PEFC) 1004 • Proton Exchange Membrane (PEM) 1004 • Range 1012 • Specific energy 1003 • Ultracapacitor 1007 • Wheel motors 1008 • Wind farms 1013

FUEL-CELL TECHNOLOGY

WHAT IS A FUEL CELL?

A **fuel cell** is an electrochemical device in which the chemical energy of hydrogen and oxygen is converted into electrical energy. The principle of the fuel cell was first discovered in 1839 by Sir William Grove, a Welsh physician. In the 1950s, NASA put this principle to work in building devices for powering space exploration vehicles. In the present day, fuel cells are being developed to power homes and vehicles while producing low or zero emissions. ● **SEE FIGURE 91–1.**

The chemical reaction in a fuel cell is the opposite of **electrolysis.** Electrolysis is the process in which electrical current is passed through water in order to break it into its components, hydrogen and oxygen. While energy is required to bring about electrolysis, this same energy can be retrieved by allowing hydrogen and oxygen to reunite in a fuel cell. It is important to note that while hydrogen can be used as a fuel, it is **not** an energy source. Instead, hydrogen is only an **energy carrier,** as energy must be expended to generate the hydrogen and store it so it can be used as a fuel.

In simple terms, a fuel cell is a hydrogen-powered battery. Hydrogen is an excellent fuel because it has a very high **specific energy** when compared to an equivalent amount of fossil fuel. One kilogram (kg) of hydrogen has three times the energy content as one kilogram of gasoline. Hydrogen is the most abundant element on earth, but it does not exist by itself in nature. This is because its natural tendency is to react with oxygen in the atmosphere to form water (H_2O). Hydrogen is also found in many other compounds, most notably hydrocarbons, such as natural gas or crude oil. In order to store hydrogen for use as a fuel, processes must be undertaken to separate it from these materials. ● **SEE FIGURE 91–2.**

BENEFITS OF A FUEL CELL

A fuel cell can be used to move a vehicle by generating electricity to power electric drive motors, as well as powering the remainder of the vehicle's electrical system. Since they are powered by hydrogen and oxygen, fuel cells by themselves do not generate carbon emissions such as CO_2. Instead, their only emissions are water vapor and heat, and this makes the fuel cell an ideal candidate for a ZEV (zero-emission vehicle).

A fuel cell is also much more energy-efficient than a typical internal combustion engine. While a vehicle powered by an internal combustion engine (ICE) is anywhere from 15% to 20% efficient, a fuel-cell vehicle can achieve efficiencies upwards of 40%. Another major benefit of fuel cells is that they have very few moving parts and have the potential to be very reliable. A number of OEMs have spent many years and millions of dollars in order to develop a low-cost, durable, and compact fuel cell that will operate satisfactorily under all driving conditions. ● **SEE FIGURE 91–3.**

A **fuel-cell vehicle (FCV)** uses the fuel cell as its only source of power, whereas a **fuel-cell hybrid vehicle (FCHV)** would also have an electrical storage device that can be used to power the vehicle. Most new designs of fuel-cell vehicles are now based on a hybrid configuration due to the significant increase in efficiency and driveability that can be achieved with this approach. ● **SEE FIGURE 91–4.**

FUEL-CELL CHALLENGES

While major automobile manufacturers continue to build demonstration vehicles and work on improving fuel-cell system design, no vehicle powered by a fuel cell has been placed into mass production. There are a number of reasons for this, including:

- High cost
- Lack of refueling infrastructure
- Safety perception
- Insufficient vehicle range

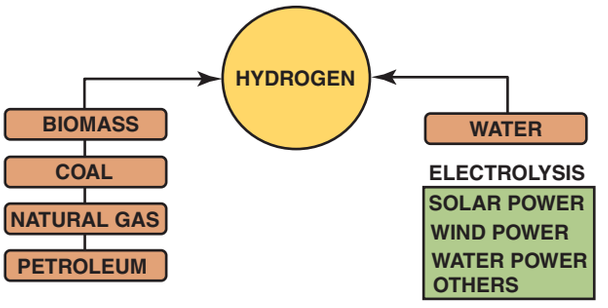


FIGURE 91–2 Hydrogen does not exist by itself in nature. Energy must be expended to separate it from other, more complex materials.

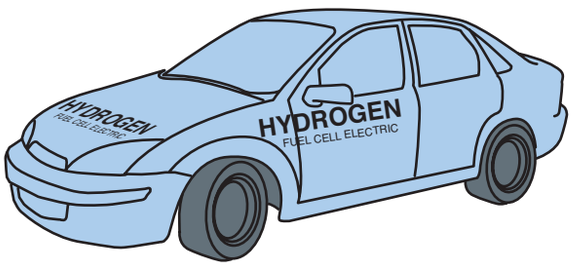


FIGURE 91–1 Ford Motor Company has produced a number of demonstration fuel-cell vehicles based on the Ford Focus.

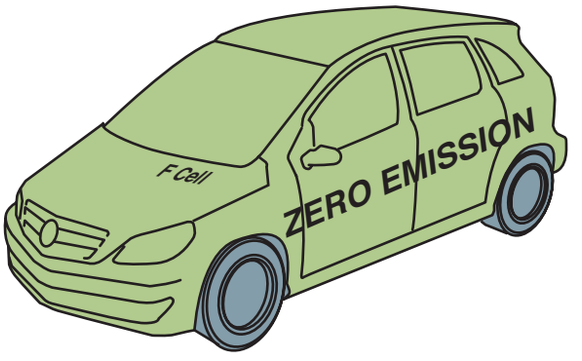


FIGURE 91–3 The Mercedes-Benz B-Class fuel-cell car was introduced in 2005.

	PAFC (PHOSPHORIC ACID FUEL CELL)	PEM (POLYMER ELECTROLYTE MEMBRANE)	MCFC (MOLTEN CARBONATE FUEL CELL)	SOFC (SOLID OXIDE FUEL CELL)
Electrolyte	Orthophosphoric acid	Sulfonic acid in polymer	Li and K carbonates	Yttrium-stabilized zirconia
Fuel	Natural gas, hydrogen	Natural gas, hydrogen, methanol	Natural gas, synthetic gas	Natural gas, synthetic gas
Operating Temp (F) (C)	360–410°F	176–212°F	1100–1300°F	1200–3300°F
	180–210°C	80–100°C	600–700°C	650–1800°C
Electric Efficiency	40%	30–40%	43–44%	50–60%
Manufacturers	ONSI Corp.	Avista, Ballard, Energy Partners, H-Power, International, Plug Power	Fuel Cell Energy, IHI, Hitachi, Siemens	Honeywell, Siemens-Westinghouse, Ceramic
Applications	Stationary power	Vehicles, portable power, small stationary power	Industrial and institutional power	Stationary power, military vehicles

CHART 91–1

Fuel cell types and their temperature operating range.



FIGURE 91–4 The Toyota FCHV is based on the Highlander platform and uses much of Toyota's Hybrid Synergy Drive (HSD) technology in its design.

- Lack of durability
- Freeze starting problems
- Insufficient power density

All of these problems are being actively addressed by researchers, and significant improvements are being made. Once cost and performance levels meet that of current vehicles, fuel cells will be adopted as a mainstream technology. ● **SEE CHART 91–1.**

TYPES OF FUEL CELLS There are a number of different types of fuel cells, and these are differentiated by the type of **electrolyte** that is used in their design. Some electrolytes operate best at room temperature, whereas others are made to operate at up to 1800°F. See the accompanying chart showing the various fuel-cell types and applications.

The fuel-cell design that is best suited for automotive applications is the **Proton Exchange Membrane (PEM).** A PEM fuel cell must have hydrogen for it to operate, and this may be stored on the vehicle or generated as needed from another type of fuel.

PEM FUEL CELLS

DESCRIPTION AND OPERATION The Proton Exchange Membrane fuel cell is also known as a **Polymer Electrolyte Fuel Cell (PEFC).** The PEM fuel cell is known for its lightweight and compact design, as well as its ability to operate at ambient temperatures. This means that a PEM fuel cell can start quickly and produce full power without an extensive warmup period. The PEM is a simple design based on a membrane that is coated on both sides with a catalyst such as platinum or palladium. There are two electrodes, one located on each side of the membrane. These are responsible for distributing hydrogen and oxygen over the membrane surface, removing waste heat, and providing a path for electrical current flow. The part of the PEM fuel cell that contains the membrane, catalyst coatings, and electrodes is known as the **Membrane Electrode Assembly (MEA).**

The negative electrode (anode) has hydrogen gas directed to it, while oxygen is sent to the positive electrode (cathode). Hydrogen is sent to the negative electrode as H_2 molecules, which break apart into H^+ ions (protons) in the presence of the catalyst. The electrons (e^-) from the hydrogen atoms are sent through the external circuit, generating electricity that can be utilized to perform work. These same electrons are then sent to the positive electrode where they rejoin the H^+ ions that have passed through the membrane and have reacted with oxygen in the presence of the catalyst. This creates H_2O and waste heat, which are the only emissions from a PEM fuel cell. ● **SEE FIGURE 91–5.**

NOTE: It is important to remember that a fuel cell generates direct current (DC) electricity as electrons only flow in one direction (from the anode to the cathode).

FUEL-CELL STACKS A single fuel cell by itself is not particularly useful, as it will generate less than 1 volt of electrical potential. It is more common for hundreds of fuel cells to be built together in a **fuel-cell stack.** In this arrangement, the fuel cells are connected in series so that total voltage of the stack is the sum of the individual cell voltages. The fuel cells are placed end-to-end in the stack, much

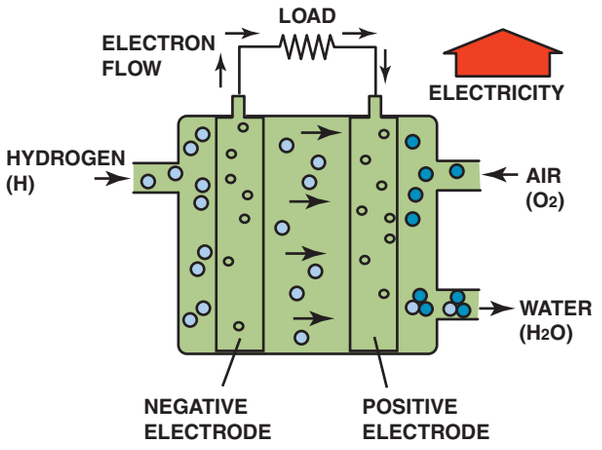


FIGURE 91–5 The polymer electrolyte membrane only allows H^+ ions (protons) to pass through it. This means that electrons must follow the external circuit and pass through the load to perform work.

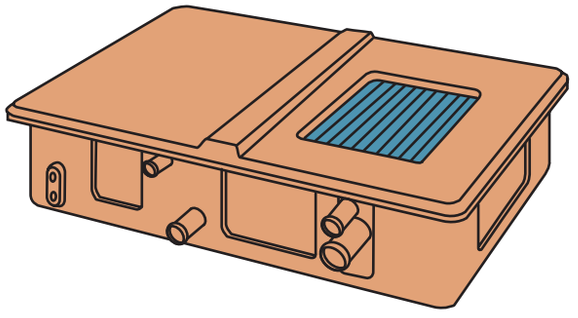


FIGURE 91–6 A fuel-cell stack is made up of hundreds of individual cells connected in series.

like slices in a loaf of bread. Automotive fuel-cell stacks contain upwards of 400 cells in their construction. ● **SEE FIGURE 91–6.**

The total voltage of the fuel-cell stack is determined by the number of individual cells incorporated into the assembly. The current-producing ability of the stack, however, is dependent on the surface area of the electrodes. Since output of the fuel-cell stack is related to both voltage and current (voltage × current = power), increasing the number of cells or increasing the surface area of the cells will increase power output. Some fuel-cell vehicles will use more than one stack, depending on power output requirements and space limitations.

DIRECT METHANOL FUEL CELLS High-pressure cylinders are one method of storing hydrogen onboard a vehicle for use in a fuel cell. This is a simple and lightweight storage method, but often does not provide sufficient vehicle driving range. Another approach has been to fuel a modified PEM fuel cell with liquid methanol instead of hydrogen gas. ● **SEE FIGURE 91–7.**

Methanol is most often produced from natural gas and has a chemical symbol of CH_3OH. It has a higher **energy density** than gaseous hydrogen because it exists in a liquid state at normal temperatures, and is easier to handle since no compressors or other high-pressure equipment is needed. This means that a fuel-cell vehicle can be refueled with a liquid instead of high-pressure gas, which makes the refueling process simpler and produces a greater vehicle driving range. ● **SEE FIGURE 91–8.**

Unfortunately, direct methanol fuel cells suffer from a number of problems, not the least of which is the corrosive nature of methanol itself. This means that methanol cannot be stored in existing

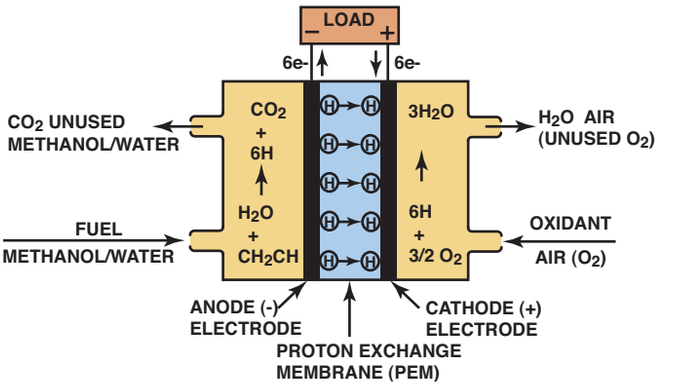


FIGURE 91–7 A direct methanol fuel cell uses a methanol/water solution for fuel instead of hydrogen gas.



FIGURE 91–8 A direct methanol fuel cell can be refueled similar to a gasoline-powered vehicle.

TECH TIP

CO Poisons the PEM Fuel-Cell Catalyst

Purity of the fuel gas is critical with PEM fuel cells. If more than 10 parts per million (ppm) of carbon monoxide is present in the hydrogen stream being fed to the PEM anode, the catalyst will be gradually poisoned and the fuel cell will eventually be disabled. This means that the purity must be "five nines" (99.999% pure). This is a major concern in vehicles where hydrogen is generated by reforming hydrocarbons such as gasoline, because it is difficult to remove all CO from the hydrogen during the reforming process. In these applications, some means of hydrogen purification must be used to prevent CO poisoning of the catalyst.

tanks and thus requires a separate infrastructure for handling and storage. Another problem is "fuel crossover," in which methanol makes its way across the membrane assembly and diminishes performance of the cell. Direct methanol fuel cells also require much greater amounts of catalyst in their construction, which leads to higher costs. These challenges are leading researchers to look for alternative electrolyte materials and catalysts to lower cost and improve cell performance.

NOTE: Direct methanol fuel cells are not likely to see service in automotive applications. However, they are well suited for low-power applications, such as cell phones or laptop computers.

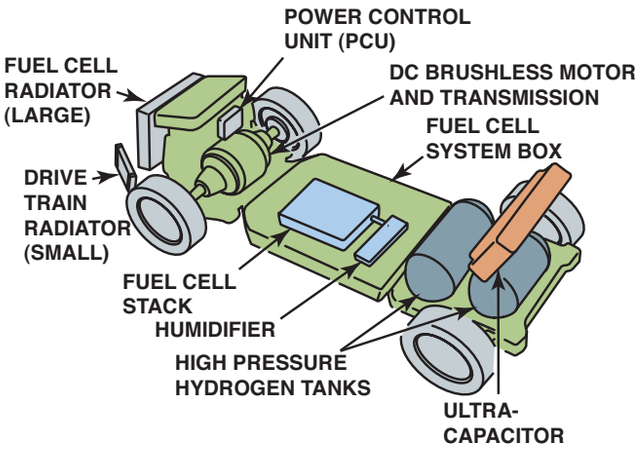


FIGURE 91–9 Powertrain layout in a Honda FCX fuel-cell vehicle. Note the use of a humidifier behind the fuel-cell stack to maintain moisture levels in the membrane electrode assemblies.

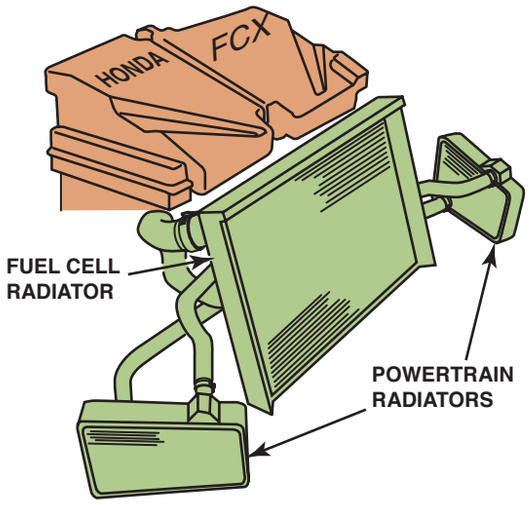


FIGURE 91–10 The Honda FCX uses one large radiator for cooling the fuel cell, and two smaller ones on either side for cooling drive train components.

FREQUENTLY ASKED QUESTION

What Is the Role of the Humidifier in a PEM Fuel Cell?

The polymer electrolyte membrane assembly in a PEM fuel cell acts as conductor of positive ions and as a gas separator. However, it can only perform these functions effectively if it is kept moist. A fuel-cell vehicle uses an air compressor to supply air to the positive electrodes of each cell, and this air is sometimes sent through a humidifier first to increase its moisture content. The humid air then comes in contact with the membrane assembly and keeps the electrolyte damp and functioning correctly.

FREQUENTLY ASKED QUESTION

When Is Methanol Considered to Be a "Carbon-Neutral" Fuel?

Most of the methanol in the world is produced by reforming natural gas. Natural gas is a hydrocarbon, but does not increase the carbon content of our atmosphere as long as it remains in reservoirs below the earth's surface. However, natural gas that is used as a fuel causes extra carbon to be released into the atmosphere, which is said to contribute to global warming. Natural gas is not a carbon-neutral fuel, and neither is methanol that is made from natural gas.

Fortunately, it is possible to generate methanol from biomass and wood waste. Methanol made from renewable resources is carbon neutral, because no extra carbon is being released into the earth's atmosphere than what was originally absorbed by the plants used to make the methanol.

FUEL-CELL VEHICLE SYSTEMS

HUMIDIFIERS Water management inside a PEM fuel cell is critical. Too much water can prevent oxygen from making contact with the positive electrode; too little water can allow the electrolyte to dry out and lower its conductivity. The amount of water and where it resides in the fuel cell is also critical in determining at how low a temperature the fuel cell will start, because water freezing in the fuel cell can prevent it from starting. The role of the humidifier is to achieve a balance where it is providing sufficient moisture to the fuel cell by recycling water that is evaporating at the cathode. The humidifier is located in the air line leading to the cathode of the fuel-cell stack. ● **SEE FIGURE 91–9.**

Some newer PEM designs manage the water in the cells in such a way that there is no need to pre-humidify the incoming reactant gases. This eliminates the need for the humidifier assembly and makes the system simpler overall.

FUEL-CELL COOLING SYSTEMS Heat is generated by the fuel cell during normal operation. Excess heat can lead to a breakdown of the polymer electrolyte membrane, so a liquid cooling system must be utilized to remove waste heat from the fuel-cell stack. One of the major challenges for engineers in this regard is the fact that the heat generated by the fuel cell is classified as **low-grade heat.** This means that there is only a small difference between the temperature of the coolant and that of the ambient air. Heat transfers very slowly under these conditions, so heat exchangers with a much larger surface area must be utilized. ● **SEE FIGURE 91–10.**

In some cases, heat exchangers may be placed in other areas of the vehicle when available space at the front of the engine compartment is insufficient. In the case of the Toyota FCHV, an auxiliary heat exchanger is located underneath the vehicle to increase the cooling system heat-rejection capacity. ● **SEE FIGURE 91–11.**

An electric water pump and a fan drive motor are used to enable operation of the fuel cell's cooling system. These and other support devices use electrical power that is generated by the fuel cell, and therefore tend to decrease the overall efficiency of the vehicle.

AIR SUPPLY PUMPS Air must be supplied to the fuel-cell stack at the proper pressure and flow rate to enable proper performance under all driving conditions. This function is performed by an onboard air supply pump that compresses atmospheric air and



FIGURE 91–11 Space is limited at the front of the Toyota FCHV engine compartment, so an auxiliary heat exchanger is located under the vehicle to help cool the fuel-cell stack.

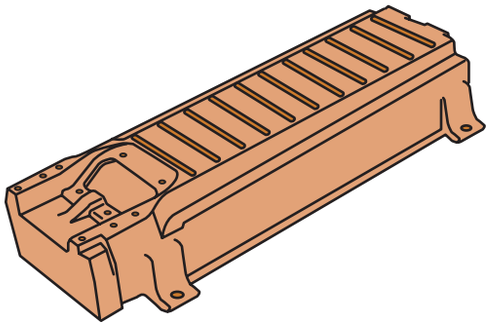


FIGURE 91–12 The secondary battery in a fuel-cell hybrid vehicle is made up of many individual cells connected in series, much like a fuel-cell stack.

supplies it to the fuel cell's positive electrode (cathode). This pump is often driven by a high-voltage electric drive motor.

FUEL-CELL HYBRID VEHICLES

Hybridization tends to increase efficiency in vehicles with conventional drive trains, as energy that was once lost during braking and otherwise normal operation is instead stored for later use in a high-voltage battery or **ultracapacitor.** This same advantage can be gained by applying the hybrid design concept to fuel-cell vehicles. Whereas the fuel cell is the only power source in a fuel-cell vehicle, the fuel-cell hybrid vehicle (FCHV) relies on both the fuel cell and an electrical storage device for motive power. Driveability is also enhanced with this design, as the electrical storage device is able to supply energy immediately to the drive motors and overcome any "throttle lag" on the part of the fuel cell.

SECONDARY BATTERIES. All hybrid vehicle designs require a means of storing electrical energy that is generated during regenerative braking and other applications. In most FCHV designs, a high-voltage nickel-metal hydride (NiMH) battery pack is used as a secondary battery. This is most often located near the back of the vehicle, either under or behind the rear passenger seat. ● **SEE FIGURE 91–12.** The secondary battery is built similar to a fuel-cell stack, because it is made up of many low-voltage cells connected in series to build a high-voltage battery.

ULTRACAPACITORS. An alternative to storing electrical energy in batteries is to use ultracapacitors. A capacitor is best known as an electrical device that will block DC current, but allow AC to pass. However, a capacitor can also be used to store electrical energy, and it is able to do this without a chemical reaction. Instead, a

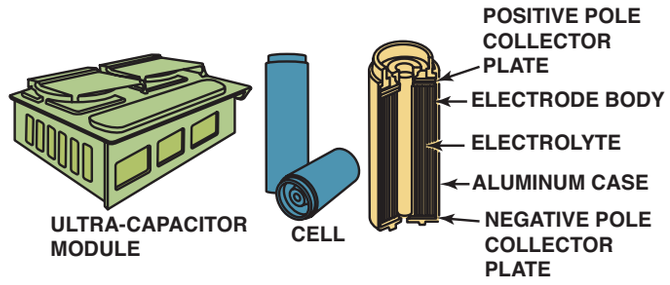


FIGURE 91–13 The Honda ultracapacitor module and construction of the individual cells.

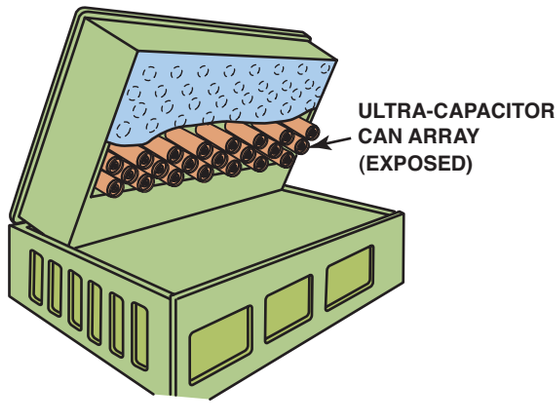


FIGURE 91–14 An ultracapacitor can be used in place of a high-voltage battery in a hybrid electric vehicle. This example is from the Honda FCX fuel-cell hybrid vehicle.

capacitor stores electrical energy using the principle of electrostatic attraction between positive and negative charges.

Ultracapacitors are built very different from conventional capacitors. Ultracapacitor cells are based on **double-layer technology,** in which two activated-carbon electrodes are immersed in an organic electrolyte. The electrodes have a very large surface area and are separated by a membrane that allows ions to migrate but prevents the electrodes from touching. ● **SEE FIGURE 91–13.** Charging and discharging occurs as ions move within the electrolyte but no chemical reaction takes place. Ultracapacitors can charge and discharge quickly and efficiently, making them especially suited for electric assist applications in fuel-cell hybrid vehicles.

Ultracapacitors that are used in fuel-cell hybrid vehicles are made up of multiple cylindrical cells connected in parallel. ● **SEE FIGURE 91–14.** This results in the total capacitance being the sum of the values of each individual cell. For example, ten 1.0-**farad** capacitors connected in parallel will have a total capacitance of 10.0 farads. Greater capacitance means greater electrical storage ability, and this contributes to greater assist for the electric motors in a fuel-cell hybrid vehicle.

Ultracapacitors have excellent cycle life, meaning that they can be fully charged and discharged many times without degrading their performance. They are also able to operate over a wide temperature range and are not affected by low temperatures to the same degree as many battery technologies. The one major downside of ultracapacitors is a lack of specific energy, which means that they are best suited for sudden bursts of energy as opposed to prolonged discharge cycles. Research is being conducted to improve this and other aspects of ultracapacitor performance.

FUEL-CELL TRACTION MOTORS. Much of the technology behind the electric drive motors being used in fuel-cell vehicles was developed during the early days of the California ZEV mandate. This was a period when battery-powered electric vehicles were being built by the

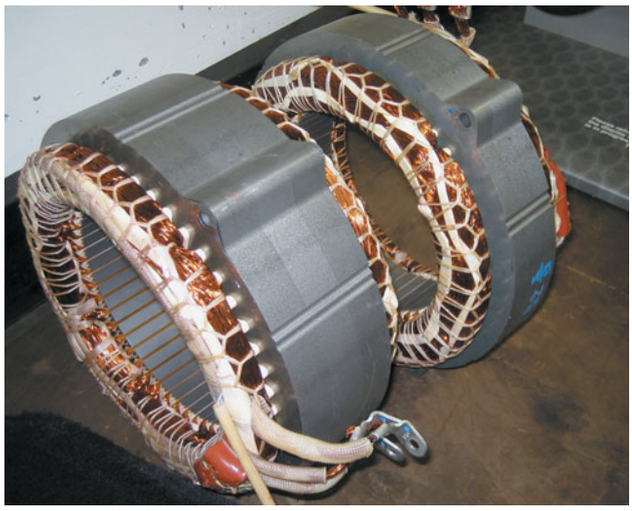


FIGURE 91–15 Drive motors in fuel-cell hybrid vehicles often use stator assemblies similar to ones found in Toyota hybrid electric vehicles. The rotor turns inside the stator and has permanent magnets on its outer circumference.

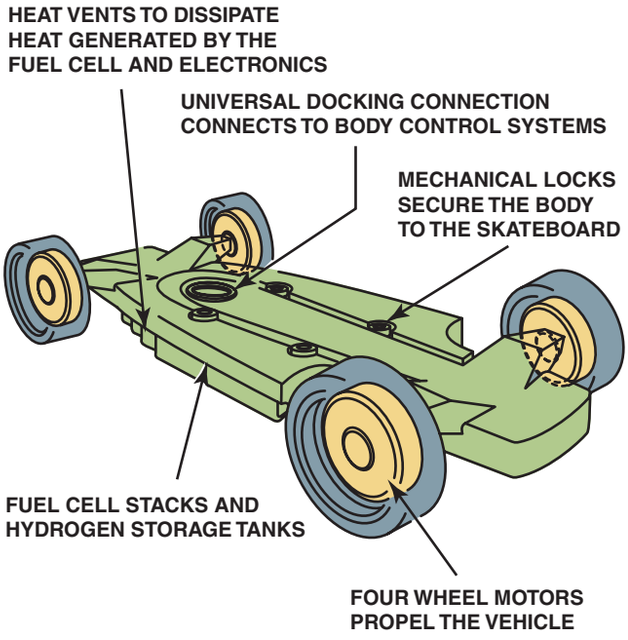


FIGURE 91–16 The General Motors "Skateboard" concept uses a fuel-cell propulsion system with wheel motors at all four corners.

major vehicle manufacturers in an effort to meet a legislated quota in the state of California. The ZEV mandate rules were eventually relaxed to allow other types of vehicles to be substituted for credit, but the technology that had been developed for pure electric vehicles was now put to work in these other vehicle designs.

The electric traction motors used in fuel-cell hybrid vehicles are very similar to those being used in current hybrid electric vehicles. The typical drive motor is based on an AC synchronous design, which is sometimes referred to as a DC brushless motor. This design is very reliable as it does not use a commutator or brushes, but instead has a three-phase stator and a permanent magnet rotor. ● **SEE FIGURE 91–15.** An electronic controller (inverter) is used to generate the three-phase high-voltage AC current required by the motor. While the motor itself is very simple, the electronics required to power and control it are complex.

Some fuel-cell hybrid vehicles use a single electric drive motor and a transaxle to direct power to the vehicle's wheels. It is also possible to use **wheel motors** to drive individual wheels. While this approach adds a significant amount of unsprung weight to the chassis, it allows for greater control of the torque being applied to each individual wheel. ● **SEE FIGURE 91–16.**

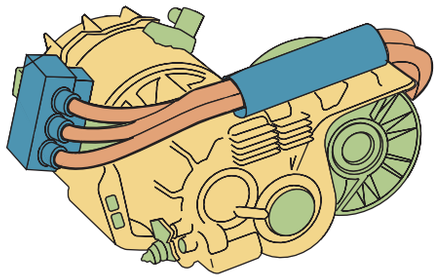


FIGURE 91–17 The electric drive motor and transaxle assembly from a Toyota FCHV. Note the three orange cables, indicating that this motor is powered by high-voltage three-phase alternating current.

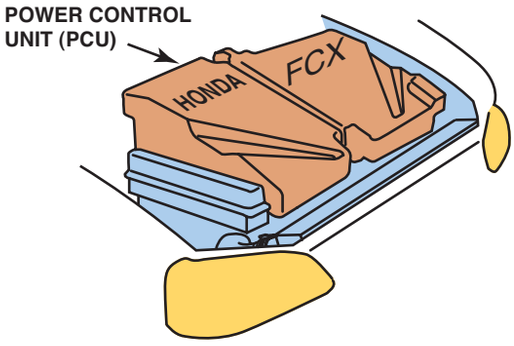


FIGURE 91–18 The power control unit (PCU) on a Honda FCX fuel-cell hybrid vehicle is located under the hood.

TRANSAXLES. Aside from the hydrogen fueling system, fuel-cell hybrid vehicles are effectively pure electric vehicles in that their drive train is electrically driven. Electric motors work very well for automotive applications because they produce high torque at low RPMs and are able to maintain a consistent power output throughout their entire RPM range. This is in contrast to vehicles powered by internal combustion engines, which produce very little torque at low RPMs and have a narrow range where significant horsepower is produced.

ICE-powered vehicles require complex transmissions with multiple speed ranges in order to accelerate the vehicle quickly and maximize the efficiency of the ICE. Fuel-cell hybrid vehicles use electric drive motors that require only a simple reduction in their final drive and a differential to send power to the drive wheels. No gear shifting is required and mechanisms such as torque converters and clutches are done away with completely. A reverse gear is not required either, as the electric drive motor is simply powered in the opposite direction. The transaxles used in fuel-cell hybrid vehicles are extremely simple with few moving parts, making them extremely durable, quiet, and reliable. ● **SEE FIGURE 91–17.**

POWER CONTROL UNITS. The drive train of a fuel-cell hybrid vehicle is controlled by a power control unit (PCU), which controls fuel-cell output and directs the flow of electricity between the various components. One of the functions of the PCU is to act as an **inverter,** which changes direct current from the fuel-cell stack into three-phase alternating current for use in the vehicle drive motor(s). ● **SEE FIGURE 91–18.**

Power to and from the secondary battery is directed through the power control unit, which is also responsible for maintaining the battery pack's state of charge and for controlling and directing the output of the fuel-cell stack. ● **SEE FIGURE 91–19.**

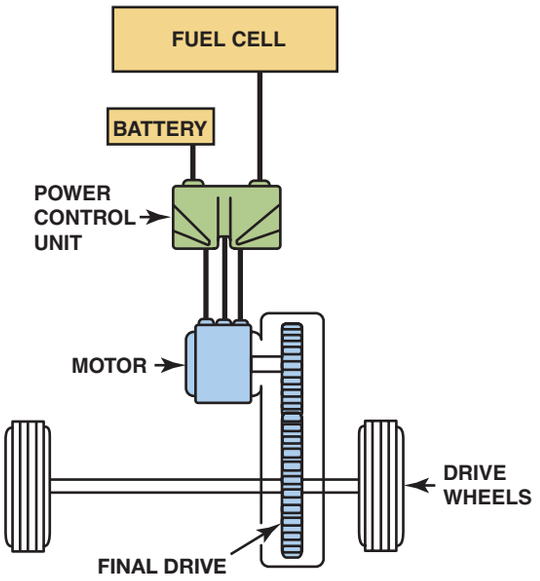


FIGURE 91–19 Toyota's FCHV uses a power control unit that directs electrical energy flow between the fuel cell, battery, and drive motor.

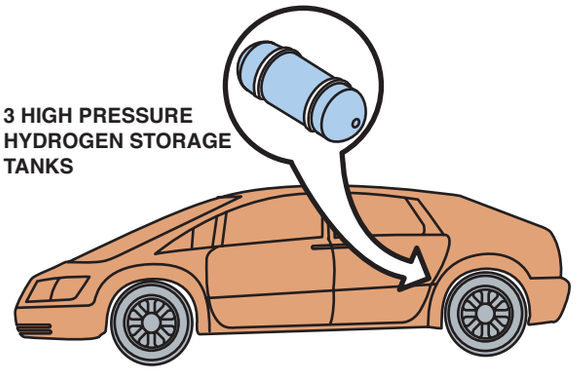


FIGURE 91–20 This GM fuel-cell vehicle uses compressed hydrogen in three high-pressure storage tanks.

During regenerative braking, the electric drive motor acts as a generator and converts kinetic (moving) energy of the vehicle into electricity for recharging the high-voltage battery pack. The PCU must take the three-phase power from the motor (generator) and convert (or *rectify*) this into DC voltage to be sent to the battery. DC power from the fuel cell will also be processed through the PCU for recharging the battery pack.

A DC-to-DC converter is used in hybrid-electric vehicles for converting the high voltage from the secondary battery pack into the 12 volts required for the remainder of the vehicle's electrical system. Depending on the vehicle, there may also be 42 volts required to operate accessories such as the electric-assist power steering. In fuel-cell hybrid vehicles, the DC-to-DC converter function may be built into the power control unit, giving it full responsibility for the vehicle's power distribution.

HYDROGEN STORAGE

One of the pivotal design issues with fuel-cell hybrid vehicles is how to store sufficient hydrogen onboard to allow for reasonable vehicle range. Modern drivers have grown accustomed to having a minimum of 300 miles between refueling stops, a goal that is extremely difficult to achieve when fueling the vehicle with hydrogen. Hydrogen has a very high energy content on a pound-for-pound basis, but its energy density is less than that of conventional liquid fuels. This is because gaseous hydrogen, even at high pressure, has a very low physical density (mass per unit volume). ● **SEE FIGURE 91–20.**

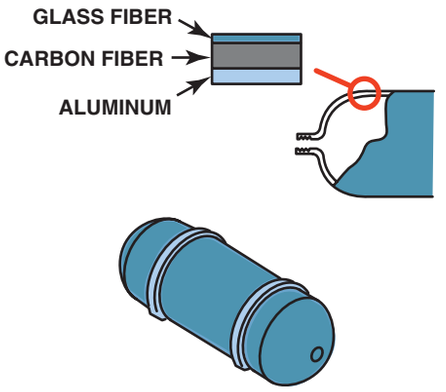


FIGURE 91–21 The Toyota FCHV uses high-pressure storage tanks that are rated at 350 bar. This is the equivalent of 5,000 pounds per square inch.



FIGURE 91–22 The high-pressure fitting used to refuel a fuel-cell hybrid vehicle.

A number of methods of hydrogen storage are being considered for use in fuel-cell hybrid vehicles. These include high-pressure compressed gas, liquefied hydrogen, and solid storage in metal hydrides. Efficient hydrogen storage is one of the technical issues that must be solved in order for fuel cells to be adopted for vehicle applications. Much research is being conducted to solve the issue of onboard hydrogen storage.

HIGH-PRESSURE COMPRESSED GAS. Most current fuel-cell hybrid vehicles use compressed hydrogen that is stored in tanks as a high-pressure gas. This approach is the least complex of all the storage possibilities, but also has the least energy density. Multiple small storage tanks are often used rather than one large one in order to fit them into unused areas of the vehicle. One drawback with this approach is that only cylinders can be used to store gases at the required pressures. This creates a good deal of unused space around the outside of the cylinders and leads to further reductions in hydrogen storage capacity. It is common for a pressure of 5000 psi (350 bar) to be used, but technology is available to store hydrogen at up to 10,000 psi (700 bar). ● **SEE FIGURE 91–21.**

The tanks used for compressed hydrogen storage are typically made with an aluminum liner wrapped in several layers of carbon fiber and an external coating of fiberglass. In order to refuel the compressed hydrogen storage tanks, a special high-pressure fitting is installed in place of the filler neck used for conventional vehicles. ● **SEE FIGURE 91–22.** There is also a special electrical connector



FIGURE 91–23 Note that high-pressure hydrogen storage tanks must be replaced in 2020.

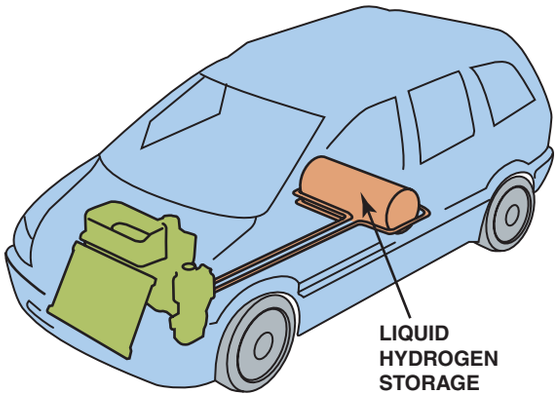


FIGURE 91–24 GM's Hydrogen3 has a range of 249 miles when using liquid hydrogen.

that is used to enable communication between the vehicle and the filling station during the refueling process. ● **SEE FIGURE 91–23.**

The filling station utilizes a special coupler to connect to the vehicle's high-pressure refueling fitting. The coupler is placed on the vehicle fitting, and a lever on the coupler is rotated to seal and lock it into place.

LIQUID HYDROGEN. Hydrogen can be liquefied in an effort to increase its energy density, but this requires that it be stored in cryogenic tanks at −423°F (−253°C). This increases vehicle range, but impacts overall efficiency, as a great deal of energy is required to liquefy the hydrogen and a certain amount of the liquid hydrogen will "boil off" while in storage.

One liter of liquid hydrogen only has one-fourth the energy content of 1 liter of gasoline. ● **SEE FIGURES 91–24 AND 91–25.**

SOLID STORAGE OF HYDROGEN. One method discovered to store hydrogen in solid form is as a metal hydride, similar to how a nickel-metal hydride (NiMH) battery works.

A demonstration vehicle features a lightweight fiber-wrapped storage tank under the body that stores 3 kg (about 6.6 pounds) of hydrogen as a metal hydride at low pressure. The vehicle can travel almost 200 miles with this amount of fuel. One kilogram of hydrogen is equal to 1 gallon of gasoline. Three gallons of water will generate 1 kilogram of hydrogen.

A metal hydride is formed when gaseous hydrogen molecules disassociate into individual hydrogen atoms and bond with the metal atoms in the storage tank. This process uses powdered metallic alloys capable of rapidly absorbing hydrogen to make this occur.

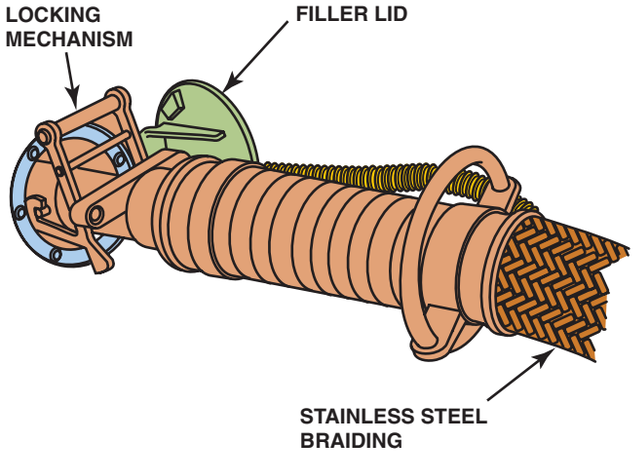


FIGURE 91–25 Refueling a vehicle with liquid hydrogen.

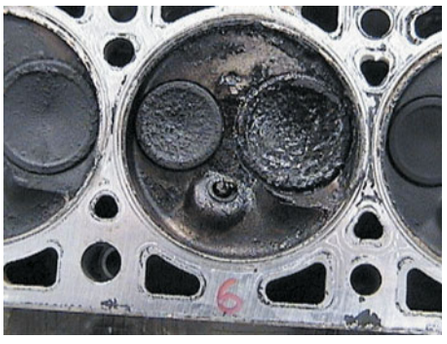


FIGURE 91–26 Carbon deposits, such as these, are created by incomplete combustion of a hydrocarbon fuel.

TECH TIP

Hydrogen Fuel = No Carbon

Most fuels contain hydrocarbons or molecules that contain both hydrogen and carbon. During combustion, the first element that is burned is the hydrogen. If combustion is complete, then all of the carbon is converted to carbon dioxide gas and exits the engine in the exhaust. However, if combustion is not complete, carbon monoxide is formed, plus leaving some unburned carbon to accumulate in the combustion chamber. ● **SEE FIGURE 91–26.**

HYDRAULIC HYBRID STORAGE SYSTEM

Ford Motor Co. is experimenting with a system it calls **Hydraulic Power Assist (HPA).** This system converts kinetic energy to hydraulic pressure, and then uses that pressure to help accelerate the vehicle. It is currently being tested on a four-wheel-drive (4WD) Lincoln Navigator with a 4.0-L V-8 engine in place of the standard 5.4-L engine.

A variable-displacement hydraulic pump/motor is mounted on the transfer case and connected to the output shaft that powers the front drive shaft. The HPA system works with or without 4WD engaged. A valve block mounted on the pump contains solenoid valves to control the flow of hydraulic fluid. A 14-gallon, high-pressure accumulator is mounted behind the rear axle, with a low-pressure accumulator right behind it to store hydraulic fluid. The master cylinder has a

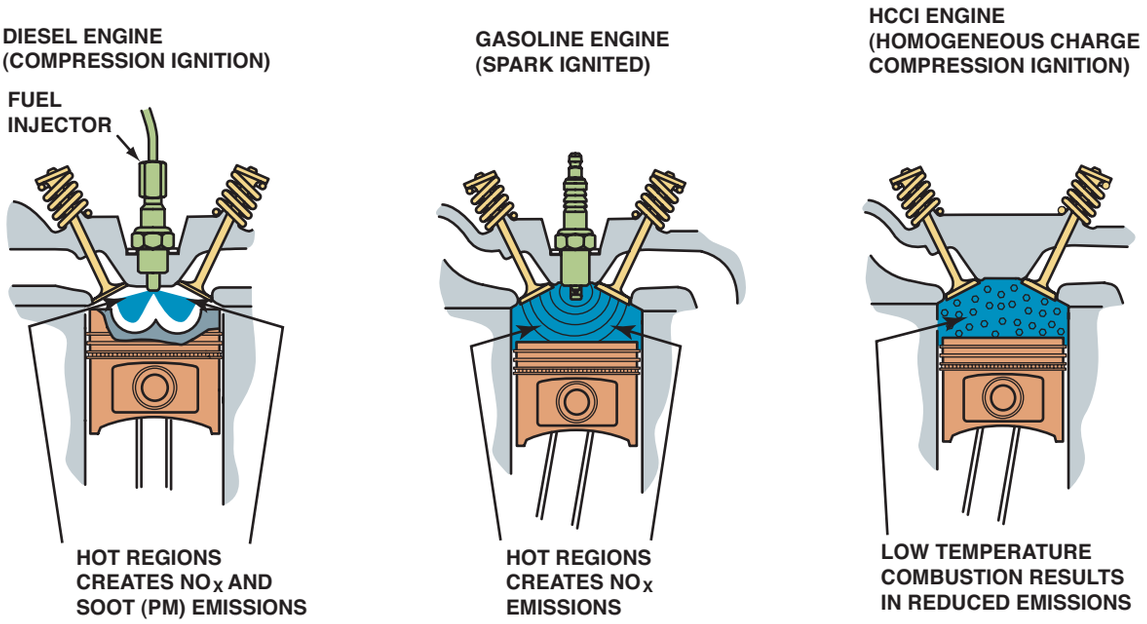


FIGURE 91–27 Both diesel and conventional gasoline engines create exhaust emissions due to high peak temperatures created in the combustion chamber. The lower combustion temperatures during HCCI operation result in high efficiency with reduced emissions.

"deadband," meaning the first few fractions of an inch of travel do not pressurize the brake system. When the driver depresses the brake pedal, a pedal movement sensor signals the control unit, which then operates solenoid valves to send hydraulic fluid from the low-pressure reservoir to the pump. The pumping action slows the vehicle, similar to engine compression braking, and the fluid is pumped into the high-pressure reservoir. Releasing the brake and pressing on the accelerator signals the control unit to send that high-pressure fluid back to the pump, which then acts as a hydraulic motor and adds torque to the drive line. The system can be used to launch the vehicle from a stop and/or add torque for accelerating from any speed.

While the concept is simple, the system itself is very complicated. Additional components include:

- Pulse suppressors
- Filters
- An electric circulator pump for cooling the main pump/motor

Potential problems with this system include leakage problems with seals and valves, getting air out of the hydraulic fluid system, and noise. In prototype stages the system demands different driving techniques. Still, this system was built to prove the concept, and the engineers believe that these problems can be solved and that a control system can be developed that will make HPA transparent to the driver. A 23% improvement in fuel economy and improvements in emissions reduction were achieved using a dynamometer set for a 7,000-pound vehicle. While the HPA system could be developed for any type of vehicle with any type of drive train, it does add weight and complexity, which would add to the cost.

HCCI

Homogeneous Charge Compression Ignition (HCCI) is a combustion process. HCCI is the combustion of a very lean gasoline air–fuel mixture without the use of a spark ignition. It is a low-temperature, chemically controlled (flameless) combustion process. ● **SEE FIGURE 91–27.**

HCCI combustion is difficult to control and extremely sensitive to changes in temperature, pressure, and fuel type. While the challenges of HCCI are difficult, the advantages include having a gasoline engine being able to deliver 80% of diesel efficiency (a 20% increase in fuel economy) for 50% of the cost. A diesel engine using HCCI can deliver gasoline-like emissions. Spark and injection timing are no longer a factor as they are in a conventional port-fuel injection system.

While much research and development needs to be performed using this combustion process, it has been shown to give excellent performance from idle to mid-load, and from ambient to warm operating temperatures as well as cold-start and run capability. Because an engine only operates in HCCI mode at light throttle settings, such as during cruise conditions at highway speeds, engineers need to improve the transition in and out of the HCCI mode. Work is also being done on piston and combustion chamber shape to reduce combustion noise and vibration that is created during operation in the HCCI operating mode.

Ongoing research is focusing on improving fuel economy under real-world operating conditions as well as controlling costs.

PLUG-IN HYBRID ELECTRIC VEHICLES

A **plug-in hybrid electric vehicle (PHEV)** is a hybrid electric vehicle that is designed to be plugged into an electrical outlet at night to charge the batteries. By charging the batteries in the vehicle, it can operate using electric power alone (stealth mode) for a longer time, thereby reducing the use of the internal combustion engine (ICE). The less the ICE is operating, the less fuel is consumed and the lower the emissions. At the present time, plug-in hybrids are not offered by any major manufacturer but many conventional HEVs are being converted to plug-in hybrids by adding additional batteries.

If a production plug-in hybrid is built, it should be able to get about twice the fuel economy of a conventional hybrid. The extra weight of the batteries will be offset, somewhat, by the reduced weight of a smaller ICE. At highway speeds, fuel efficiency is affected primarily by aerodynamics, and therefore the added weight of the extra batteries is equal to one or two additional passengers and thus would only slightly reduce fuel economy. Recharging will normally take place at night during cheaper off-peak hours. Counting fuel and service, the total lifetime cost of ownership will be lower than a conventional gasoline-powered vehicle.



FIGURE 91–28 A typical electric vehicle charging station on the campus of a college in southern California.



FIGURE 91–29 A conductive-type charging connector. This type of battery charging connector is sometimes called an AVCON connector, named for the manufacturer.

There are emissions related to the production of the electricity, which are called *well-to-wheel emissions.* These emissions, including greenhouse gases, are far lower than those of gasoline, even for the national power grid, which is 50% coal. Vehicles charging off-peak will use power from plants that cannot be turned off at night and often use cleaner sources such as natural gas and hydroelectric power. Plug-in hybrids could be recharged using rooftop photovoltaic systems, which would create zero emissions.

THE FUTURE FOR ELECTRIC VEHICLES

The future of electric vehicles depends on many factors, including:

1. The legislative and environmental incentives to overcome the cost and research efforts to bring a usable electric vehicle to the market.
2. The cost of alternative energy. If the cost of fossil fuels increases to the point that the average consumer cannot afford to drive a conventional vehicle, then electric vehicles (EVs) may be a saleable alternative.
3. Advancement in battery technology that would allow the use of lighter-weight and higher-energy batteries.

COLD-WEATHER CONCERNS Past models of electric vehicles such as the General Motors electric vehicle (EV1) were restricted to locations such as Arizona and southern California that had a warm climate, because cold weather is a major disadvantage to the use of electric vehicles for the following reasons:

- Cold temperatures reduce battery efficiency.
- Additional electrical power from the batteries is needed to heat the batteries themselves to be able to achieve reasonable performance.
- Passenger compartment heating is a concern for an electric vehicle because it would require the use of resistance units or other technology that would reduce the range of the vehicle.

HOT-WEATHER CONCERNS Batteries do not function well at high temperatures, and therefore some type of battery cooling must be added to the vehicle to allow for maximum battery performance. This would then result in a reduction of vehicle range due to the use of battery power needed just to keep the batteries working properly. Besides battery concerns, the batteries would also have to supply the power needed to keep the interior cool as well as all of the other accessories. These combined electrical loads represent a huge battery drain and reduce the range of the vehicle.

RECHARGING METHODS AND CONCERNS How far an electric vehicle can travel on a full battery charge is called its **range.** The range of an electric vehicle depends on many factors, including:

- Battery energy storage capacity
- Vehicle weight
- Outside temperature
- Terrain (driving in hilly or mountainous areas requires more energy from the battery)
- Use of air conditioning and other electrical devices

Because electric vehicles have a relatively short range, charging stations must be made available in areas where these vehicles are driven. For example, when the state of California mandated the sale of zero-emission vehicles (ZEV), charging stations were set up in many areas, usually in parking lots of businesses and schools. ● **SEE FIGURE 91–28.** The parking spaces near the charging stations were designated for electric vehicles only and could be used for free to recharge electric vehicles. If electric vehicles are going to become widely used, charging stations will have to be established to allow the necessary recharging for trips to work and back home.

CHARGING METHODS When the state of California set up electric vehicle charging stations, both a conductive- and inductive-type charger was made available at each station.

CONDUCTIVE CHARGING. Conductive charging uses an electrical plug that makes physical contact with terminals in the vehicle. The charger can be powered by 110-V AC, or most commonly 220-V AC. ● **SEE FIGURE 91–29.** This type of charger connection is used on some Ford and Honda electric vehicles.

INDUCTIVE CHARGING. Inductive charging is achieved by inserting a paddlelike probe into a charging receptacle (opening) in the vehicle. The charger is powered by 220-volt AC and does not make physical contact with the vehicle. ● **SEE FIGURE 91–30.**

An inductive charger paddle contains a coil of wire and the AC current from the charger flows through the winding, which creates a moving magnetic field around the paddle. Inside the charging receptacle of the vehicle is another coil of wire. The alternating magnetic field induces an AC voltage in the coil winding.



FIGURE 91–30 An inductive-type electric vehicle battery charger connector. This type of connector fits into a charging slot in the vehicle, but does not make electrical contact.

FREQUENTLY ASKED QUESTION

What Is NEDRA?

NEDRA is the **National Electric Drag Racing Association** that holds drag races for electric-powered vehicles throughout the United States. The association does the following:

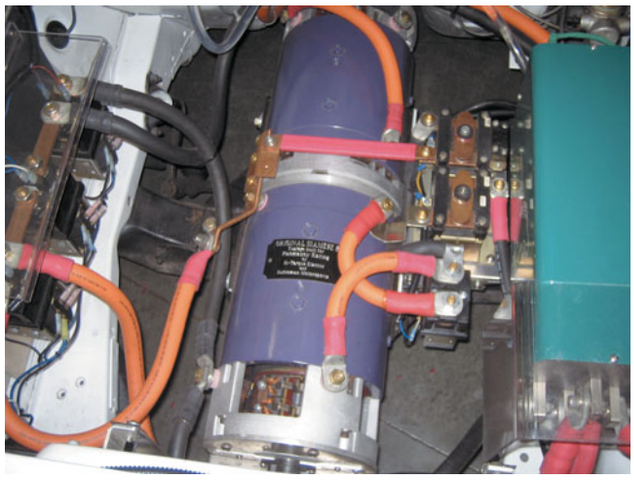
1. Coordinates a standard rule set for electric vehicle drag racing, to balance the needs and interests of all those involved in the sport.
2. Sanctions electric vehicle drag racing events, to:
   - Make the events as safe as possible.
   - Record and maintain official records.
   - Maintain consistency on a national scale.
   - Coordinate and schedule electric vehicle drag racing events.
3. Promotes electric vehicle drag racing to:
   - Educate the public and increase people's awareness of electric vehicles while eliminating any misconceptions.
   - Have fun in a safe and silent drag racing environment.

● **SEE FIGURE 91–31.**

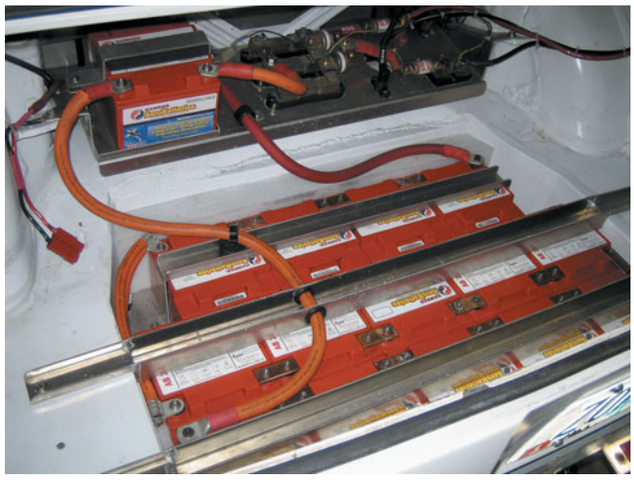
The electronics in the vehicle then changes the induced AC current into DC current to charge the batteries. Inductive-type chargers are used with the General Motors EV-1, as well as Nissan and Toyota electric vehicles.

WIND POWER

Wind power is used to help supplement electric power generation in many parts of the country. Because AC electricity cannot be stored, this energy source is best used to reduce the use of natural gas and coal to help reduce CO_2 emissions. Wind power is most economical if the windmills are located where the wind blows consistently above 8 miles per hour (13 km/h). Locations include the eastern slope of mountain ranges, such as the Rocky Mountains, or on high ground in many states. Often, wind power is used as supplemental power in the evenings when it is most needed, and is allowed to stop rotating in daylight hours when the power is not needed. Windmills are usually grouped together to form **wind farms,** where the product is electrical energy. Energy from wind farms can be used to charge plug-in hybrid vehicles, as well as for domestic lighting and power needs. ● **SEE FIGURES 91–32 AND 91–33.**



(a)



(b)

FIGURE 91–31 (a) The motor in a compact electric drag car. This 8-inch-diameter motor is controlled by an electronic controller that limits the voltage to 170 volts to prevent commutator flashover yet provides up to 2,000 amperes. This results in an amazing 340,000 watts or 455 Hp. (b) The batteries used for the compact drag car include twenty 12-volt absorbed glass mat (AGM) batteries connected in series to provide 240 volts.

HYDROELECTRIC POWER

Hydroelectric power is limited to locations where there are dammed rivers and hydroelectric plants. However, electricity can and is transmitted long distances—so that electricity generated at the Hoover Dam can be used in California and other remote locations. Electrical power from hydroelectric sources can be used to charge plug-in hybrid electric vehicles, thereby reducing emissions that would normally be created by burning coal or natural gas to create electricity. However, hydroelectric plants are limited as to the amount of power they can produce, and constructing new plants is extremely expensive. ● **SEE FIGURE 91–34.**

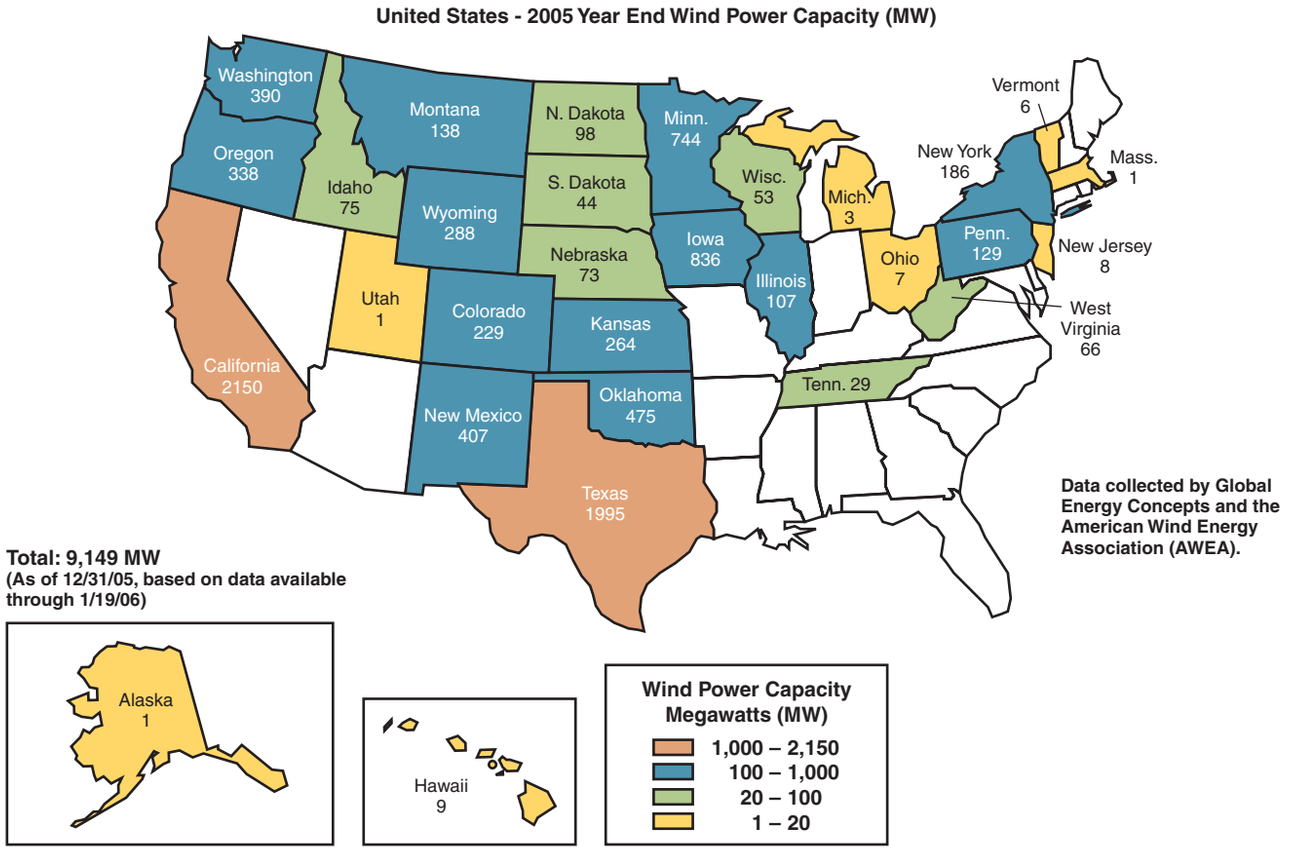


FIGURE 91–32 Wind power capacity by area. *(Courtesy of U.S. Department of Energy)*



FIGURE 91–33 A typical wind generator that is used to generate electricity.



FIGURE 91–34 The Hoover Dam in Nevada/Arizona is used to create electricity for use in the southwest United States.

REVIEW QUESTIONS

1. How does a fuel cell work?
2. What are the advantages and disadvantages of fuel cells?
3. What are the uses of the various types of fuel cells?
4. How does an ultracapacitor work?
5. What are the advantages and disadvantages of using hydrogen?
6. What alternative power sources could be used for vehicles?

CHAPTER QUIZ

1. A fuel cell produces electricity from _____ and _____.
   a. Gasoline/oxygen
   b. Nitrogen/hydrogen
   c. Hydrogen/oxygen
   d. Water/oxygen
2. What are the by-products (emissions) from a fuel cell?
   a. Water
   b. CO_2
   c. CO
   d. Nonmethane hydrocarbon

3. Which type of fuel cell is the most likely to be used to power vehicles?
   a. PAFC **c.** MCFC
   b. PEM **d.** SOFC
4. Which liquid fuel could be used to directly power a fuel cell?
   a. Methanol **c.** Biodiesel
   b. Ethanol **d.** Unleaded gasoline
5. Which is *not* a function of an ultracapacitor?
   a. Can pass AC current
   b. Can be charged with DC current
   c. Discharges DC current
   d. Can pass DC current
6. Hydrogen is commonly stored at what pressure?
   a. 100,000 psi **c.** 5,000 psi
   b. 50,000 psi **d.** 1,000 psi
7. Hydrogen storage tanks are usually constructed from _____.
   a. Steel **c.** Carbon fiber
   b. Aluminum **d.** Both b and c
8. HCCI is a process that eliminates what parts or components in a gasoline engine?
   a. Fuel tank **c.** Fuel injectors
   b. Battery **d.** Ignition system
9. A plug-in hybrid is different from a conventional hybrid electric vehicle because it has _____.
   a. A built-in battery charger **c.** More batteries
   b. Li Ox batteries **d.** Bigger motor/generator
10. Which energy source(s) is (are) currently being used to help reduce the use of fossil fuels?
    a. Hydrogen **c.** Hydroelectric power
    b. Wind power **d.** Both b and c

SECTION XI Brakes

92 Braking System Components and Performance Standards
93 Braking System Principles
94 Brake Hydraulic Systems
95 Hydraulic Valves and Switches
96 Brake Fluid and Lines
97 Brake Bleeding Methods and Procedures
98 Wheel Bearings and Service
99 Drum Brakes
100 Drum Brake Diagnosis and Service
101 Disc Brakes
102 Disc Brake Diagnosis and Service
103 Parking Brake Operation, Diagnosis, and Service
104 Machining Brake Drums and Rotors
105 Power Brake Unit Operation, Diagnosis, and Service
106 ABS Components and Operation
107 ABS Diagnosis and Service
108 Electronic Stability Control Systems

chapter 92 BRAKING SYSTEM COMPONENTS AND PERFORMANCE STANDARDS

OBJECTIVES: **After studying Chapter 92, the reader will be able to:** • Prepare for the Brakes (A5) ASE certification test. • List the parts and terms for disc and drum brakes. • Describe brake design requirements. • List the six brake system categories. • Discuss federal braking and stopping standards.

KEY TERMS: Adjustable pedals 1019 • Antilock braking system (ABS) 1018 • Apply system 1017 • Base brakes 1016 • Boost system 1017 • Brake balance control system 1017 • Brake pedal 1017 • Brake warning lights 1017 • Disc brakes 1016 • DOT 1019 • Drum brakes 1016 • EAP 1019 • FMVSS 1019 • Foundation brakes 1016 • GVWR 1020 • Hydraulic system 1017 • LLVW 1020 • Parking brake 1017 • Red brake warning lamp 1017 • Service brakes 1016 • Wheel brakes 1017

FUNDAMENTALS OF BRAKE SYSTEMS

Brakes are by far the most important mechanism on any vehicle because the safety and lives of those riding in the vehicle depend on proper operation of the braking system. It has been estimated that the brakes on the average vehicle are applied 50,000 times a year!

Brakes are an energy-absorbing mechanism that converts vehicle movement into heat while stopping the rotation of the wheels. All braking systems are designed to reduce the speed and stop a moving vehicle and to keep it from moving if the vehicle is stationary. **Service brakes** are the main driver-operated brakes of the vehicle. Service brakes are also called **base brakes** or **foundation brakes.** ● **SEE FIGURE 92–1.**

BRAKE SYSTEM PARTS

Most vehicles built since the late 1920s use a brake on each wheel. To stop a wheel, the driver exerts a force on a brake pedal. The force on the brake pedal pressurizes brake fluid in a master cylinder. This hydraulic force (liquid under pressure) is transferred through steel lines and flexible brake lines to a wheel cylinder or caliper at each wheel. Hydraulic pressure to each wheel cylinder or caliper is used to force friction materials against the brake drum or rotor. The friction between the stationary friction material and the rotating drum or rotor (disc) causes the rotating part to slow and eventually stop. Since the wheels are attached to the drums or rotors, the wheels of the vehicles also stop.

The heavier the vehicle and the higher the speed, the more heat the brakes have to be able to absorb. Long, steep hills can cause the brakes to overheat which results in the brakes not being able to produce the friction necessary to slow or stop a vehicle.

DRUM BRAKES. **Drum brakes** are used on the rear of many rear-wheel-drive, front-wheel-drive, and four-wheel-drive vehicles. When drum brakes are applied, brake shoes are moved outward against a rotating brake drum. The wheel studs for the wheels are attached to the drum. When the drum slows and stops, the wheels also slow and stop.

Drum brakes are economical to manufacture, service, and repair. Parts for drum brakes are generally readily available and reasonably priced. On some vehicles, an additional drum brake is used as a parking brake on vehicles equipped with rear disc brakes. ● **SEE FIGURE 92–2.**

DISC BRAKES. **Disc brakes** are used on the front of most vehicles built since the early 1970s and on the rear wheels of many vehicles.

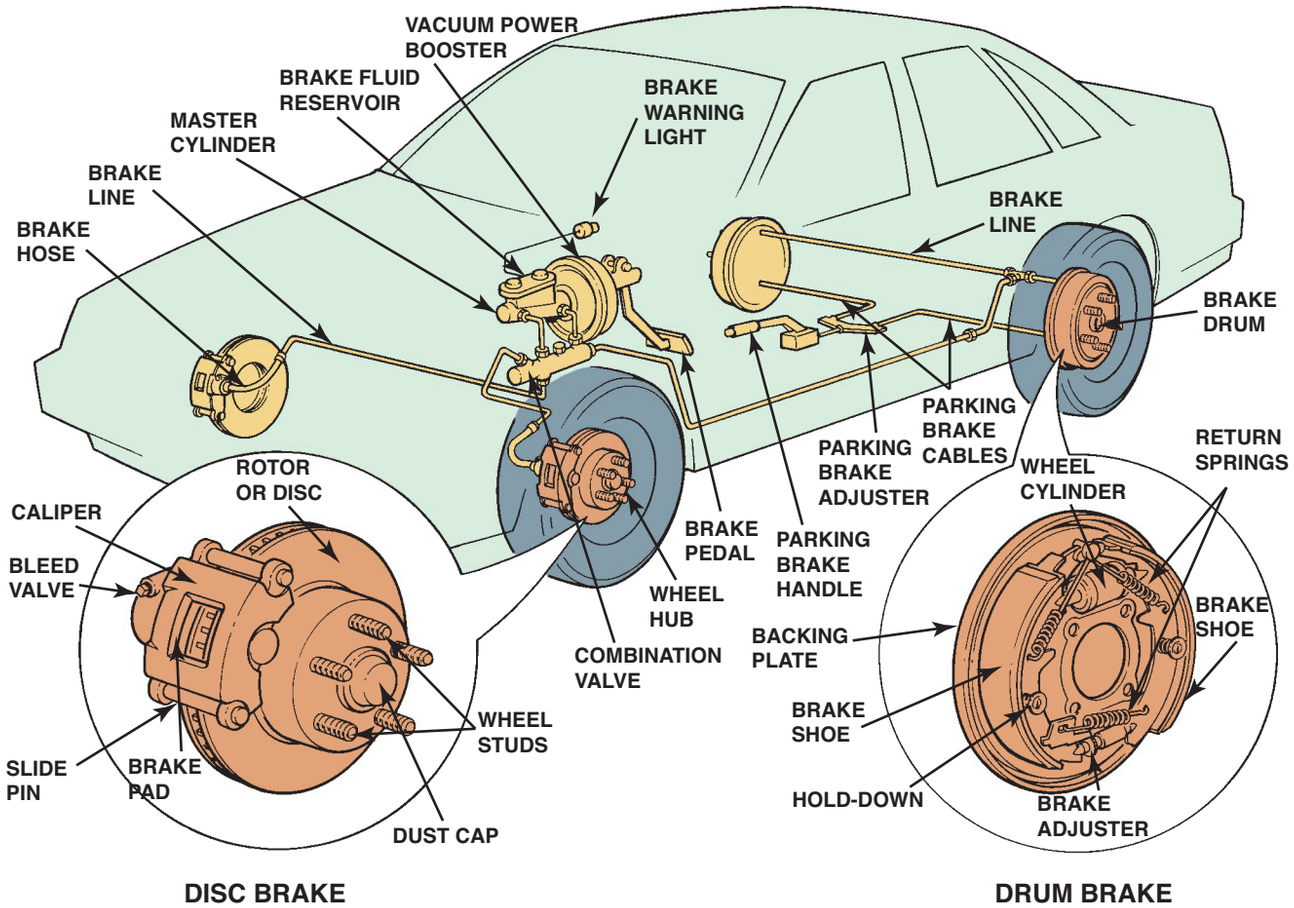


FIGURE 92–1 Typical vehicle brake system showing all typical components.

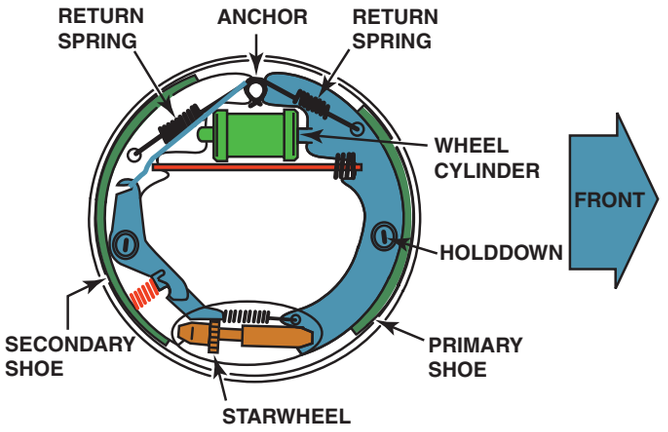


FIGURE 92–2 Typical drum brake assembly.

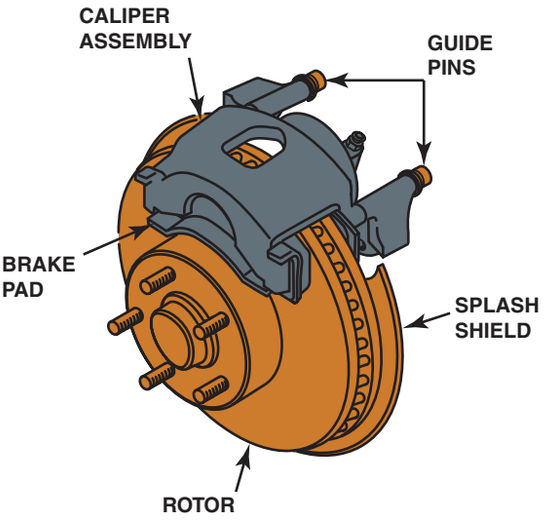


FIGURE 92–3 Typical disc brake assembly.

A disc brake operates by squeezing brake pads on both sides of a rotor or disc that is attached to the wheel. ● **SEE FIGURE 92–3.**

Type of Brake	Rotating Part	Friction Part
Drum brakes	Brake drum	Brake shoes
Disc brakes	Rotor or disc	Brake pads

Due to the friction between the road surface and the tires, the vehicle stops. To summarize, the sequence of events necessary to stop a vehicle include the following:

1. The driver presses on the brake pedal.
2. The brake pedal force is transferred hydraulically to a wheel cylinder or caliper at each wheel.
3. Hydraulic pressure inside the wheel cylinder or caliper presses friction materials (brake shoes or pads) against rotating brake drums or rotors.
4. The friction slows and stops the drum or rotor. Since the drum or rotor is bolted to the wheel of the vehicle, the wheel also stops.
5. When the wheels of the vehicle slow and stop, the tires must have friction (traction) with the road surface to stop the vehicle.

BRAKE DESIGN REQUIREMENTS

All braking forces must provide for the following:

- Equal forces must be applied to both the left and right sides of the vehicle to assure straight stops.
- Hydraulic systems must be properly engineered and serviced to provide for changes as vehicle weight shifts forward during braking. Hydraulic valves must be used in the hydraulic system to permit the maximum possible braking forces but still prevent undesirable wheel lockup. Antilock braking systems (ABS) are specifically designed to prevent wheel lockup under all driving conditions, including wet or icy road conditions.
- The hydraulic system must use a fluid that will not evaporate or freeze. The fluid has to withstand extreme temperatures without boiling and must not damage rubber or metal parts of the braking system.
- The friction material (brake shoes or brake pads) must be designed to provide adequate friction between the stationary shoes or pads and the rotating drum or rotor. The friction material should be environmentally safe. Nonasbestos lining is generally considered to be safe for the environment and the technician.
- The design of the braking system should secure the brake lining solidly to prevent the movement of the friction material during braking. It is this movement of the friction material that causes brake noise (squeal).
- Most braking systems incorporate a power assist unit that reduces the driver's effort but does not reduce stopping distance. The most commonly used brake booster is vacuum operated.

BRAKE SYSTEM CATEGORIES

Brake system components can be classified and placed into six subsystem categories, depending on their function. ● **SEE FIGURE 92–4** for an overall view of the entire braking system.

1. **Apply System.** The driver starts the operation of the braking system by pressing on the **brake pedal** or applying the **parking brake.** The apply system includes all the levers, pedals, or linkage needed to activate a braking force.
2. **Boost System.** The boost (power brake) system is used on most vehicles to reduce the force that the driver must exert on the brake pedal.
3. **Hydraulic System.** The brake pedal force is transferred to the hydraulic system, where the force is directed through lines and hoses to the wheel brakes.
4. **Wheel Brakes.** Hydraulic pressure from the hydraulic system moves a piston, in either a disc or drum brake system, which uses friction to press material against a rotating drum or rotor. The resulting friction slows the rotation of the wheels.
5. **Brake Balance Control System.** Mechanical, electrical, and hydraulic components are used to ensure that brakes are applied quickly and with balanced pressure for safe operation. Components in this category include metering valves, proportioning valves, and antilock braking system components.
6. **Brake warning lights.** There are two brake system-related warning lights.
   - The **red brake warning lamp (RBWL)** lights whenever a hydraulic system failure occurs. The red brake warning

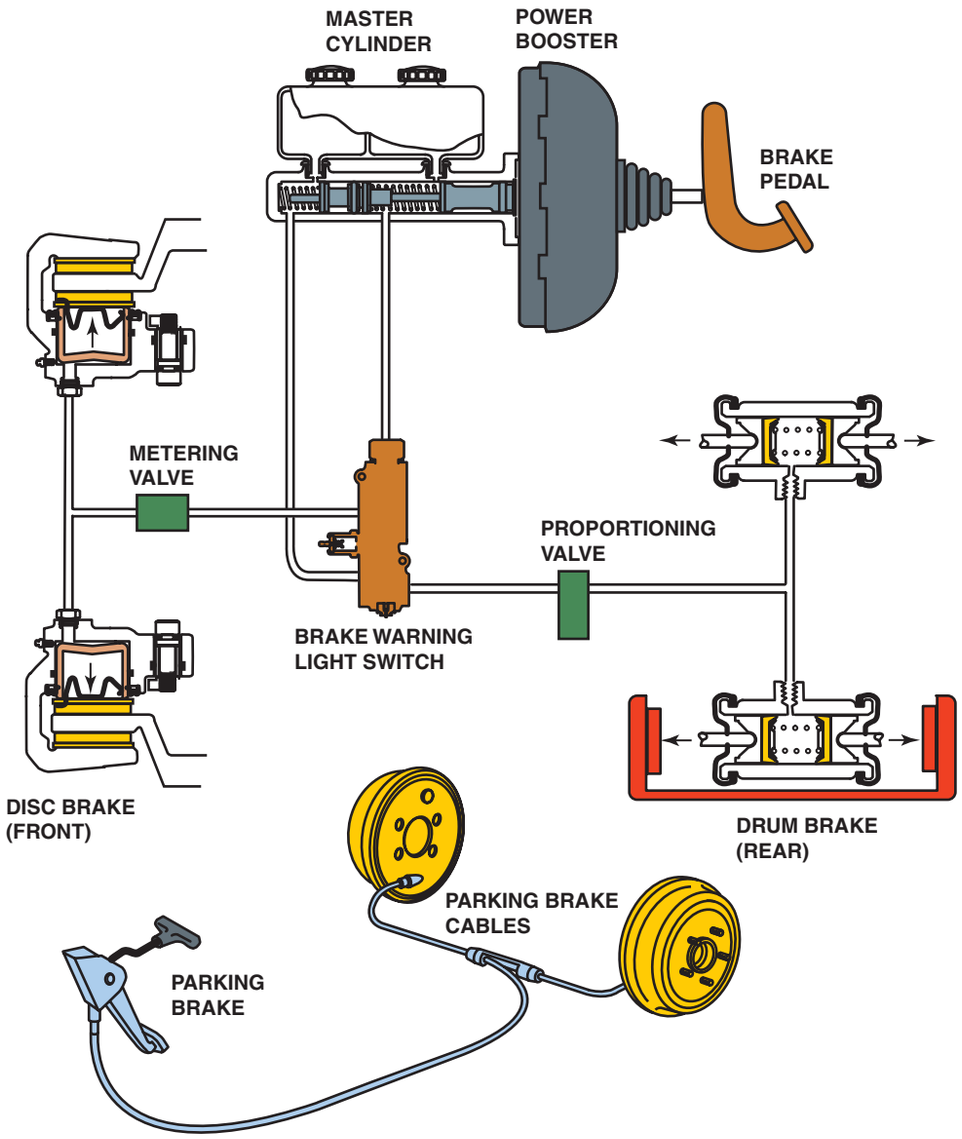


FIGURE 92–4 Typical brake system components.

lamp lights when the ignition is turned on as a bulb check then goes out unless a hydraulic fault has been detected. ● **SEE FIGURE 92–5.**

CAUTION: Do not test-drive a vehicle if the red brake warning light is on.

- The amber ABS warning lamp or dim red brake light indicates an ABS self-test and/or a possible problem in the ABS system. This warning light will usually flash several times during a self-test when the engine is first started and then go out unless a fault with the antilock braking system was detected.



FIGURE 92–5 The red brake warning light will remain on after a bulb test if there is a fault with the hydraulic part of the brake system.

ANTILOCK BRAKE SYSTEM OVERVIEW

The purpose of an **antilock braking system (ABS)** is to prevent the wheels from locking during braking, especially on low-friction surfaces such as wet, icy, or snowy roads. Remember, it is the friction between the tire tread and the road that does the actual stopping of the vehicle. Therefore, ABS does not mean that a vehicle can stop quickly on all road surfaces. ABS uses sensors at the wheels to measure the wheel speed. If a wheel is rotating slower than the others, indicating possible lockup (for example, on an icy spot), the ABS hydraulic controller will reduce the brake fluid pressure to that

wheel for a fraction of a second. *A locked wheel has less traction to the road surface than a rotating wheel.*

The ABS controller can reapply the pressure from the master cylinder to the wheel a fraction of a second later. Therefore, if a wheel starts to lock up, the purpose of the ABS system is to pulse the brakes on and off to maintain directional stability with maximum braking force. Many ABS units will cause the brake pedal to pulse if the unit is working in the ABS mode. The pulsating brake pedal is a cause for concern for some drivers. However, the pulsing brake pedal informs the driver that the ABS is being activated. Some ABS units use an isolator valve in the ABS unit to prevent brake pedal pulsations during ABS operation. With these types of systems, it is often difficult for the driver to know if and when the ABS unit is working to control a locking wheel. ● **SEE FIGURE 92–7** for an overview of a typical ABS on a rear-wheel-drive vehicle.

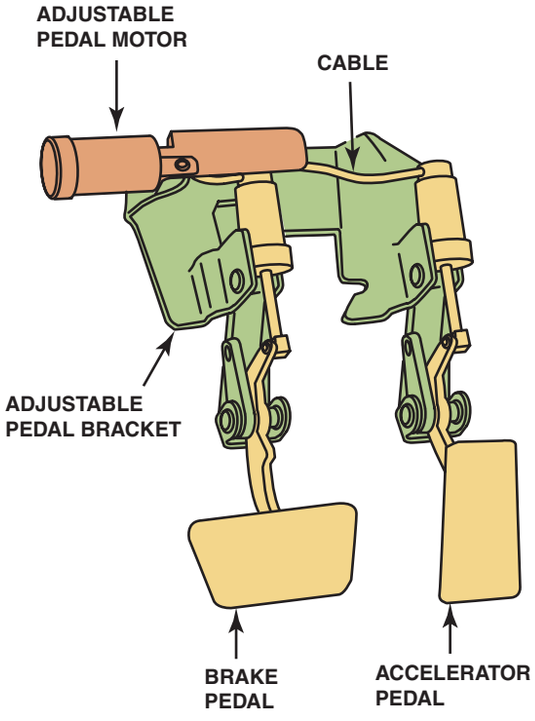


FIGURE 92–6 A typical adjustable pedal assembly. Both the accelerator and the brake pedal can be moved forward and rearward by using the adjustable pedal position switch.

FREQUENTLY ASKED QUESTION

How Do Adjustable Pedals Work?

Adjustable pedals, also called **electric adjustable pedals (EAP),** place the brake pedal and the accelerator pedal on movable brackets that are motor operated. A typical adjustable pedal system includes the following components:

- **Adjustable pedal position switch,** which allows the driver to position the pedals.
- **Adjustable pedal assembly,** which includes the motor, threaded adjustment rods, and a pedal position sensor. ● **SEE FIGURE 92–6.**

The position of the pedals, as well as the position of the seat system, is usually included as part of the memory seat function and can be set for two or more drivers.

Another symptom of normal ABS unit operation is the activation of the hydraulic pressure pump used by many ABS units. In some ABS units, the hydraulic pump is run every time the vehicle is started and moved. Other types of units operate randomly or whenever the pressure in the system calls for the pump to operate.

FEDERAL BRAKE STANDARDS

The statutes pertaining to automotive brake systems are part of the **Federal Motor Vehicle Safety Standards (FMVSS)** established by the United States **Department of Transportation (DOT).** Several standards apply to specific components within the brake system. The overall service and parking brake systems are dealt within standard 135.

FMVSS 135 was first mandated on September 1, 2000, for passenger vehicles, and September 1, 2002, for multipurpose vehicles, trucks, and buses with a gross vehicle weight rating (GVWR) of

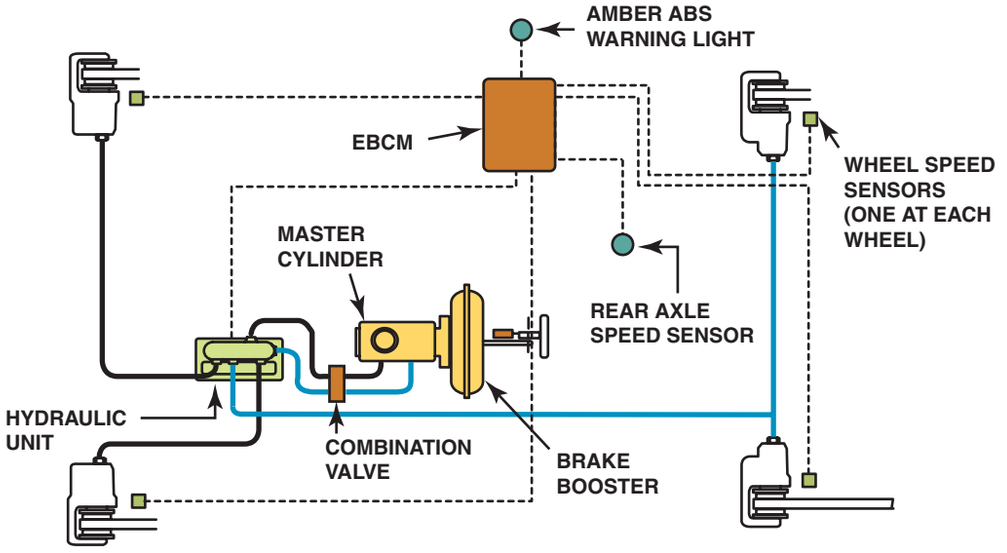


FIGURE 92–7 Typical components of an antilock braking system (ABS) used on a rear-wheel-drive vehicle.

7,716 pounds (3,500 kilograms). Its purpose is to "ensure safe braking performance under normal and emergency conditions." FMVSS 135 applies to "passenger vehicles, multipurpose passenger vehicles, trucks, and buses."

FMVSS 135 deals with brake system safety by establishing specific brake performance requirements. It does not dictate the *design* of the system, although some requirements may make older technologies impractical or obsolete. Only four parts of the brake system are specifically regulated:

- Fluid reservoir and labeling
- Dashboard warning lights
- A method of automatic adjustment
- A mechanically engaging, friction-type parking brake system

The FMVSS 135 tests are used by manufacturers to certify the braking performance of all new vehicles available for public purchase.

FMVSS 135 BRAKE TEST

The overall FMVSS 135 brake test procedure consists of up to 24 steps, depending on the vehicle's configuration and braking system. The actual performance tests are made with the vehicle loaded to both the manufacturer's specified **gross vehicle weight rating (GVWR)** and the **lightly loaded vehicle weight (LLVW),** with certain applied brake forces. There are precise instructions for every step of the test, including the number of times the tests must be repeated, the sequence of the testing, and the allowable stopping distance for the particular type of vehicle. Some highlights of the testing procedure include:

- **Burnish Procedure.** The brakes are burnished by making 200 stops from 50 mph (80 km/h) at a fixed rate of deceleration with a controlled cool-down period after each stop. This procedure conditions the friction material.
- **Adhesion Utilization (torque wheel method).** For vehicles not equipped with ABS, this test is to determine if the brake system will make adequate use of the road surface in stopping the vehicle.
- **Cold Effectiveness.** This test is performed to determine if the vehicle will have sufficient stopping power when the brake lining materials are not preheated by previous stops.
- **High Speed Effectiveness.** This test is performed to determine if the brake system will provide adequate stopping power for all loading conditions. The allowable stopping distance is calculated from the maximum speed the vehicle can attain.
- **Stops With the Engine Off.** This test is for vehicles equipped with brake power assist units. The vehicle, loaded to GVWR, must stop within 230 ft (70 m), from a speed of 62 mph (100 km/h). This test must be repeated six times.
- **Antilock Functional Failure.** This test ensures that service brakes will function correctly in the event of an antilock functional failure, and the brake system warning indicator is activated when an ABS electrical function failure occurs.
- **Variable Brake Proportioning System.** This test is performed on vehicles equipped with either a mechanical or an electrical variable proportioning system. It ensures that, in the event of a failure, the vehicle can still come to a stop in an acceptable distance.
- **Hydraulic Circuit Failure.** This test is performed to ensure that the driver will be alerted via the brake warning system indicator that a failure has occurred, and that the vehicle can still be stopped in an acceptable distance.

? **FREQUENTLY ASKED QUESTION**

Do the FMVSS 135 Standards Apply to Replacement Brake Part Performance?

No. The Federal Motor Vehicle Safety Standard 135 applies to new vehicles. Replacement parts used during a brake repair or replacement may or may not permit the vehicle to achieve the same standards as when new.

To help ensure like-new braking performance, the service technician should always use quality brake parts from a known manufacturer.

- **Brake Power Assist Unit Inoperative.** This test makes sure the service brake can stop the vehicle in an acceptable distance with the brake power assist unit in an inoperative state. It is performed on vehicles with brake power assist units turned off or inoperative.
- **Parking Brake.** The parking brake alone will hold the vehicle stationary in either the forward or reverse direction on a 20% grade for a period of at least 5 minutes.
- **Brake Heat Test.** This procedure heats the brake system by making a series of 15 stops from a high speed. The vehicle is loaded to GVWR, with rapid acceleration between each stop to minimize cooling the brakes.
- **Hot Performance.** After the brake system has been heated by a series of controlled stops, the hot performance test is immediately performed. The vehicle is loaded to GVWR and two stops are made. The stopping distance must be within acceptable limits as specified in the test. This test ensures that the brake system on the vehicle will not fade following a series of high-speed stops at GVWR.

Although these tests may seem extreme, these tests are only a minimum standard of performance. Any brake repair work should also leave the brake system capable of meeting FMVSS 135.

BRAKE REPAIR AND THE LAW

Once an automobile leaves the factory, the responsibility for maintaining the designed-in level of braking performance falls on the owner of the vehicle. Owners look to trained automotive technicians to service their brake systems. Many states have laws that regulate brake work to help ensure safe repairs. These laws vary from one area to another, but they may require special licensing for brake technicians, or special business practices when selling brake work. In some cases, the laws provide the consumer with specific warranties and the right to outside arbitration in cases of defective or substandard repairs.

Regardless of whether there are specific laws governing brake repair, a technician is always liable for damage or injuries resulting from repairs performed in an unprofessional or unworkman-like manner. Considering the lives and property that depend on good brakes, there is only one acceptable goal when making brake system repairs: to restore the system and its component parts so they perform to original specifications. In other words, *the purpose of any repair is to restore like-new performance.*

REVIEW QUESTIONS

1. List the differences between drum brakes and disc brakes.
2. List the six brake subsystem categories.
3. Explain how ABS units prevent wheel lockup.
4. List ten of the brake tests performed under the Federal Motor Vehicle Safety Standard (FMVSS) 135.

CHAPTER QUIZ

1. Disc brakes use replaceable friction material called _____.
   a. Linings **c.** Core
   b. Pads **d.** Web
2. Drum brakes use replaceable friction material called _____.
   a. Shoes **c.** Core
   b. Pads **d.** Web
3. Technician A says that a power-assisted brake reduces stopping distances compared with a nonpower-assisted brake system. Technician B says that the power-assisted brake system reduces the force that the driver must exert on the brake pedal. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
4. A locked wheel _____ to the road surface than a rolling wheel.
   a. Has less traction
   b. Has greater traction
5. Technician A says that all vehicles equipped with ABS will experience a pulsating brake pedal even during normal braking. Technician B says that ABS will result in quicker stops on all road surfaces. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
6. The FMVSS 135 standards determine _____.
   a. The design of the braking system
   b. The performance of the braking system
   c. The materials used in the braking system
   d. All of the above
7. An owner of a vehicle equipped with ABS brakes complained that whenever he tried to stop on icy or slippery roads, the brake pedal would pulse up and down rapidly. Technician A says that this is normal for many ABS units. Technician B says that the ABS unit is malfunctioning. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. Electric adjustable pedals operate _____.
   a. Parking brake only
   b. Accelerator pedal only
   c. Brake pedal only
   d. Both the accelerator and brake pedal
9. All of the following are specified by the FMVSS 135 *except*:
   a. Brake burnish procedure
   b. Variable brake proportioning system
   c. Brake noise levels
   d. Cold effectiveness
10. What is the purpose of any brake repair?
    a. Reduce noise during braking
    b. Replace pads and linings
    c. Restore proper brake pedal height
    d. Restore like-new performance

chapter 93

BRAKING SYSTEM PRINCIPLES

OBJECTIVES: **After studying Chapter 93, the reader will be able to:** • Prepare for the Brakes (A5) ASE certification test. • Explain kinetic energy and why it is so important to brake design. • Discuss mechanical advantage and how it relates to the braking system. • Explain the coefficient of friction. • Describe how brakes can fade due to excessive heat.

KEY TERMS: Coefficient of friction 1024 • Energy 1022 • Friction 1024 • Fulcrum 1023 • Inertia 1023 • Kinetic energy 1022 • Kinetic friction 1025 • Leverage 1023 • Mechanical advantage 1024 • Pedal ratio 1024 • Static friction 1025 • Weight bias 1023 • Weight transfer 1023 • Work 1022

ENERGY PRINCIPLES

Energy is the ability to do work. There are many forms of energy, but chemical, mechanical, and electrical energy are the most familiar kinds involved in the operation of an automobile. ● **SEE FIGURE 93–1.**

For example, when the ignition key is turned to the "Start" position, chemical energy in the battery is converted into electrical energy to operate the starter motor. The starter motor then converts the electrical energy into mechanical energy that is used to crank the engine.

In the example above, energy is being used to perform work. **Work** is the transfer of energy from one physical system to another—especially the transfer of energy to an object through the application of force. This is precisely what occurs when a vehicle's brakes are applied: The *force* of the actuating system *transfers* the energy of the vehicle's motion to the brake drums or rotors where friction *converts* it into heat energy and stops the vehicle.

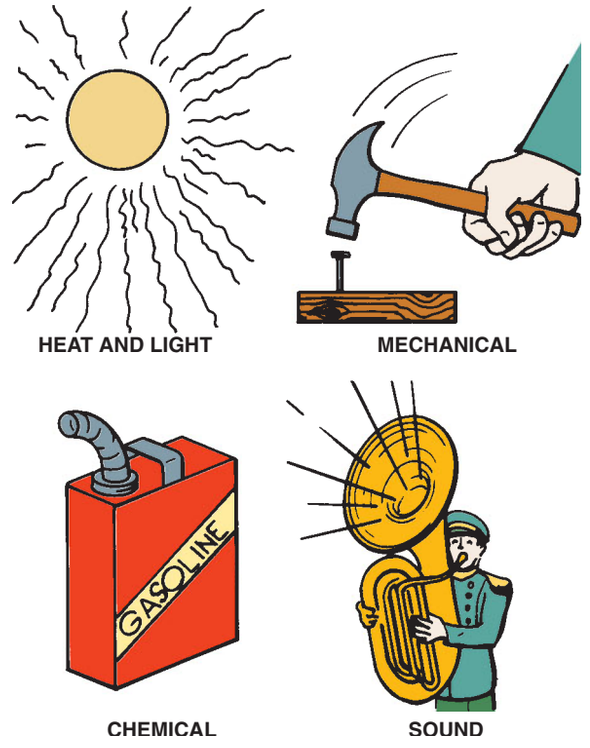


FIGURE 93–1 Energy which is the ability to perform work exists in many forms.

KINETIC ENERGY

Kinetic energy is a fundamental form of mechanical energy. It is the energy of mass in motion. Every moving object possesses kinetic energy, and the amount of that energy is determined by the object's mass and speed. The greater the mass of an object and the faster it moves, the more kinetic energy it possesses. Even at low speeds, a moving vehicle has enough kinetic energy to cause serious injury and damage. The job of the brake system is to dispose of that energy in a safe and controlled manner.

Engineers calculate kinetic energy using the following formula:

$$\frac{mv^2}{29.9} = E_k$$

where:

m = mass or weight of the vehicle in pounds (lb)
v = velocity of the vehicle in miles per hour
E_k = kinetic energy in foot-pounds (ft-lb)
29.9 = a constant

Another way to express this equation is as follows.

$$\frac{\text{weight} \times \text{speed}^2}{29.9} = \text{kinetic energy}$$

If a 3,000-lb vehicle traveling at 30 mph is compared with a 6,000-lb vehicle also traveling at 30 mph as shown in ● **FIGURE 93–2,** the equations for computing their respective kinetic energies look like this:

$$\frac{3{,}000 \text{ lb} \times 30^2 \text{ mph}}{29.9} = 90{,}301 \text{ ft-lb}$$

$$\frac{6{,}000 \text{ lb} \times 30^2 \text{ mph}}{29.9} = 180{,}602 \text{ ft-lb}$$

The results show that when the weight of a vehicle is doubled from 3,000 to 6,000 lb, its kinetic energy is also doubled from 90,301 ft-lb to 180,602 ft-lb. In mathematical terms, kinetic energy increases *proportionally* as weight increases. In other words, if the weight of a moving object doubles, its kinetic energy also doubles. If the weight quadruples, the kinetic energy becomes four times as great.

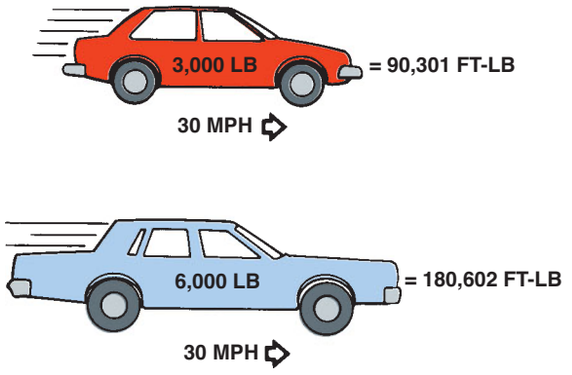


FIGURE 93–2 Kinetic energy increases in direct proportion to the weight of the vehicle.

If a 3,000-lb vehicle traveling at 30 mph is compared with the same vehicle traveling at 60 mph (● **FIGURE 93–3**), the equations for computing their respective kinetic energies look like this:

$$\frac{3{,}000 \text{ lb} \times 30^2 \text{ mph}}{29.9} = 90{,}301 \text{ ft-lb}$$

$$\frac{3{,}000 \text{ lb} \times 60^2 \text{ mph}}{29.9} = 361{,}204 \text{ ft-lb}$$

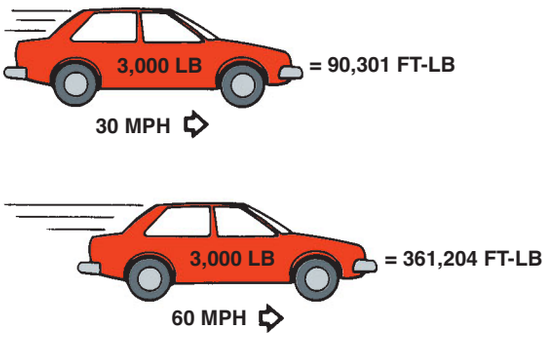


FIGURE 93–3 Kinetic energy increases as the square of any increase in vehicle speed.

The results show that the vehicle traveling at 30 mph has over 90,000 ft-lb of kinetic energy, but at 60 mph the figure increases to over 350,000 ft-lb. In fact, at twice the speed, the vehicle has exactly four times as much kinetic energy. If the speed were doubled again to 120 mph, the amount of kinetic energy would grow to almost 1,500,000 ft-lb! In mathematical terms, kinetic energy increases as the *square of its speed.* In other words, if the speed of a moving object doubles (2), the kinetic energy becomes four times as great ($2^2 = 4$). And if the speed quadruples (4), say from 15 to 60 mph, the kinetic energy becomes 16 times as great ($4^2 = 16$). This is the reason speed has such an impact on kinetic energy.

KINETIC ENERGY AND BRAKE DESIGN

The relationships between weight, speed, and kinetic energy have significant practical consequences for the brake system engineer. If vehicle A weighs twice as much as vehicle B, it needs a brake system that is twice as powerful. But if vehicle C has twice the speed potential of vehicle D, it needs brakes that are, not twice, but four times more powerful.

INERTIA

Although brake engineers take both weight and speed capability into account when designing a brake system, these are not the only factors involved. Another physical property, inertia, also affects the braking process and the selection of brake components. **Inertia** is defined by Isaac Newton's first law of motion, which states that a body at rest tends to remain at rest, and a body in motion tends to remain in motion in a straight line unless acted upon by an outside force.

WEIGHT TRANSFER AND BIAS

Inertia, in the form of **weight transfer,** plays a major part in a vehicle's braking performance. Newton's first law of motion dictates that a moving vehicle will remain in motion unless acted upon by an outside force. The vehicle brakes provide that outside force, but when the brakes are applied at the wheel friction assemblies, only the wheels and tires begin to slow immediately. The rest of the vehicle, all of the weight carried by the suspension, attempts to remain in forward motion. The result is that the front suspension compresses, the rear suspension extends, and the weight is transferred toward the front of the vehicle. ● **SEE FIGURE 93–4.**

The total weight of the vehicle does not change, only the amount supported by each axle. To compound the problem of weight transfer, most vehicles also have a forward **weight bias,** which means that even when stopped, more than 50% of their weight is supported by the front wheels. This occurs because the engine, transmission, and most other heavy parts are located toward the front of the vehicle. ● **SEE FIGURE 93–5.**

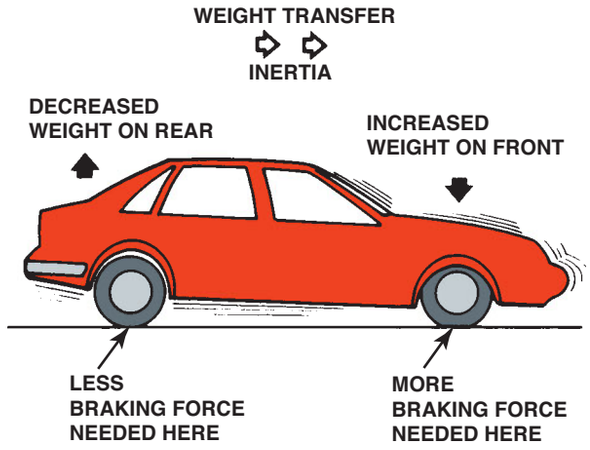


FIGURE 93–4 Inertia creates weight transfer that requires the front brakes to provide most of the braking force.

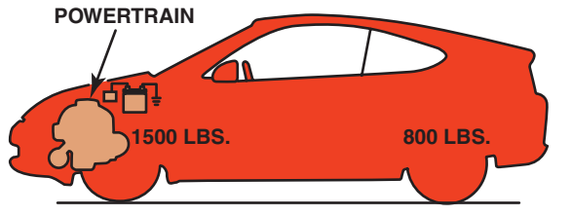


FIGURE 93–5 Front wheel drive vehicles have most of their weight over the front wheels.

TECH TIP

Brakes Cannot Overcome the Laws of Physics

No vehicle can stop on a dime. The energy required to slow or stop a vehicle must be absorbed by the braking system. All drivers should be aware of this fact and drive at a reasonable speed for the road and traffic conditions.

Front-wheel-drive (FWD) vehicles, in particular, have a forward weight bias. Whenever the brakes are applied, weight transfer and weight bias greatly increase the load on the front wheels, while the load on the rear wheels is substantially reduced. This requires the front brakes to provide 80% to 90% of the total braking force. To deal with the extra load, the front brakes are much more powerful than the rear brakes. They are able to convert more kinetic energy into heat energy.

MECHANICAL PRINCIPLES

LEVERS

The primary mechanical principle used to increase application force in every brake system is **leverage.** In the science of mechanics, a lever is a simple machine that consists of a rigid object, typically a metal bar that pivots about a fixed point called a **fulcrum.**

LEVERS IN BRAKING SYSTEMS

The levers in brake systems are used to increase force, so they are either first- or second-class. Second-class levers are the most common, and the service brake pedal is a good example. In a typical suspended brake pedal, the pedal arm is the lever, the pivot point is the fulcrum, and the force is applied at the foot pedal pad. ● **SEE FIGURE 93–6.**

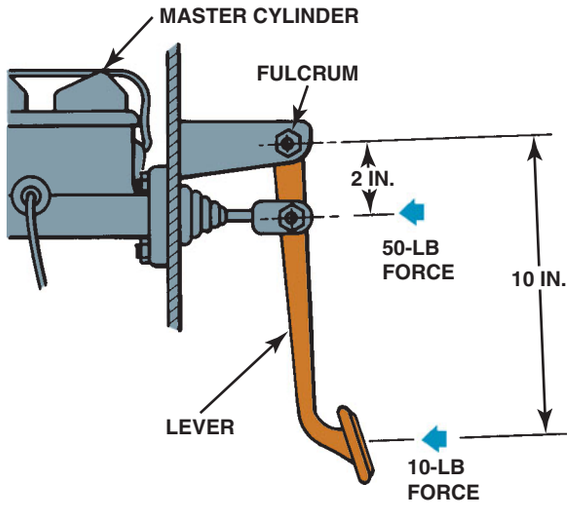


FIGURE 93–6 A brake pedal assembly is a second-class lever design that provides a 5 to 1 mechanical advantage.

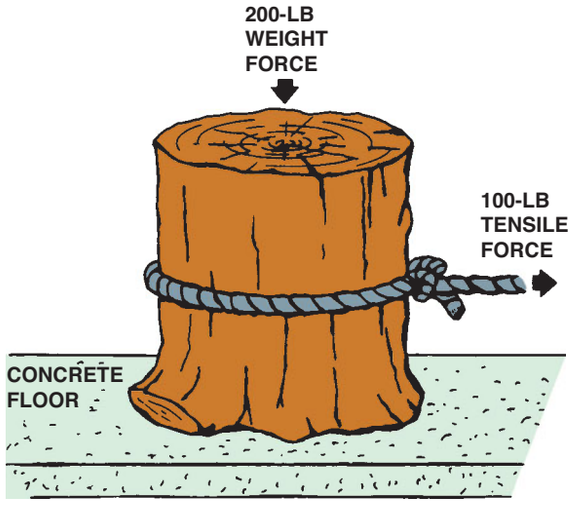


FIGURE 93–7 The coefficient of friction in this example is 0.5.

The force applied to the master cylinder by the pedal pushrod attached to the pivot is much greater than the force applied at the pedal pad, but the pushrod does not travel nearly as far.

MECHANICAL ADVANTAGE

Leverage creates a **mechanical advantage** that, at the brake pedal, is called the **pedal ratio.** For example, a pedal ratio of 5 to 1 is common for manual brakes, which means that a force of 10 lb at the brake pedal will result in a force of 50 lb at the pedal pushrod. In practice, leverage is used at many points in both the service and parking brake systems to increase braking force while making it easier for the driver to control the amount of force applied.

FRICTION PRINCIPLES

The wheel brakes use friction to convert kinetic energy into heat energy. **Friction** is the resistance to movement between two surfaces in contact with one another. Brake performance is improved by increasing friction (at least to a point), and brakes that apply enough friction to use all the grip the tires have to offer will always have the potential to stop a vehicle faster than brakes with less ability to apply friction.

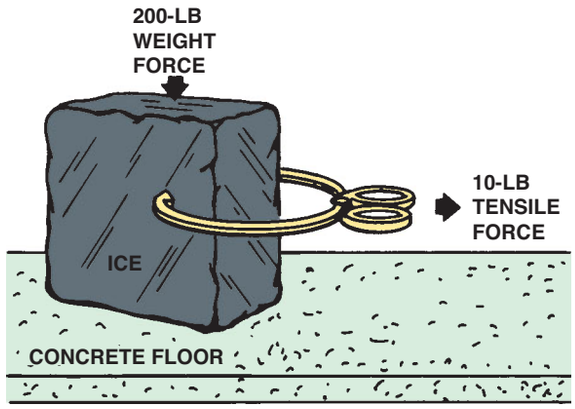


FIGURE 93–8 The type of friction material affects the coefficient of friction which is just 0.05 in this example.

COEFFICIENT OF FRICTION

The amount of friction between two objects or surfaces is commonly expressed as a value called the **coefficient of friction** and is represented by the Greek letter mu (μ).

$$\frac{F_t}{G} = \mu$$

$$\frac{\text{Tensile force}}{\text{Weight force}} = \text{Coefficient of friction}$$

SURFACE FINISH EFFECTS

The effect of surface finish on the friction coefficient can be seen in ● **FIGURE 93–7.**

In this case, 100 lb of tensile force is required to pull a 200-lb block of wood across a concrete floor. The equation for computing the coefficient of friction is as follows.

$$\frac{100 \text{ lb}}{200 \text{ lb}} = 0.5$$

The friction coefficient in this instance is 0.5. Now take the same example, except assume that the block of wood has been sanded smooth, which improves its surface finish and reduces the force required to move it to only 50 lb. In this case the equation reads as follows.

$$\frac{50 \text{ lb}}{200 \text{ lb}} = 0.25$$

The friction coefficient drops by half, and it would decrease even further if the surface finish of the floor were changed from rough concrete to smooth marble.

It is obvious that the *surface finish* of two connecting surfaces has a major effect on their coefficient of friction.

FRICTION MATERIAL EFFECTS

Taking the example above one step further, consider the effect if a 200-lb block of ice, a totally different type of material, is substituted for the wood block. In this case, it requires only a 10-lb force to pull the block across the concrete. ● **SEE FIGURE 93–8.**

The equation reads as follows.

$$\frac{10 \text{ lb}}{200 \text{ lb}} = 0.05$$

The coefficient of friction in this example decreases dramatically to only 0.05, and once again, even further reductions would be seen if the floor surface were changed to polished marble or some other similar smooth surface.

It is obvious that the *type* of materials being rubbed together have a very significant effect on the coefficient of friction. The choice of

materials for brake drums and rotors is limited. Iron and steel are used most often because they are relatively inexpensive and can stand up under the extreme friction brake drums and rotors must endure.

The brake lining material, however, can be replaced relatively quickly and inexpensively, and therefore does not need to have as long a service life. Brake shoe and pad friction materials play a major part in determining coefficient of friction. There are several fundamentally different materials to choose from, and each has its own unique friction coefficient and performance characteristics.

FRICTION CONTACT AREA For *sliding* surfaces, such as those in wheel friction assemblies, the amount of contact area has no effect on the amount of friction generated. This fact is related to the earlier statement that brake friction materials always have a friction coefficient of less than 1.0. To have a friction coefficient of 1.0 or more, material must be *transferred* between the two friction surfaces. The amount of contact area does not affect the coefficient of friction, but it does have significant effects on lining life and the dissipation of heat that can lead to brake fade.

Tires are an example where contact area makes a difference. All other things being equal, a wide tire with a large contact area on the road has a higher coefficient of friction than a narrow tire with less contact area. This occurs because the tire and road *do not* have a sliding relationship. A tire conforms to and engages the road surface, and during a hard stop, a portion of the breaking force comes from shearing or tearing away the tire tread rubber. The rubber's tensile strength, its internal resistance to being pulled apart, adds to the braking efforts of friction. A racing tire making a hard stop on dry pavement, for example, has a friction coefficient of 1.0 or better. The transfer of material between the two surfaces can be seen as skid marks on the pavement.

STATIC AND KINETIC FRICTION There are actually two measurements of the coefficient of friction, the **static friction** coefficient and the **kinetic friction** coefficient. The static value is the coefficient of friction with the two friction surfaces at rest. The kinetic value is the coefficient of friction while the two surfaces are sliding against one another.

The coefficient of static friction is always higher than that of kinetic friction, which explains why it is harder to *start* an object moving than to *keep* it moving. In the example shown in ● **FIGURE 93–9,** it takes 100 lb of tensile force to start the wooden block sliding, but once in motion, it takes only 50 lb to keep it sliding.

The relatively high static friction is harder to overcome than the somewhat lower kinetic friction. The static and kinetic friction coefficients for several combinations of materials are shown in ● **CHART 93–1.**

The difference between static and kinetic friction explains why parking brakes, although much less powerful than service brakes, are still able to hold a vehicle in position on a hill. The job of the parking brakes is relatively easy because the stationary vehicle has no kinetic energy, and the brake lining and drum or disc are not moving when they are applied. To start the vehicle moving, enough force would have to be applied to overcome the relatively high static friction of the parking brakes. The service brakes, however, have a much more difficult job. The moving vehicle has a great deal of kinetic energy, and the fact that the brake friction surfaces are in relative motion means that kinetic friction makes them less efficient.

FRICTION AND HEAT

The function of the brake system is to convert kinetic energy into heat energy through friction.

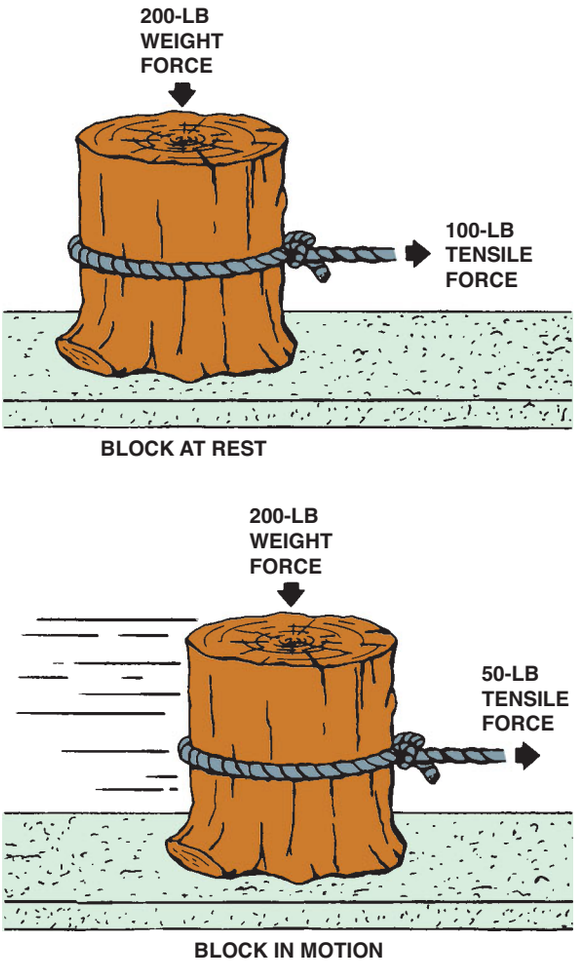


FIGURE 93–9 The static coefficient of friction of an object at rest is higher than the kinetic (dynamic) friction coefficient once in motion.

CONTACTING SURFACES	COEFFICIENT OF FRICTION	
	STATIC	KINETIC
STEEL ON STEEL (DRY)	0.6	0.4
STEEL ON STEEL (GREASY)	0.1	0.05
TEFLON ON STEEL	0.04	0.04
BRASS ON STEEL (DRY)	0.5	0.4
BRAKE LINING ON CAST IRON	0.4	0.3
RUBBER TIRES		
ON SMOOTH PAVEMENT (DRY)	0.9	0.8
METAL ON ICE	–	0.02

CHART 93–1

Every combination of materials has different static and kinetic friction coefficients.

It is the *change* in kinetic energy that determines the amount of temperature increase, and kinetic energy increases proportionately with increases in weight, and as the square of any increase in speed. If the weight of the vehicle is doubled to 6,000 lb, the change in kinetic energy required to bring it to a full stop will be 180,602 ft-lb.

The thicker and heavier the brake rotors and drums, the more heat they can absorb. Some of the heat is absorbed by the brake drums and rotors, some goes into the shoes and pads, and some is conducted into the wheel cylinders, calipers, and brake fluid. In addition, the front

brakes provide 60% to 80% of the total braking force and they receive a similar percentage of the average temperature increase. The increase at each axle is divided evenly between the two wheel friction assemblies unless there is unequal traction from one side to the other, or there is a problem within the brake system itself.

DECELERATION RATES

Deceleration rates are measured in units of "feet per second per second" (No, this is not a misprint). What it means is that the vehicle will change in velocity during a certain time interval divided by the time interval. Deceleration is abbreviated "ft/sec^2" (pronounced "feet per second per second" or "feet per second squared") or meters per sec^2 (m/sec^2) in the metric system. Typical deceleration rates include the following.

- Comfortable deceleration is about 8.5 ft/sec^2 (3 m/sec^2).
- Loose items in the vehicle will "fly" above 11 ft/sec^2 (3.5 m/sec^2).
- Maximum deceleration rates for most vehicles and light trucks range from 16 to 32 ft/sec^2 (5 to 10 m/sec^2).

An average deceleration rate of 15 ft/sec^2 (3 m/sec^2) can stop a vehicle traveling at 55 mph (88 km/h) in about 200 ft (61 m) in less than 4 seconds. During a standard brake system test, a vehicle is braked at this rate 15 times. Temperatures at the front brake pads can reach 1,300°F (700°C) or higher, sometimes reaching as high as 1,800°F (980°C). Brake fluid and rubber components may reach 300°F (150°C) or higher.

REVIEW QUESTIONS

1. What is kinetic energy?
2. How is mechanical advantage used in the braking system?
3. What is the coefficient of friction?
4. Why do brakes fade due to excessive heat or water?

CHAPTER QUIZ

1. All of the following are correct statements about braking *except*:
   a. Kinetic energy must be absorbed by the braking system.
   b. Kinetic energy of a vehicle doubles when the speed doubles.
   c. The heavier the vehicle, the greater the kinetic energy when moving.
   d. If the vehicle weight is doubled, the kinetic energy of a moving vehicle is doubled.
2. Technician A says that the front brakes do most of the braking because the front brakes are larger. Technician B says that due to weight transfer, most of the braking force needs to be done by the front brakes. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
3. The brake pedal assembly uses a mechanical lever to _____.
   a. Increase the driver's force on the brake pedal applied to the master cylinder
   b. Increase the distance the brake pedal needs to be depressed by the driver
   c. Decrease the driver's force on the brake pedal applied to the master cylinder
   d. Allow for clearance between the brake pedal and the floor when the brakes are applied
4. The friction between two surfaces is affected by all *except* _____.
   a. Speed difference between the two surfaces
   b. Surface finish
   c. Frictional material
   d. Heat
5. Technician A says that the thicker or heavier the disc brake rotor, the more heat can be absorbed. Technician B says that the faster the vehicle is traveling when the brakes are applied, the greater the amount of heat created in the brake system. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
6. All of the following are types of brake fade *except* _____.
   a. Mechanical fade
   b. Lining fade
   c. Gas fade
   d. Rotor fade
7. Brake fade caused by water can occur _____.
   a. Only if the vehicle is driven in water above the centerline of the axle
   b. Whenever it rains and the roads are wet or damp
   c. Due to moisture in the air on a humid day
   d. Whenever driving through water puddles or during a severe rainstorm
8. What can the driver do to reduce the possibility of brake fade caused by heat?
   a. Ride the brakes to keep the shoes and pads against the drum or rotor
   b. Pump the brake pedal while descending a steep hill
   c. Select a lower transmission gear
   d. Shift the transmission into neutral and allow the vehicle to coast down long or steep hills
9. Maximum deceleration rates for a typical passenger car or light truck range from _____.
   a. 1 to 3 ft/sec
   b. 5 to 10 ft/sec
   c. 16 to 32 ft/sec^2
   d. 200 to 250 ft/sec^2
10. Disc brake pads can reach temperatures as high as _____.
    a. 300°F (150°C)
    b. 1,000°F (540°C)
    c. 1,300°F (700°C)
    d. 2,000°F (1093°C)

chapter 94

BRAKE HYDRAULIC SYSTEMS

OBJECTIVES: After studying Chapter 94, the reader will be able to: • Prepare for the Brakes (A5) ASE certification test content area "A" (Hydraulic System Diagnosis and Repair). • State Pascal's law. • Describe the function, purpose, and operation of the master cylinder. • Explain how hydraulic force can be used to supply high pressures to each individual wheel brake. • Describe the process of troubleshooting master cylinders and related brake hydraulic components. • Explain how a quick take-up master cylinder works. • Describe how to bench bleed a master cylinder.

KEY TERMS: Breather port 1032 • Bypass port 1032 • Bypassing 1038 • Compensating port 1032 • Diagonal split master cylinder 1036 • Dual-diameter bore master cylinder 1036 • Dual split master cylinder 1034 • Fast-fill master cylinder 1036 • Filler port 1032 • Hydraulic system 1027 • Master cylinder 1031 • Pascal's law 1028 • Pedal free play 1037 • Pedal height 1037 • Pedal reserve distance 1037 • Piston assemblies 1039 • Quick take-up master cylinder 1036 • Replenishing port 1032 • Self-apply 1033 • Step-bore master cylinder 1036 • Vent port 1032

HYDRAULIC PRINCIPLES

In addition to the mechanical advantage provided by leverage, all vehicles use hydraulic pressure to help increase brake application force.

All braking systems require that a driver's force is transmitted to the drum or rotor attached to each wheel. ● **SEE FIGURE 94–1.**

The force that can be exerted on the brake pedal varies due to the strength and size of the driver. Engineers design braking systems to require less than 150 lb of force (68 kg) from the driver, yet provide the force necessary to stop a heavy vehicle from high speed.

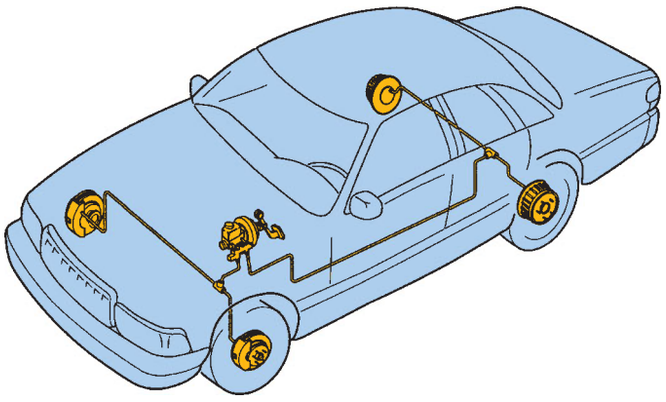


FIGURE 94–1 Hydraulic brake lines transfer the brake effort to each brake assembly attached to all four wheels.

NONCOMPRESSIBILITY OF LIQUIDS

Hydraulic systems use liquids to transmit motion. For all practical purposes, a liquid cannot be compressed. No matter how much pressure or force is placed on a quantity of liquid, its volume will remain the same. This fact enables liquids in a closed system to transmit motion. ● **SEE FIGURE 94–2.**

If piston A is moved a distance of 1 in., the liquid will be displaced ahead of it and piston B will move 1 in. as well.

Liquids cannot be compressed, but any air trapped in the system can be compressed. For example, the simple hydraulic system has been contaminated with air. ● **SEE FIGURE 94–3.**

Even though piston A is moved a distance of 1 in., piston B will not move if the load on it is greater than the pressure of the air in the system. For example, if the load on piston B is 50 pounds per square inch (PSI), the movement of piston A must compress the air in the system to that same pressure before piston B will begin to move. A brake hydraulic system must be air free or the brakes will not operate correctly and the driver will feel a spongy brake pedal that is also often lower than normal.

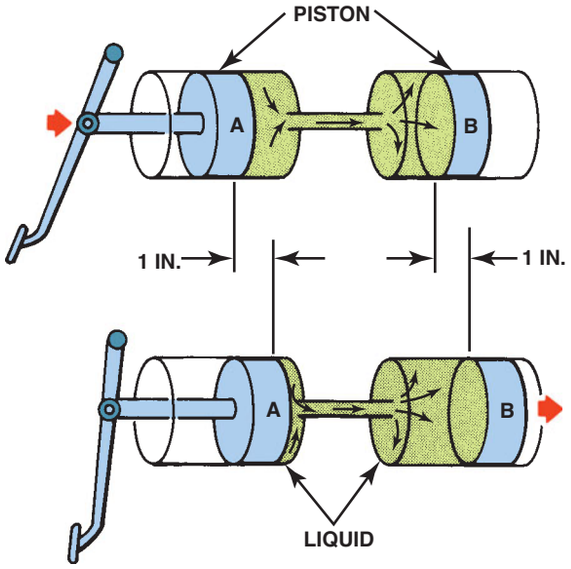


FIGURE 94–2 Because liquids cannot be compressed, they are able to transmit motion in a closed system.

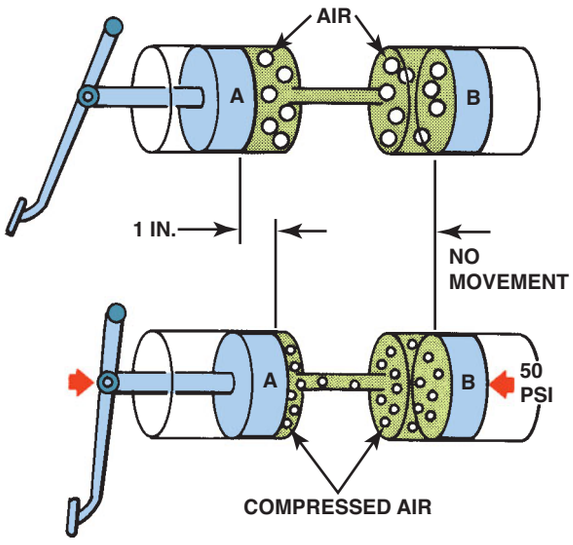


FIGURE 94–3 Hydraulic system must be free of air to operate properly. If air is in the system, the air is compressed when the brake pedal is depressed and the brake fluid does not transmit the force to the wheel brakes.

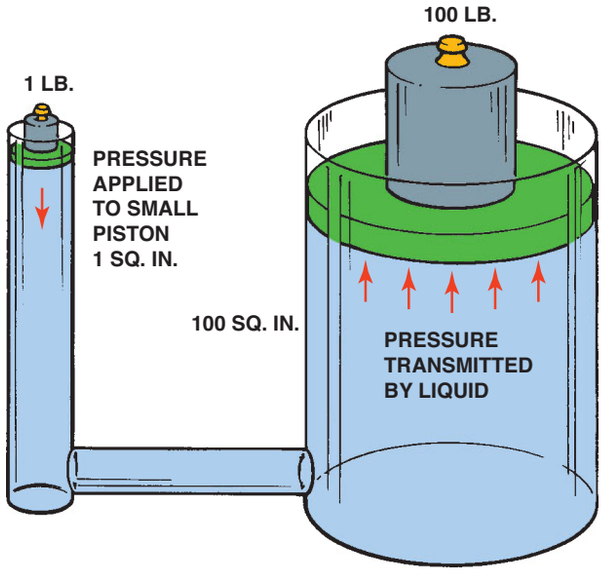


FIGURE 94–4 A one-pound force exerted on a small piston in a sealed system transfers the pressure to each square inch throughout the system. In this example, the 1-lb force is able to lift a 100-lb weight because it is supported by a piston that is 100 times larger in area than the small piston.

PASCAL'S LAW

The hydraulic principles that permit a brake system to function were discovered by a French physicist, Blaise Pascal (1632–1662). **Pascal's law** states that "when force is applied to a liquid confined in a container or an enclosure, the pressure is transmitted equal and undiminished in every direction." To help understand this principle, assume that a force of 10 lb is exerted on a piston with a surface area of 1 square inch (sq. in.). Since this *force* measured in lb or Newtons (N) is applied to a piston with an area measured in square inches (sq. in.), the *pressure* is the force divided by the area or "10 pounds per square inch (PSI)." It is this "pressure" that is transmitted, without loss, throughout the entire hydraulic system. ● **SEE FIGURE 94–4.**

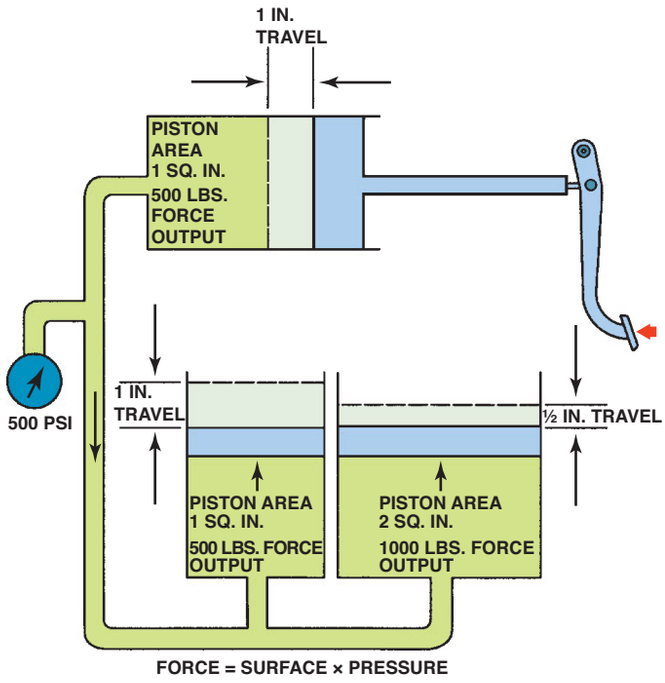


FIGURE 94–5 The amount of force (F) on the piston is the result of pressure (P) multiplied by the surface area (A). In this example, the driver is applying a force of 150 pounds but through the mechanical advantage of the brake pedal (3.3 to 1 ratio), the force is increased to 500 pounds into the master cylinder.

If two out of the three factors are known, then the other one can be calculated by using this formula.

***F* = *P* × *A* (force is equal to the pressure multiplied by the area)**

***P* = *F* ÷ *A* (pressure is equal to the force divided by the area)**

***A* = *F* ÷ *P* (area is equal to the force divided by the pressure)**

where the capital letters mean:

***F* = force (lb) (Newtons)**
***P* = pressure in lb per sq. in. (kilo Pascals [kPa])**
***A* = area in sq. in. (cm^2)**

A practical example involves a master cylinder with a piston area of 1 sq. in., and one wheel cylinder with an area of 1 sq. in., and one wheel cylinder with a piston area of 2 sq. in. ● **SEE FIGURE 94–5.**

The real "magic" of a hydraulic brake system is the fact that different forces can be created at different wheel cylinders. More force is necessary for front brakes than for rear brakes because, as the brakes are applied, the weight of the vehicle moves forward.

Larger (area) pistons are used in brake calipers on the front wheels to increase the force used to apply the front brakes.

Not only can hydraulics act as a "force machine" (by varying piston size), but the hydraulic system also can be varied to change piston stroke distances.

On a typical vehicle, a driver-input force of 150 lb (660 Newtons) is boosted both mechanically (through the brake pedal linkage) and by the power booster to a fluid pressure of about 1,700 PSI (11,700 kPa). With a drum brake, the wheel cylinder expands and pushes the brake shoes against a brake drum. *The distance the shoes move is only about 0.005–0.012 in. (5 to 12 thousandths of an inch) (0.015–0.30 mm).* ● **SEE FIGURE 94–6.**

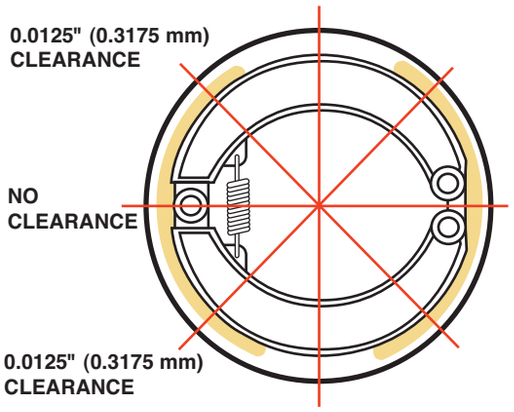


FIGURE 94–6 Drum brake illustrating the typical clearance between the brake shoes (friction material) and the rotating brake drum represented as the outermost black circle.

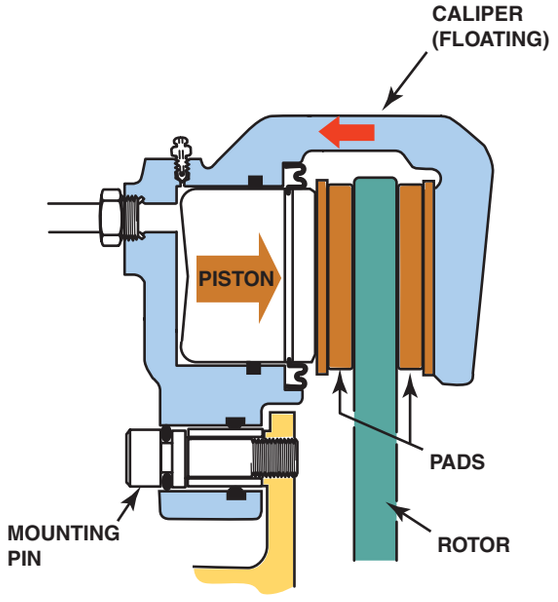


FIGURE 94–7 The brake pad (friction material) is pressed on both sides of the rotating rotor by the hydraulic pressure of the caliper.

FREQUENTLY ASKED QUESTION

How Much Brake Fluid Is Moved When the Brake Pedal Is Depressed?

During a typical brake application, only about *1 teaspoon (5 ml or cc) of brake fluid* actually is moved from the master cylinder and into the hydraulic system to cause the pressure buildup to occur.

With a disc brake, brake fluid pressure pushes on the piston in the caliper a small amount and causes a clamping of the disc brake pads against both sides of a rotor (disc). ● **SEE FIGURE 94–7.** *The typical distance the pads move is only about 0.001–0.003 in. (1 to 3 thousandths of an inch) (0.025–0.076 mm).*

HYDRAULIC PRESSURE AND PISTON SIZE

If a mechanical force of 100 lb is exerted by the brake pedal pushrod onto a master cylinder piston with 1 sq. in. of surface area, the equation reads as follows.

$$\frac{\text{100 lb}}{\text{1 sq. in.}} = \text{100 PSI}$$

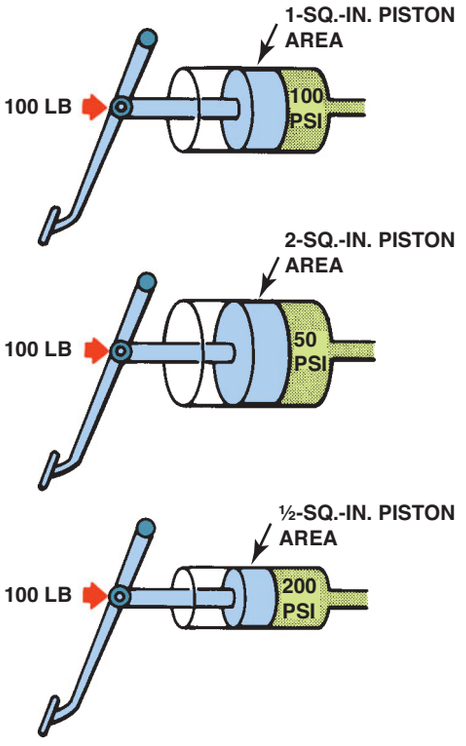


FIGURE 94–8 Mechanical force and the master cylinder piston area determine the hydraulic pressure in the brake system.

The result in this case is 100 PSI of brake system hydraulic pressure. ● **SEE FIGURE 94–8.** However, if the same 100-lb force is applied to a master cylinder piston with twice the area (2 sq. in.) the equation will read as follows.

$$\frac{\text{100 lb}}{\text{2 sq. in.}} = \text{50 PSI}$$

Doubling the area of the master cylinder piston cuts the hydraulic system pressure in half. Conversely, if the same 100-lb force is applied to a master cylinder piston with only half the area (0.5 or 1/2 sq. in.), the equation will show that the system pressure is doubled:

$$\frac{\text{100 lb}}{\text{0.5 sq. in.}} = \text{200 PSI}$$

APPLICATION FORCE AND PISTON SIZE

While the size of the master cylinder piston affects the hydraulic pressure of the entire brake system, weight shift and bias require that the heavily loaded front brakes receive much higher application force than the lightly loaded rear brakes. These differences in force are obtained by using different-sized pistons in the wheel cylinders and brake calipers. Pascal's law states that a pressurized liquid in a confined space acts with equal pressure on equal *areas* and as long as the pistons in a hydraulic system have the same area, 100 PSI from the master cylinder will result in 100 PSI of braking force. ● **SEE FIGURE 94–9.** However, when equal pressure acts on *unequal* areas, as with different-sized pistons, the brake application force will differ as well.

The mechanical *force(f)* at the brake pedal pushrod is applied to the master cylinder piston *area(a)* and converted into brake system hydraulic *pressure(p).* Brake calipers and wheel cylinders perform exactly the opposite. Hydraulic *pressure* applied to the wheel cylinder or brake caliper piston *area* is converted back into mechanical *force* that is used to apply the wheel friction assemblies. Because the variables are identical, the same equation can

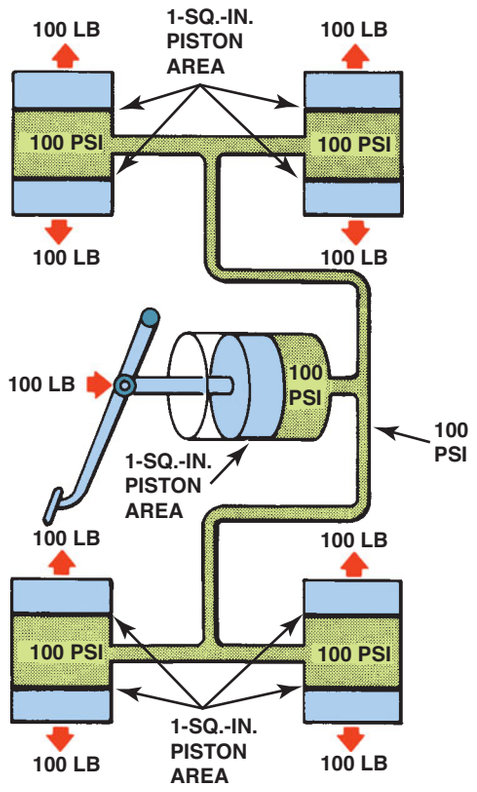


FIGURE 94–9 Hydraulic pressure is the same throughout a closed system and acts with equal force on equal areas.

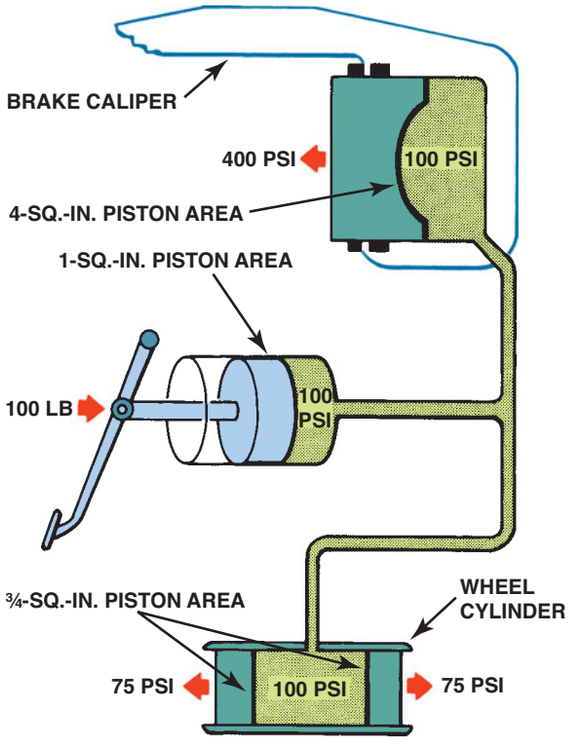


FIGURE 94–10 Differences in brake caliper and wheel cylinder piston area have a major effect on brake application force.

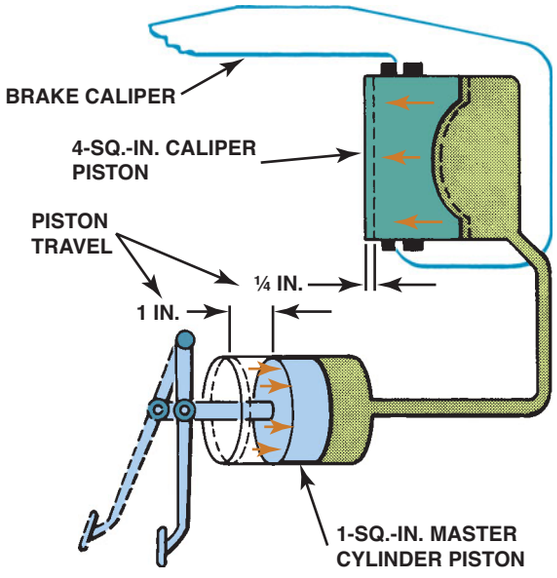


FIGURE 94–11 The increase in application force created by the large brake caliper piston is offset by a decrease in piston travel.

be rewritten to explain how changes in piston size affect brake application force.

$$P \times A = F$$

It is piston surface *area,* not diameter, that affects force.

In the simple brake system, the pedal and linkage apply a 100-lb force on a master cylinder piston with an area of 1 sq. in. ● **SEE FIGURE 94–10.** This results in a pressure of 100 PSI throughout the hydraulic system. At the front wheels, the 100 PSI is applied to a brake caliper piston that has an area of 4 sq. in. The equation for this example is as follows.

100 PSI × 4 sq. in. = 400 lb

In this case the difference in piston areas (1 sq. in. compared to 4 sq. in.) results in the 100-PSI brake pedal pushrod force being increased for 400 lb of application force at the wheel friction assembly. The hydraulic pressure is still 100 PSI at all points within the system and the increase in application pressure is solely the result of 100 PSI acting on a 4-sq.-in. piston. The 400 lb is a mechanical force, not hydraulic pressure.

The drum brakes at the rear wheels of the same brake system use wheel cylinders whose pistons have three-quarters (3/4 or 0.75) of an inch of surface area. If the hydraulic system pressure remains 100 PSI, the equation for this example is as follows.

100 PSI × 0.75 sq. in. = 75 lb

Just as larger pistons increase application force, this example shows that smaller pistons decrease it. The system hydraulic pressure remains 100 PSI at all points, but the smaller piston is unable to transmit all of the available pressure. As a result, the mechanical application force is reduced to only 75 lb.

PISTON SIZE VERSUS PISTON TRAVEL

In disc brakes, the mechanical force available to apply the brakes is four times greater because of the size difference between the master cylinder and caliper pistons. Some of the hydraulic energy is converted into *increased* mechanical force. The trade-off is that the larger caliper piston with the greater force will not move as far as the smaller master cylinder piston. The amount of hydraulic energy converted into mechanical motion is *decreased.* For example in a typical disc brake system, if the master cylinder piston stroke is 1 in., the caliper piston will move only 1/4 inch. ● **SEE FIGURE 94–11.**

HYDRAULIC PRINCIPLES AND BRAKE DESIGN

When a brake system is designed, the hydraulic relationships play a major part in determining the sizes of the many pistons within the system. The piston sizes selected must move enough fluid to operate the wheel cylinder and brake caliper pistons through a wide range of

REAL WORLD FIX

Bigger Is Not Better

A vehicle owner wanted better braking performance from his off-road race vehicle. Thinking that a larger master cylinder would help, a technician replaced the original 1-in.-bore-diameter master cylinder with a larger master cylinder with a 1 1/8-in.-bore-diameter master cylinder.

After bleeding the system, the technician was anxious to test-drive the "new" brake system. During the test-drive the technician noticed that the brake pedal "grabbed" much higher than with the original master cylinder. This delighted the technician. The owner of the vehicle was also delighted until he tried to stop from highway speed. *The driver had to use both feet to stop!*

The technician realized, after the complaint, that the larger master cylinder was able to move more brake fluid, but with *less* pressure to the wheel cylinders. The new master cylinder gave the impression of better brakes because the fluid was moved into the wheel cylinders (and calipers) quickly, and the pads and shoes contacted the rotor and drums sooner because of the greater volume of brake fluid moved by the larger pistons in the master cylinder.

To calculate the difference in pressure between the original (stock) master cylinder and the larger replacement, the technician used Pascal's law with the following results:

Original Master Cylinder (1 in. bore)	**Replacement Master Cylinder (1 1/8 in. bore)**
$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$	$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$
$\text{PSI} = \frac{450\text{ lb}}{\text{Area}}\text{ (typical)}$	$\text{PSI} = \frac{450\text{ lb}}{\text{Area}}\text{ (typical)}$
Area = $\pi r^2 = 3.14 \times .5^2$ (1/2 of 1 in.)	Area = πr^2 5 $3.14 \times .5625^2$ (1/2 of 1 1/8 in.)
Area = $3.14 \times .25$	Area = $3.14 \times .316$
Area = .785 sq. in.	Area = .992 sq. in.
$\text{Pressure} = \frac{450}{.785} = 573\text{ PSI}$	$\text{Pressure} = \frac{450}{.992} = 454\text{ PSI}$

The difference in pressure is 119 PSI less with the larger master cylinder (573 − 454 = 119).

The stopping power of the brakes was reduced because the larger diameter master cylinder piston produced lower pressure (the same force was spread over a larger area and this means that the pressure [PSI] is less).

All master cylinders are sized correctly from the factory for the correct braking effort, pressure, pedal travel, and stopping ability. *A technician should never change the sizing of any hydraulic brake component on any vehicle!*

travel, while at the same time they must create enough application force to lock the wheel brakes. The piston sizes chosen should also provide the driver with good brake pedal "feel" so the brakes are easy to apply in a controlled manner.

Most vehicles with disc brakes have large master cylinder pistons to move the required volume of fluid, and a power booster to increase the force that the driver applies to the master cylinder.

MASTER CYLINDERS

PURPOSE AND FUNCTION

The **master cylinder** is the heart of the entire braking system. No braking occurs until the driver depresses the brake pedal. The brake pedal linkage is used to apply the force of the driver's foot into a closed hydraulic system that begins with the master cylinder.

MASTER CYLINDER RESERVOIRS

Most vehicles built since the early 1980s are equipped with see-through master cylinder reservoirs, which permit owners and service technicians to check the brake fluid level without having to remove the top of the reservoir. Some countries have laws that require this type of reservoir. ● **SEE FIGURE 94–12.**

The reservoir capacity is great enough to allow for the brakes to become completely worn out and still have enough fluid reserve for safe operation. The typical capacity of the entire braking system is usually 2 to 3 pints (1 to 1.5 liters). Vehicles equipped with four-wheel disc brakes usually hold 4 pints (2 liters) or more.

MASTER CYLINDER RESERVOIR DIAPHRAGM

The entire brake system is filled with brake fluid up to the "full" level of the master cylinder reservoir.

CAUTION: The master cylinder should never be filled higher than the recommended full mark to allow for brake fluid expansion that occurs normally when the brake fluid gets hot due to the heat generated by the brakes.

The reservoir is vented to the atmosphere so the fluid can expand and contract without difficulty as would be the case if the reservoir were sealed.

Being open to the atmosphere allows the moisture in the air to come in contact with the brake fluid. This moisture in the air is absorbed into the brake fluid because brake fluid has an affinity (attraction) to moisture (water).

To help reduce the moisture from getting in contact with the brake fluid, master cylinders use a rubber diaphragm or floating disc to help seal outside air from direct contact with brake fluid. This seal

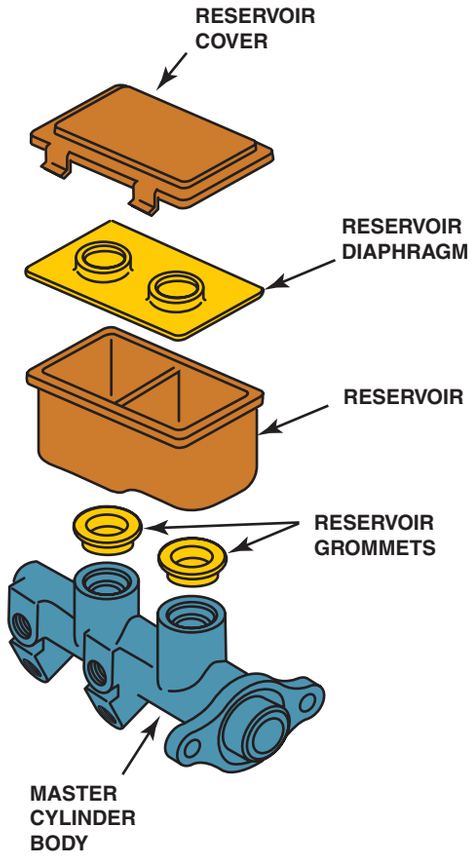


FIGURE 94–12 Typical master cylinder showing the reservoir and associated parts. The reservoir diaphragm lays directly on top of the brake fluid, which helps keep air from the surface of the brake fluid because brake fluid easily absorbs moisture from the air.



FIGURE 94–13 Master cylinder with brake fluid level at the "max" (maximum) line.

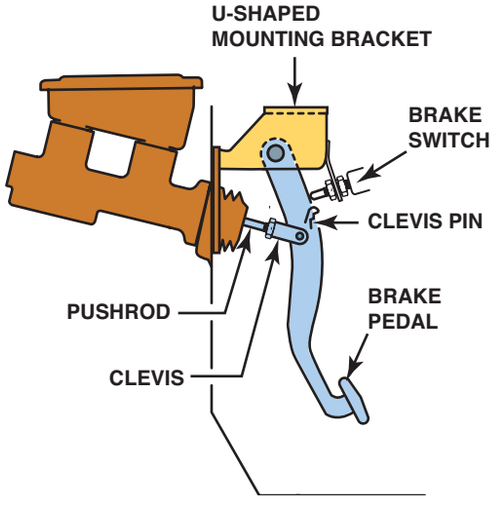


FIGURE 94–14 The typical brake pedal is supported by a mount and attached to the pushrod by a U-shaped bracket. The pin used to retain the clevis to the brake pedal is usually called a clevis pin.

TECH TIP

Don't Fill the Master Cylinder Without Seeing Me!

The boss explained to the beginning technician that there are two reasons why the customer should be told not to fill the master cylinder reservoir when the brake fluid is down to the "minimum" mark, as shown in ● **FIGURE 94–13.**

1. If the master cylinder reservoir is low, there may be a leak that should be repaired.
2. As the brakes wear, the disc brake piston moves outward to maintain the same distance between friction materials and the rotor. Therefore, as the disc brake pads wear, the brake fluid level goes down to compensate.

Therefore if the brake fluid is low, the vehicle should be serviced—either for new brakes or to repair a leak.

still allows the brake fluid to expand and contract as the fluid heats up and cools down during normal brake system operation. This rubber diaphragm is vented between the steel cap and diaphragm. As the brake fluid level drops due to normal disc brake pad wear, the rubber diaphragm also lowers to remain like a second skin on top of the brake fluid.

Whenever adding brake fluid, push the rubber diaphragm back up into the cover. Normal atmospheric pressure will allow the diaphragm to return to its normal position on top of the brake fluid. Whenever servicing a brake system, be sure to check that the vent hole is clear on the cover to allow air to get between the cover and the diaphragm.

MASTER CYLINDER OPERATION

The master cylinder is the heart of any hydraulic braking system. Brake pedal movement and force are transferred to the brake fluid and directed to wheel cylinders or calipers. ● **SEE FIGURE 94–14.** The master cylinder is also separated into two pressure-building chambers (or circuits) to provide braking force to one-half of the brake in the event of a leak or damage to one circuit. ● **SEE FIGURE 94–15.**

Both pressure-building sections of the master cylinder contain two holes from the reservoir. The Society of Automotive Engineers' (SAE) term for the forward (tapered) hole is the **vent port,** and the rearward straight drilled hole is called the **replenishing port.** ● **SEE FIGURE 94–16.**

Various vehicle and brake component manufacturers call these ports by various names. For example, the vent port is the high-pressure port. This tapered forward hole is also called the **compensating port.**

The replenishing port is the low-pressure rearward, larger diameter hole. The inlet port is also called the **bypass port, filler port,** or **breather port.**

The function of the master cylinder can be explained from the at-rest, applied, and released positions.

AT-REST POSITION. The primary (forward facing) sealing cups are between the compensating port hole and the inlet port hole. In this position, if the temperature of the brake fluid rises and the fluid expands, the brake fluid is free to expand up into the reservoir through the vent port (compensating port). If the fluid was trapped, the pressure of the brake fluid would increase with temperature, causing the brakes to **self-apply.** ● **SEE FIGURE 94–17.**

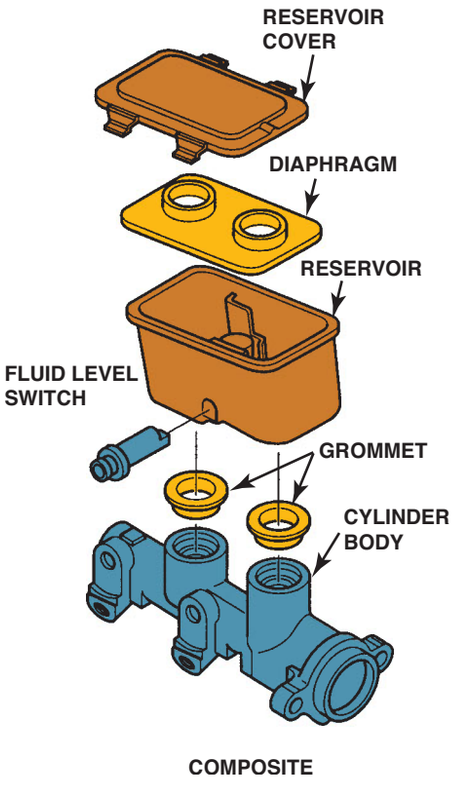


FIGURE 94–15 The composite master cylinder is made from two different materials—aluminum for the body and plastic materials for the reservoir and reservoir cover. This type of reservoir feeds both primary (closest to the driver) and secondary chambers, and therefore uses a fluid level switch that activates the red dash warning lamp if the brake fluid level drops.

APPLIED POSITION. When the brake pedal is depressed, the pedal linkage forces the pushrod and primary piston (closest to the driver) down the bore of the master cylinder. ● **SEE FIGURE 94–18.** As the piston moves forward, the primary sealing cup covers and blocks off the vent port (compensating port). Hydraulic pressure builds in front of the primary seal as the pushrod moves forward. The back of the piston is kept filled through the replenishing port. ● **SEE FIGURE 94–19.** This stops any suction (vacuum) from forming behind the piston. The secondary piston is moved forward as pressure is exerted by the primary piston. If, for any reason, such as a leak, the primary piston cannot build pressure, a mechanical extension rod on the front of the primary piston will touch the secondary piston and move it forward, as the primary piston is pushed forward by the pushrod and brake

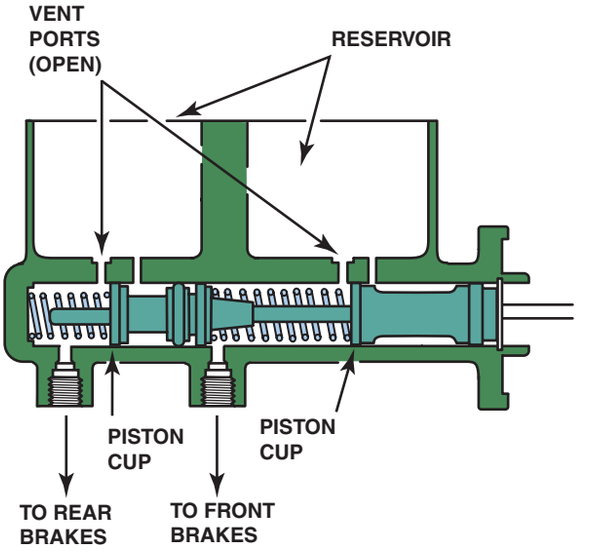
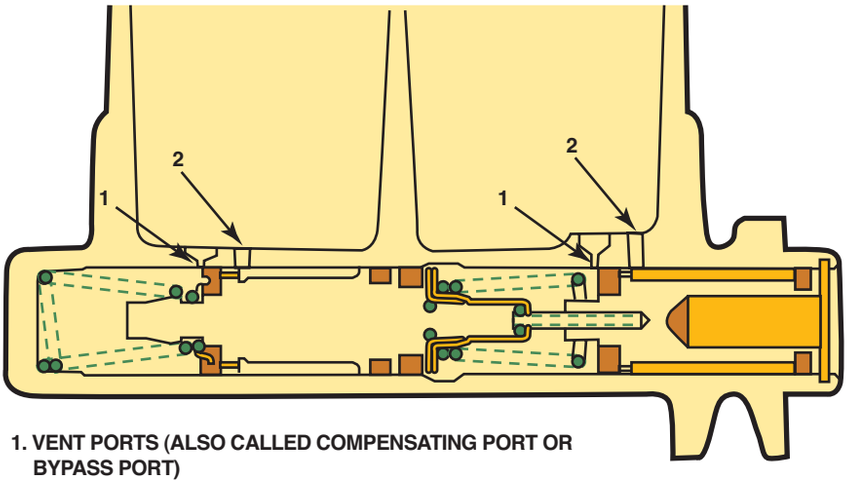


FIGURE 94–17 The vent ports must remain open to allow brake fluid to expand when heated by the friction material and transferred to the caliper and/or wheel cylinder. As the brake fluid increases in temperature, it expands causing the brakes to self-apply which is prevented by the open vent ports.



1. VENT PORTS (ALSO CALLED COMPENSATING PORT OR BYPASS PORT)
2. REPLENISHING PORTS (ALSO CALLED INLET PORT, BYPASS PORT, FILLER PORT, OR BREATHER PORT)

FIGURE 94–16 Note the various names for the vent port (front port) and the replenishing port (rear port). Names vary by vehicle and brake component manufacturer. The names vent port and replenishing port are the terms recommended by the Society of Automotive Engineers (SAE).

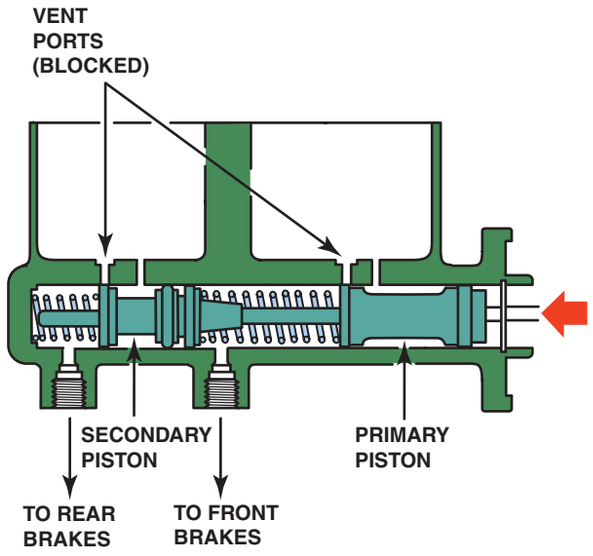


FIGURE 94–18 As the brake pedal is depressed, the pushrod moves the primary piston forward, closing off the vent port. As soon as the port is blocked, pressure builds in front of the primary sealing cup, which pushes on the secondary piston. The secondary piston also moves forward, blocking the secondary vent port and building pressure in front of the primary sealing cup.

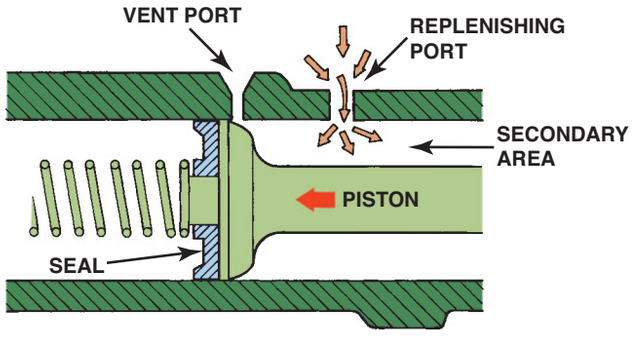


FIGURE 94–19 The purpose of the replenishing port is to keep the volume behind the primary piston filled with brake fluid from the reservoir as the piston moves forward during a brake application.

TECH TIP

Too Much Is Bad

Some vehicle owners or inexperienced service people may fill the master cylinder to the top. Master cylinders should only be filled to the "maximum" level line or about 1/4 in. (6 mm) from the top to allow room for expansion when the brake fluid gets hot during normal operation. If the master cylinder is filled to the top, the expanding brake fluid has no place to expand and the pressure increases. This increased pressure can cause the brakes to "self-apply," shortening brake friction material life and increasing fuel consumption. Overheated brakes can result and the brake fluid may boil, causing a total loss of braking.

pedal. As a result of these actions, brake fluid pressure is applied to both outlets of the master cylinder.

RELEASED POSITION. Releasing the brake pedal removes the pressure on the pushrod and master cylinder pistons. A spring on the brake pedal linkage returns the brake pedal to its normal at-rest (up)

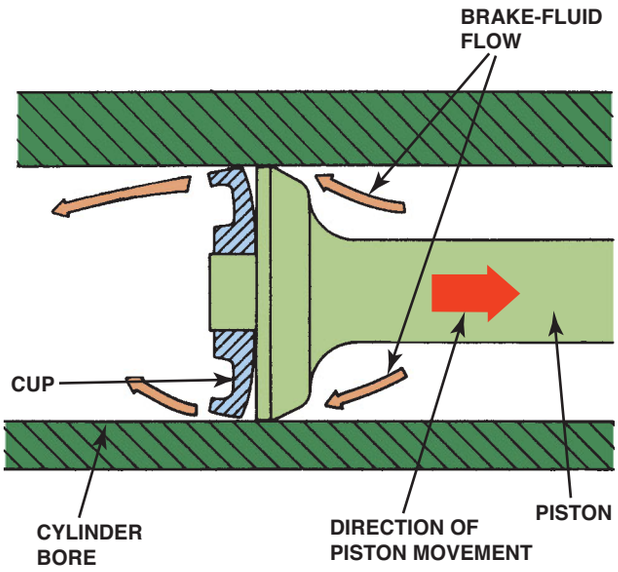


FIGURE 94–20 When the brake pedal is released, the master cylinder piston moves rearward. Some of the brake fluid is pushed back up through the replenishing port, but most of the fluid flows past the sealing cup. Therefore, when the driver pumps the brake pedal, the additional fluid in front of the pressure-building sealing cup is available quickly.

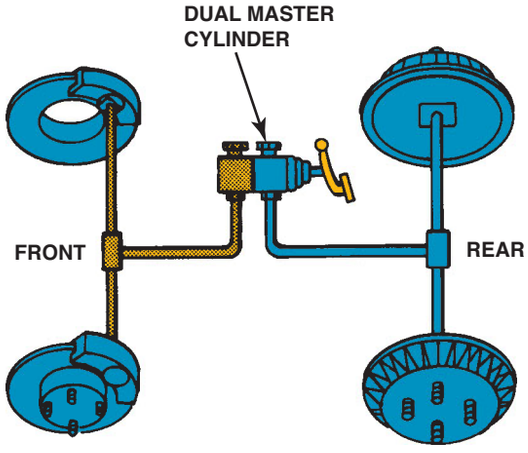


FIGURE 94–21 Rear-wheel-drive vehicles use a dual split master cylinder.

position. The spring in front of the master cylinder piston expands, pushing the pistons rearward. At the same time, pressure is released from the entire braking system and the released brake fluid pressure is exerted on the master cylinder pistons, forcing them rearward. As the piston is pushed back, the lips of the seal fold forward allowing fluid to quickly move past the piston, as shown in ● **FIGURE 94–20.** Some pistons have small holes that allow the fluid to move more quickly. Once the primary seal passes the vent port, the remaining hydraulic pressure forces any excess fluid into the reservoir.

MASTER CYLINDER DESIGNS

DUAL SPLIT MASTER CYLINDERS **Dual split master cylinders** use two separate pressure-building sections. One section operates the front brakes and the other section operates the rear brakes on vehicles equipped with a front/rear-split system. ● **SEE FIGURE 94–21.** The *nose end* of the master cylinder is the

TECH TIP

Always Check for Venting (Compensation)

Whenever diagnosing any braking problem, start the diagnosis at the master cylinder—the heart of any braking system. Remove the reservoir cover and observe the brake fluid for spurting while an assistant depresses the brake pedal.

Normal operation (movement of fluid observed in the reservoir)

There should be a squirt or movement of brake fluid out of the vent port of both the primary and secondary chambers. This indicates that the vent port is open and that the sealing cup is capable of moving fluid upward through the port before the cup seals off the port as it moves forward to pressurize the fluid.

No movement of fluid observed in the reservoir in the primary piston

This indicates that brake fluid is not being moved as the brake pedal is depressed. This can be caused by the following:

a. Incorrect brake pedal height—brake pedal or pushrod adjustment could be allowing the primary piston to be too far forward, causing the seal cup to be forward of the vent port. Adjust the brake pedal height to a higher level and check for a too-long pushrod length.
b. A defective or swollen rubber sealing cup on the primary piston could cause the cup itself to block the vent port.

NOTE: If the vent port is blocked for any reason, the brakes of the vehicle may *self-apply* when the brake fluid heats up during normal braking. Since the vent port is blocked, the expanded hotter brake fluid has no place to expand and instead increases the pressure in the brake lines. The increase in pressure causes the brakes to apply. Loosening the bleeder valves and releasing the built-up pressure is a check that the brakes are self-applying. Then check the master cylinder to see if it is "venting."

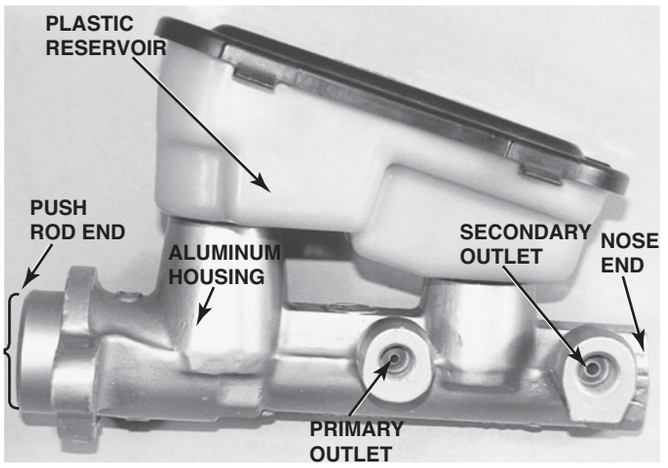


FIGURE 94–22 The primary outlet is the outlet closest to the pushrod end of the master cylinder and the secondary outlet is closest to the nose end of the master cylinder.

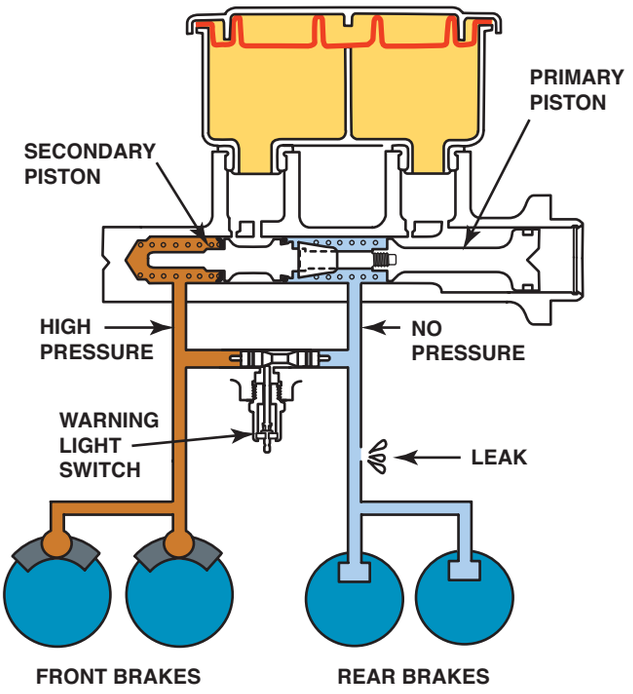


FIGURE 94–23 In the event of a primary system failure, no hydraulic pressure is available to push the second piston forward. As a result, the primary piston extension rod contacts the secondary piston and pushes on the secondary piston mechanically rather than hydraulically. The loss of pressure in the primary system is usually noticed by the driver by a lower-than-normal brake pedal and the lighting of the red brake warning lamp.

closed end toward the front of the vehicle. The open end is often called the *pushrod end* of the master cylinder. ● **SEE FIGURE 94–22.** Some manufacturers operate the front brakes (which do the most braking) from the "nose end" section (secondary piston end) of the master cylinder. The secondary piston has only one pressure-building seal. The primary piston (pushrod end) requires two seals to build pressure. Therefore, the nose end of the master cylinder is considered the more reliable of the two master cylinder pressure-building sections.

NOTE: On vehicles equipped with front and rear split master cylinders, the front brakes may or may *not* be operated from the front chamber. General Motors typically uses the front (nose end) chamber for the front brakes and the rear (pushrod end) for the rear brakes. Many other makes and models of vehicles use the rear chamber for the front brakes. If in doubt, consult the factory service information for the exact vehicle being serviced.

If the rear section of the hydraulic system fails, the primary piston will not build pressure to operate the secondary piston. To permit the operation of the secondary piston (nose end piston) in the event of a hydraulic failure of the rear section, the primary piston extension rod will mechanically contact and push on the secondary piston. ● **SEE FIGURE 94–23.** If there is a failure of the front section hydraulic system, the primary piston (pushrod end) operates normally and exerts pressure on the secondary piston. The secondary piston, however, will not be able to build pressure because of the leak in the system.

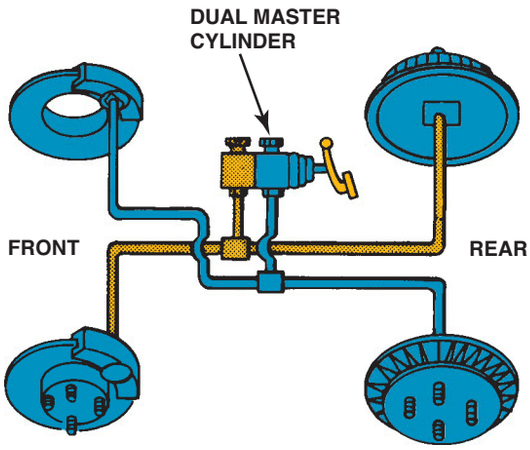


FIGURE 94–24 Front-wheel-drive vehicles use a diagonal split master cylinder. In this design one section of the master cylinder operates the right front and the left rear brake and the other section operates the left front and right rear. In the event of a failure in one section, at least one front brake will still function.

DIAGONAL SPLIT MASTER CYLINDERS

With front-wheel-drive vehicles, the weight of the entire powertrain is on the front wheels and 80% to 90% of the braking force is achieved by the front brakes. This means that only 10% to 20% of the braking force is being handled by the rear brakes. If the front brakes fail, the rear brakes alone would not provide adequate braking force. The solution is the use of a **diagonal split master cylinder.** ● **SEE FIGURE 94–24.**

In a diagonal split braking system, the left front brake and the right rear brake are on one circuit, and the right front with the left rear is another circuit of the master cylinder. If one circuit fails, the remaining circuit can still stop the vehicle in a reasonable fashion because each circuit has one front brake. To prevent this one front brake from causing the vehicle to pull toward one side during braking, the front suspension is designed with negative scrub radius geometry. This effectively eliminates any handling problem in the event of a brake circuit failure.

QUICK TAKE-UP MASTER CYLINDERS

Many newer vehicles use low-drag disc brake calipers to increase fuel economy. However, due to the larger distance between the rotor and the friction pads, excessive brake pedal travel would be required before the pads touched the rotor. The solution to this problem is a master cylinder design that can take up this extra clearance.

The design of a **quick take-up master cylinder** includes a larger diameter primary piston (low-pressure chamber) and a quick take-up valve. This type of master cylinder is also called **dual-diameter bore, step-bore,** or **fast-fill master cylinders.**

A spring-loaded check ball valve holds pressure on the brake fluid in the large diameter rear chamber of the primary piston. When the brakes are first applied, the movement of the rear larger piston forces this larger volume of brake fluid forward past the primary piston seal and into the primary high-pressure chamber. This extra volume of brake fluid "takes up" the extra clearance of the front disc brake calipers without increasing the brake pedal travel distance. ● **SEE FIGURE 94–25.**

At 70 to 100 PSI, the check ball valve in the quick take-up valve allows fluid to return to the brake fluid reservoir. Because the quick take-up "works" until 100 PSI is reached, a metering valve is not required to hold back the fluid pressure to the front brakes.

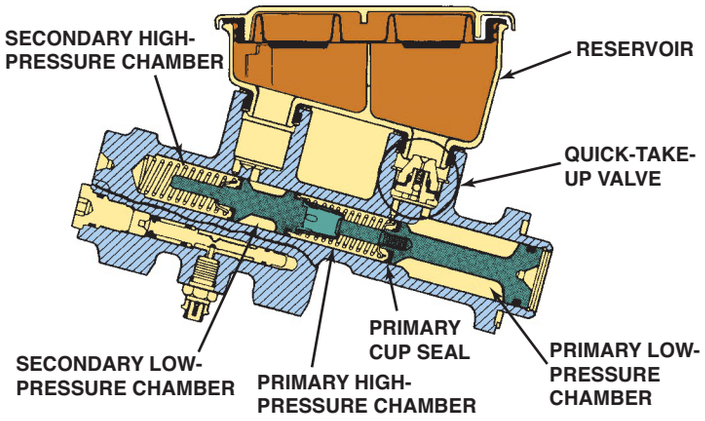


FIGURE 94–25 Quick take-up master cylinder can be identified by the oversize primary low-pressure chamber.

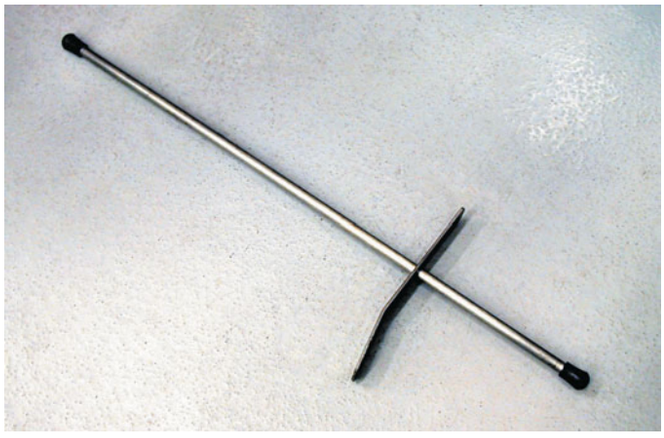


FIGURE 94–26 A brake pedal depressor like this can be used during a wheel alignment to block the flow of brake fluid from the master cylinder during service work on the hydraulic system.

TECH TIP

The Brake Pedal Depressor Trick

The master cylinder can be used to *block* the flow of brake fluid. Whenever any hydraulic brake component is removed, brake fluid tends to leak out because the master cylinder is usually higher than most other hydraulic components such as wheel cylinders and calipers.

To prevent brake fluid loss that can easily empty the master cylinder reservoir, simply *depress* the brake pedal slightly or prop a stick or other pedal depressor to keep the brake pedal down. When the brake pedal is depressed, the piston sealing cups move forward, blocking off the reservoir from the rest of the braking system. The master cylinder stays full and the brake fluid stops dripping out of brake lines that have been disconnected. ● **SEE FIGURE 94–26.**

NOTE: Try this—put a straw into a glass of water. Use a finger to seal the top of the straw and then remove the straw from the glass of water. The water remains in the straw because air cannot get into the top of the straw. This is why the brake pedal depressor trick works to prevent the loss of brake fluid from the system even if the brake line is totally disconnected.

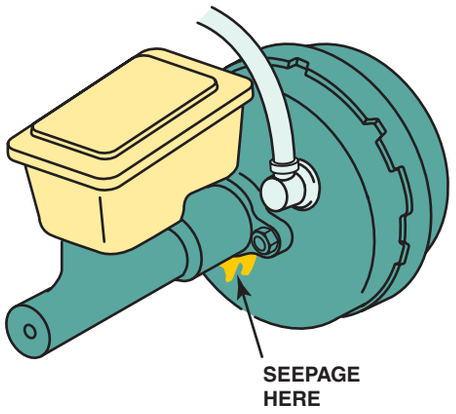


FIGURE 94–27 Some seepage is normal when a trace of fluid appears on the vacuum booster shell. Excessive leakage, however, indicates a leaking secondary (end) seal.

DIAGNOSING AND TROUBLESHOOTING MASTER CYLINDERS

A thorough visual inspection is important when inspecting any master cylinder. The visual inspection should include checking the following items:

1. Check the brake fluid for proper level and condition. (Brake fluid should not be rusty, thick, or contaminated.)
2. Check that the vent holes in the reservoir cover are open and clean.
3. Check that the reservoir cover diaphragm is not torn or enlarged.

   NOTE: If the rubber cover diaphragm is enlarged, this is an indication that a mineral oil, such as automatic transmission fluid or engine oil, has been used in or near the brake system, because rubber that is brake fluid resistant expands when exposed to mineral oil.

4. Check for any external leaks at the brake lines or at the pushrod area. ● **SEE FIGURE 94–27.**

After a thorough visual inspection, check for proper operation of **pedal height, pedal free play,** and **pedal reserve distance.** ● **SEE FIGURES 94–28 AND 94–29.**

Proper brake pedal height is important for the proper operation of the stop (brake) light switch. If the pedal is not correct, the pushrod may be in too far forward, preventing the master cylinder cups from uncovering the vent port. If the pedal is too high, the free play will be excessive. Pedal reserve height is easily checked by depressing the brake pedal with the right foot and attempting to slide your left foot under the brake pedal. ● **SEE FIGURE 94–30.** Free play is the distance the brake pedal travels before the primary piston in the master cylinder moves. *Most vehicles require brake pedal free play between 1/8 to 1 1/2 in. (3 to 38 mm).* Too little or too much free play can cause braking problems that can be mistakenly contributed to a defective master cylinder, such as the following:

- **Spongy brake pedal.** A spongy pedal with a larger than normal travel indicates air in the lines. Check for leaks and bleed the air from the system.

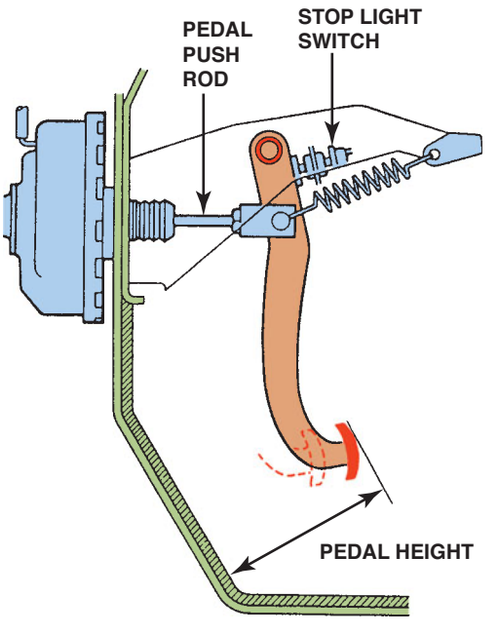


FIGURE 94–28 Pedal height is usually measured from the floor to the top of the brake pedal. Some vehicle manufacturers recommend removing the carpet and measuring from the asphalt matting on the floor for an accurate measurement. Always follow the manufacturer's recommended procedures and measurements. (*Courtesy of Toyota Motor Sales, U.S.A., Inc.*)

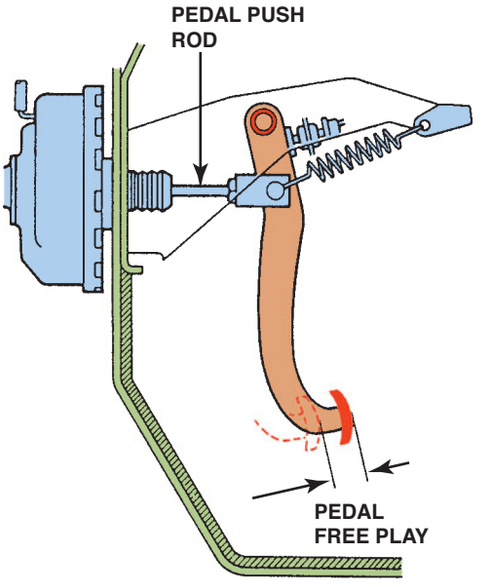


FIGURE 94–29 Brake pedal free play is the distance between the brake pedal fully released and the position of the brake pedal when braking resistance is felt. (*Courtesy of Toyota Motor Sales, U.S.A., Inc.*)

- **Lower-than-normal brake pedal.** A brake pedal that travels downward more than normal and then gets firm is an indication that one circuit of the dual-circuit hydraulic system is probably not working. Check for leaks in the system and repair as necessary. Another possible reason is an out-of-adjustment drum brake allowing too much pedal travel before the shoes touch the brake drum.

  NOTE: A lower-than-normal brake pedal may also be an indication of air in the hydraulic system.

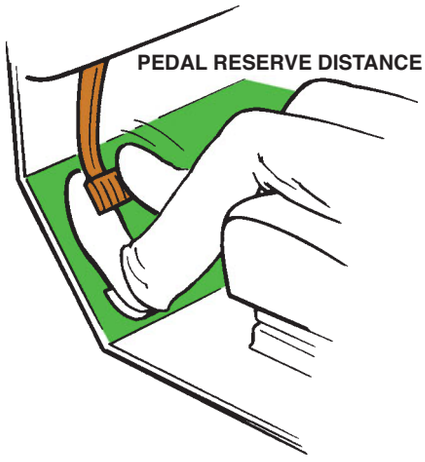


FIGURE 94–30 Brake pedal reserve is usually specified as the measurement from the floor to the top of the brake pedal with the brakes applied. A quick-and-easy test of pedal reserve is to try to place your left toe underneath the brake pedal while the brake pedal is depressed with your right foot. If your toe will *not* fit, then pedal reserve *may* not be sufficient.

TECH TIP

Check for Bypassing

If a master cylinder is leaking internally, brake fluid can be pumped from the rear chamber into the front chamber of the master cylinder. This internal leakage is called *bypassing.* When the fluid bypasses, the front chamber can overflow while emptying the rear chamber. Therefore, whenever checking the level of brake fluid, do not think that a low rear reservoir is always due to an external leak. Also, a master cylinder that is bypassing (leaking internally) will usually cause a lower-than-normal brake pedal.

- **Sinking brake pedal.** If the brake pedal sinks all the way to the floor especially when the vehicle is not moving, suspect a defective master cylinder that is leaking internally. This internal leakage is often called **bypassing** because the brake fluid is leaking past the sealing cup.

MASTER CYLINDER SERVICE

Check the vehicle manufacturer's recommendation before attempting to overhaul or service a master cylinder. Many manufacturers recommend replacing the master cylinder as an assembly. If disassembling a master cylinder, perform the following steps:

STEP 1 Remove the master cylinder from the vehicle, being careful to avoid dripping or spilling brake fluid onto painted surfaces of the vehicle. Dispose of all old brake fluid and clean the outside of the master cylinder.

STEP 2 Remove the reservoir, if possible, as shown in ● **FIGURE 94–31.**

STEP 3 Remove the retaining bolt that holds the secondary piston assembly in the bore.

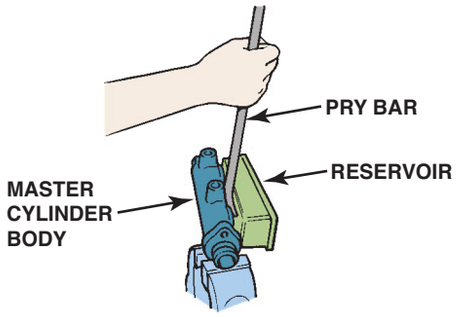


FIGURE 94–31 Using a prybar to carefully remove the reservoir from the master cylinder.

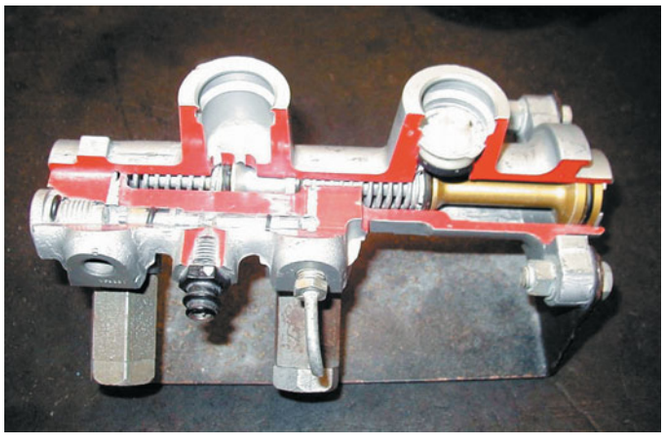


FIGURE 94–32 Whenever disassembling a master cylinder, note the exact order of parts as they are removed. Master cylinder overhaul kits (when available) often include entire piston assemblies rather than the individual seals.

STEP 4 Depress the primary piston with a *blunt* tool such as a Phillips screwdriver, a rounded wooden dowel, or an engine pushrod. Use of a straight-blade screwdriver or other non-rounded tool can damage and distort the aluminum piston.

CAUTION: If holding the master cylinder in a vise, use the flange area. Never clamp the body of the master cylinder.

STEP 5 Remove the snap ring and slowly release the pressure on the depressing tool. Spring pressure should push the primary piston out of the cylinder bore. ● **SEE FIGURE 94–32.**

STEP 6 Remove the master cylinder from the vise and tap the open end of the bore against the top of a workbench to force the secondary piston out of the bore. If necessary, use compressed air in the outlet to force the piston out.

WARNING

Use extreme care when using compressed air. The piston can be shot out of the master cylinder with a great force, which could cause personal injury.

INSPECTION AND REASSEMBLY OF THE MASTER CYLINDER Inspect the master cylinder bore for pitting, corrosion, or wear. Most cast-iron master cylinders cannot be honed because of the special bearingized surface finish that is applied to

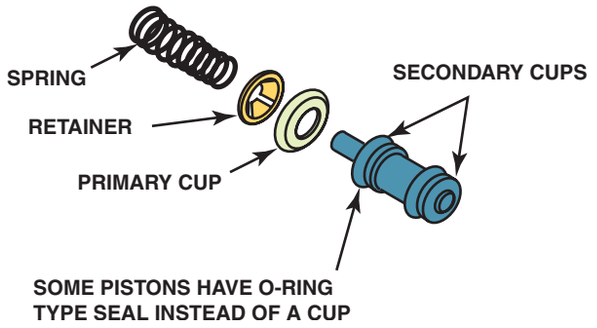


FIGURE 94–33 Piston assembly.

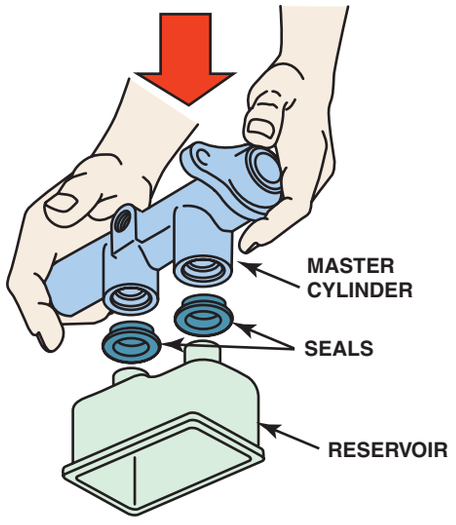


FIGURE 94–34 To reinstall the reservoir onto a master cylinder, place the reservoir on a clean flat surface and push the housing down onto the reservoir after coating the rubber seals with brake fluid.

the bore during manufacturing. Slight corrosion or surface flaws can usually be removed with a hone or crocus cloth. Otherwise, the master cylinder should be replaced as an assembly. Always follow the recommended procedures for the vehicle being serviced.

Aluminum master cylinders cannot be honed. Aluminum master cylinders have an anodized surface coating applied that is hard and wear resistant. Honing would remove this protective coating. Thoroughly clean the master cylinder and any other parts to be reused (except for rubber components) in clean denatured alcohol. If the bore is okay, replacement **piston assemblies** can be installed into the master cylinder after dipping them into clean brake fluid.

NOTE: While most master cylinder overhaul kits include the entire piston assemblies, some kits just contain the sealing cups and/or O-rings. Always follow the installation instructions that accompany the kit and always use the installation tool that is included to prevent damage to the replacement seals.

STEP 1 Install the secondary (smaller) piston assembly into the bore, spring end first. ● **SEE FIGURE 94–33.**

STEP 2 Install the primary piston assembly, spring end first.

STEP 3 Depress the primary piston and install the snap ring.

STEP 4 Install the retaining bolt.

STEP 5 Reinstall the plastic reservoir, if equipped, as shown in ● **FIGURE 94–34.**

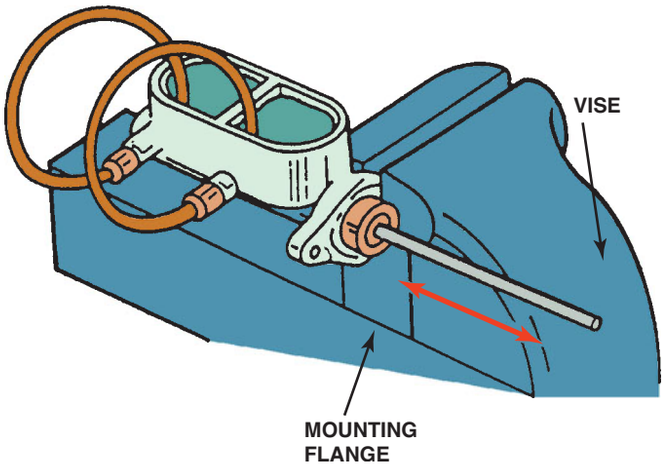


FIGURE 94–35 Bleeding a master cylinder before installing it on the vehicle. The master cylinder is clamped into a bench vise while using a rounded end of a dowel rod to push on the pushrod end with bleeder tubes down into the brake fluid. Master cylinders should be clamped on the mounting flange as shown to prevent distorting the master cylinder bore.



FIGURE 94–36 Installing a master cylinder. Always tighten the retaining fastener and brake lines to factory specifications.

STEP 6 Bench bleed the master cylinder. This step is very important. Failure to get all of the air out of the master cylinder can cause a lower than normal brake pedal and a lack of proper braking. ● **SEE FIGURE 94–35.**

INSTALLING THE MASTER CYLINDER

After the master cylinder has been bench bled, it can be installed in the vehicle.

NOTE: Brake fluid can drip from the outlet of the master cylinder and could drip onto the vehicle. Brake fluid is very corrosive and can remove paint. Use fender covers and avoid letting brake fluid touch any component of the vehicle.

Tighten the fasteners to factory specifications. ● **SEE FIGURE 94–36.** Bleed the system as needed.

REVIEW QUESTIONS

1. Explain Pascal's law.
2. Describe how a master cylinder works.
3. Discuss the difference between a dual split and a diagonal split master cylinder.
4. What is the difference between checking for venting (compensation) and bypassing?

CHAPTER QUIZ

1. Two technicians are discussing master cylinders. Technician A says that it is normal to see fluid movement in the reservoir when the brake pedal is depressed. Technician B says a defective master cylinder can cause the brake pedal to slowly sink to the floor when depressed. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
2. If the brake pedal linkage is not adjusted correctly, brake fluid may not be able to expand back into the reservoir through the _____ port of the master cylinder when the brakes get hot.
   a. Vent port (forward hole)
   b. Replenishing port (rearward hole)
3. The primary brake circuit fails due to a leak in the lines, leaving the rear section of a dual split master cylinder. Technician A says that the driver will notice a lower than normal brake pedal and some reduced braking power. Technician B says that the brake pedal will "grab" higher than normal. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
4. Two technicians are discussing a problem where the brake pedal travels too far before the vehicle starts to slow. Technician A says that the brakes may be out of adjustment. Technician B says that one circuit from the master cylinder may be leaking or defective. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
5. Air in the lines will cause what type of problem?
   a. Vibration in the brake pedal during stops
   b. Low spongy brake pedal
   c. Brake noise
   d. Hard brake pedal
6. The master cylinder is able to move about how much brake fluid during each brake application?
   a. One tablespoon
   b. One teaspoon
   c. One cu. in.
   d. 50 ml
7. Brake fluid pressure is measured in what unit?
   a. Sq. in. **c.** Inches
   b. Pounds **d.** PSI
8. How much brake fluid is in a typical master cylinder reservoir?
   a. One gallon
   b. Enough to allow all brakes to become completely worn
   c. 15 to 20 liters
   d. One pint
9. What part in the master cylinder helps keep air from contacting the brake fluid yet allows the fluid level to drop as the disc brakes wear?
   a. Vent valve
   b. Compensating valve
   c. Residual valve
   d. Rubber diaphragm or floating disc
10. The brakes on a vehicle work okay for a while, then the vehicle slows because the brakes self-applied. Technician A says that an overfilled master cylinder could be the cause. Technician B says that a blocked vent port (compensating port) could be the cause. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

chapter 95

HYDRAULIC VALVES AND SWITCHES

OBJECTIVES: **After studying Chapter 95, the reader will be able to:** • Prepare for the Brakes (A5) ASE certification test content area "A" (Hydraulic System Diagnosis and Repair). • Describe the operation of a residual check valve. • Explain how a proportioning valve works. • Discuss the need and use of a metering valve. • List testing procedures used to test hydraulic valves. • Describe how the brake fluid level and brake light switches work.

KEY TERMS: Brake fluid level sensor 1042 • Brake light switch 1048 • Combination valve 1048 • Electronic brake proportioning 1046 • Expander 1041 • Height-sensing proportioning valve 1045 • Metering valve 1046 • Pressure-differential switch 1041 • Proportioning valve 1043 • Residual check valve 1041 • Slope 1044 • Split point 1044

INTRODUCTION

The hydraulic system is the heart of the braking system. Using hydraulics is a very efficient way to transfer the force that the driver exerts on the brake pedal to apply the friction materials at the individual wheel brakes. However valves and switches need to be added to the system to meet all possible braking conditions.

RESIDUAL CHECK VALVE

PURPOSE AND FUNCTION A **residual check valve** has been used on some drum brake systems to keep a slight amount of pressure, about 5 to 12 PSI, on the entire hydraulic system for drum brakes. ● **SEE FIGURE 95–1.**

This residual check valve is located in the master cylinder at the outlet for the drum brakes. The check ball and spring in the residual check valve permit all the brake fluid to return to the master cylinder until the designated pressure is reached.

With a low pressure kept on the hydraulic system, any small hole will cause fluid to leak out rather than permit air to enter the system. This slight pressure also keeps the wheel cylinder sealing cups tight against the inside wall of the wheel cylinder. ● **SEE FIGURE 95–2.**

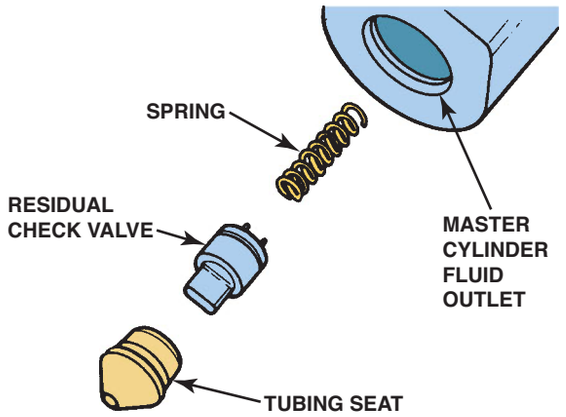


FIGURE 95–1 Most residual check valves are located under the tubing seats in the master cylinder outlet ports.

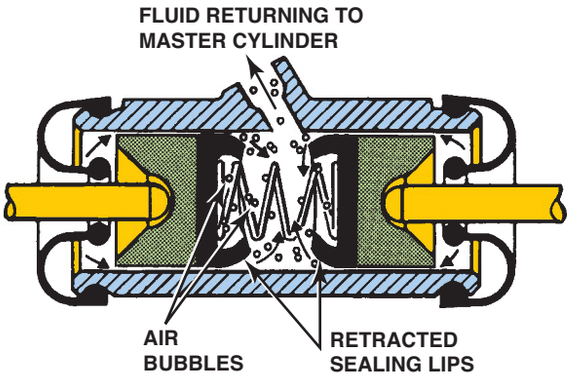


FIGURE 95–2 The momentary drop in pressure created when the brakes are released can draw air into the hydraulic system.

Residual check valves are often *not* used on late-model vehicles equipped with front disc/rear drum brakes. The residual check valve has been eliminated by equipping the wheel cylinder internal spring with a sealing cup **expander** to prevent sealing cup lip collapse. ● **SEE FIGURE 95–3.**

PRESSURE-DIFFERENTIAL SWITCH (BRAKE WARNING SWITCH)

PURPOSE AND FUNCTION A **pressure-differential switch** is used on all vehicles built after 1967 with dual master cylinders to warn the driver of a loss of pressure in one of the two separate systems by lighting the dashboard red brake warning indicator lamp. ● **SEE FIGURES 95–4 AND 95–5.**

The brake lines from both the front and the rear sections of the master cylinder are sent to this switch, which lights the brake warning indicator lamp in the event of a "difference in pressure" between the two sections. ● **SEE FIGURE 95–6.**

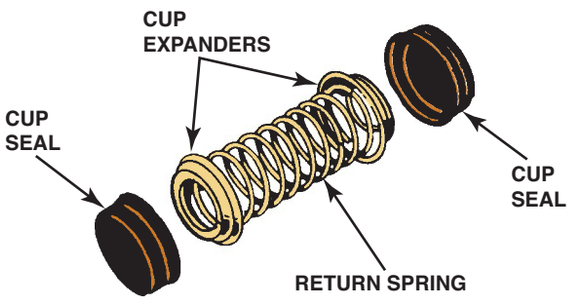


FIGURE 95–3 The use of cup expanders is the main reason why residual check valves are not used in most braking systems today.



FIGURE 95–4 A red brake warning lamp.

FIGURE 95–5 A leak in the hydraulic system causes unequal pressures between the two different brake circuits. This difference in pressures causes the plunger inside the pressure-differential switch to move, which completes the electrical ground circuit for the red brake warning lamp.

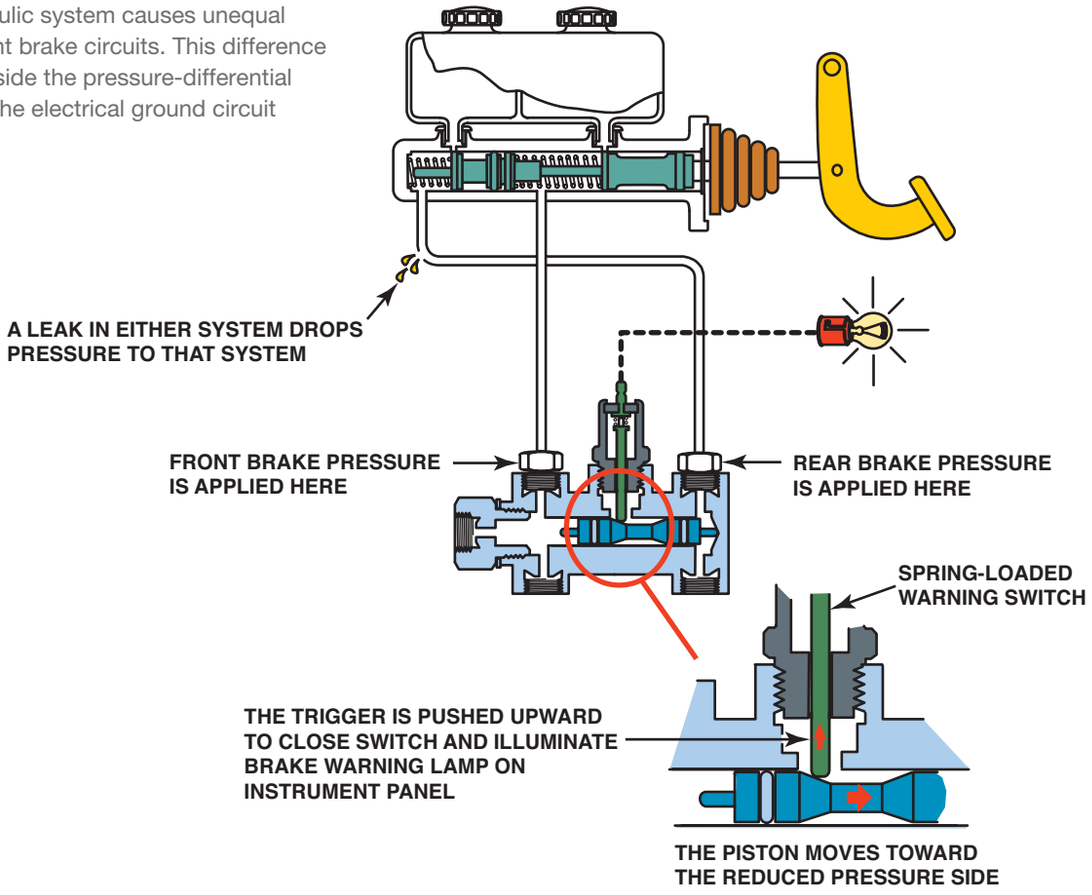
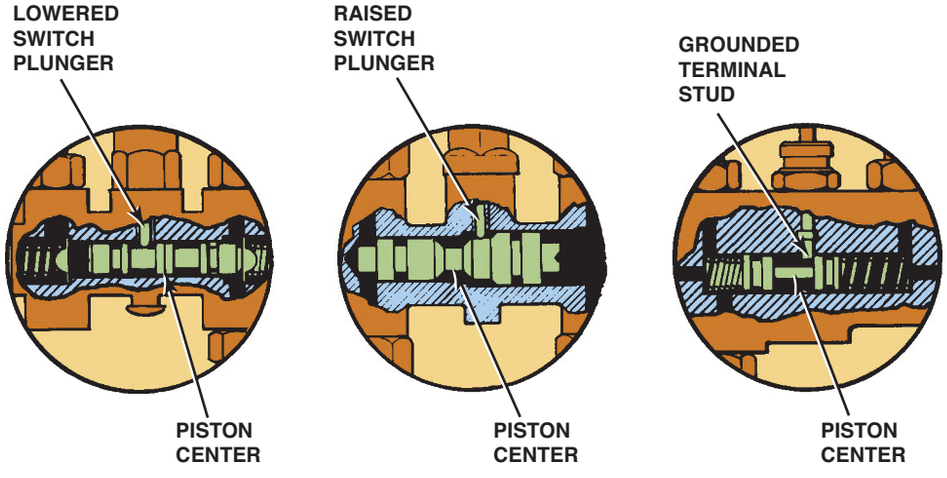


FIGURE 95–6 The pressure-differential switch piston is used to provide the electrical ground for the red brake warning light circuit.



A failure in one part of the brake system does not result in a failure of the entire hydraulic system. After the hydraulic system has been repaired and bled, moderate pressure on the brake pedal will center the piston in the switch and turn off the warning lamp.

If the lamp remains on, it may be necessary to do the following.

1. Apply light pressure to the brake pedal.
2. Momentarily open the bleeder valve on the side that did not have the failure until the warning light goes out.

This procedure should center the pressure-differential switch valve in those vehicles that are not equipped with self-centering springs.

BRAKE FLUID LEVEL SENSOR SWITCH

PURPOSE AND FUNCTION Many master cylinders, especially systems that are a diagonal split, usually use a **brake fluid level sensor** or switch in the master cylinder reservoir. This sensor will light the red brake warning lamp on the dash if low brake fluid level is detected. A float-type sensor or a magnetic reed switch are commonly used and provide a complete electrical circuit when the brake

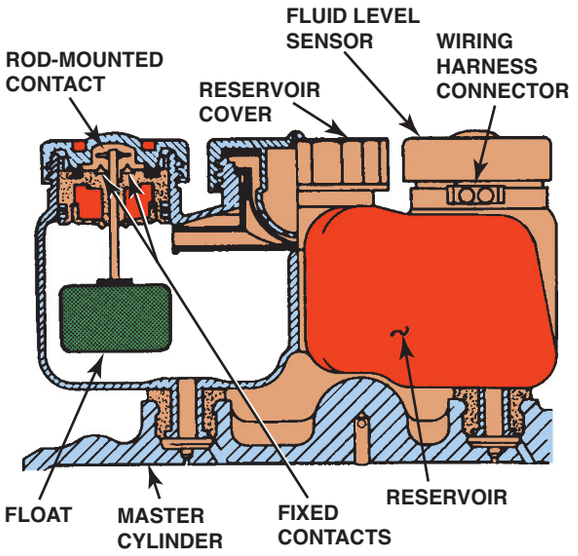


FIGURE 95–7 A movable contact brake fluid level switch. When the brake fluid level and float drop, the rod-mounted contact completes the electrical circuit which turns on the red brake warning lamp.

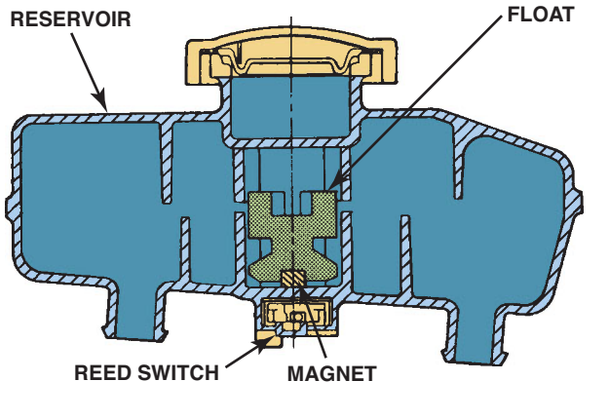


FIGURE 95–8 A magnetic brake fluid level switch.

fluid level is low. After refilling the master cylinder reservoir to the correct level, the red "brake" warning lamp should go out. ● **SEE FIGURES 95–7 AND 95–8.**

DIAGNOSING A RED "BRAKE" DASH WARNING LAMP

Activation of the red brake dash warning lamp can be for any one of several reasons:

1. **Parking Brake "On."** The same dash warning lamp is used to warn the driver that the parking brake is on.
2. **Low Brake Fluid.** This lights the red dash warning lamp on vehicles equipped with a master cylinder reservoir brake fluid level switch.
3. **Unequal Brake Pressure.** The pressure-differential switch is used on most vehicles with a front/rear brake split system to warn the driver whenever there is low brake pressure to either the front or rear brakes.

NOTE: Brake systems use *either* a pressure-differential switch *or* a low brake fluid switch to light the dash red "brake" lamp, but usually not both.

The most likely cause of the red "brake" warning lamp being on is low brake fluid caused by a leaking brake line, wheel cylinder, or caliper. Therefore, the first step in diagnosis is to determine the cause of the lamp being on, then to repair the problem.

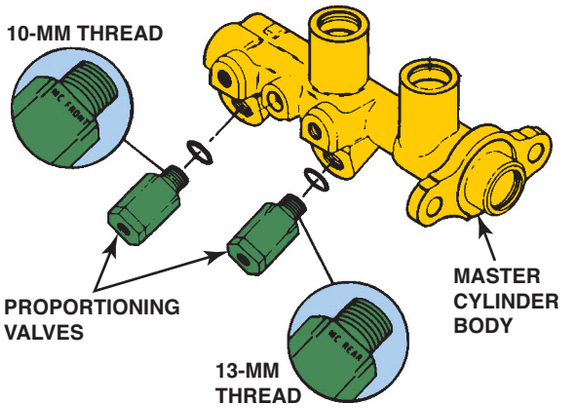


FIGURE 95–9 Many proportioning valves are mounted directly to the master cylinder in the outlet to the rear brakes.

STEP 1 **Check the Level of the Brake Fluid.** If low, carefully inspect the entire hydraulic brake system for leaks and repair as necessary.

STEP 2 **Disconnect the Wire from the Pressure-Differential Switch.** If the lamp is still "on," the problem is due to the parking brake lever switch being "on" or grounded, or the wire going to the switch is shorted to ground. If the red brake warning lamp is "off" after being disconnected from the pressure-differential switch, then the problem is due to a hydraulic failure (a low pressure in either the front or the rear system that creates a difference in pressure of at least 150 PSI).

NOTE: Some older Japanese vehicles energize the relay that turns off the red "brake" warning lamp from the output terminal of the alternator. If a quick inspection of the brake system seems to indicate that everything is okay, check for correct charging voltage before continuing a more detailed brake system inspection.

PROPORTIONING VALVE

PURPOSE AND FUNCTION

A **proportioning valve** improves brake balance during hard stops by limiting hydraulic pressure to the rear brakes. ● **SEE FIGURE 95–9.**

A proportioning valve is necessary because inertia creates weight shift toward the front of the vehicle during braking. The weight shift unloads the rear axle, which reduces traction between the tires and the road, and limits the amount of stopping power that can be delivered. Unless application pressure to the rear wheels is limited, the rear brakes will lock, making the vehicle unstable and likely to spin. The best overall braking performance is achieved when the front brakes lock just before the rear brakes.

Vehicles with front disc and rear drum brakes require a proportioning valve for two reasons.

1. Disc brakes require higher hydraulic pressure for a given stop than do drum brakes. In a disc/drum system, the front brakes always need more pressure than the rear brakes.
2. Once braking has begun, drum brakes require less pressure to *maintain* a fixed level of stopping power than they did to *establish* that level. In a disc/drum system, the rear brakes will always need less pressure than the front brakes.

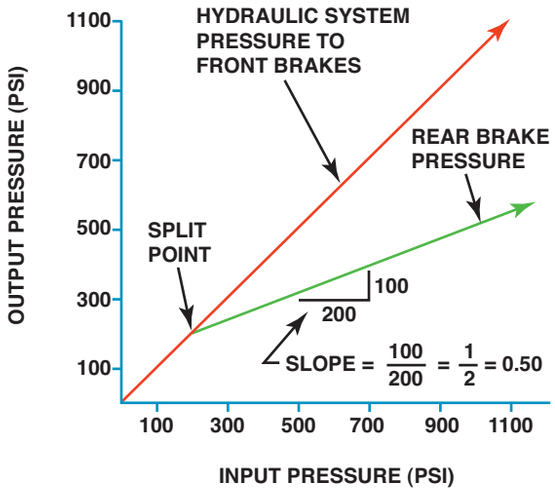


FIGURE 95–10 Typical proportioning valve pressure relationship. Note that, at low pressures, the pressure is the same to the rear brakes as is applied to the front brakes. After the split point, only a percentage (called the slope) of the master cylinder pressure is applied to the rear brakes.

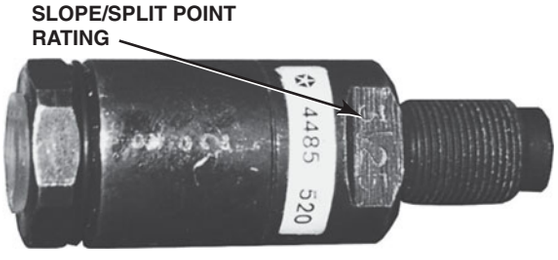


FIGURE 95–11 A Chrysler proportioning valve. Note that slope and split point are stamped on the housing.

A proportioning valve is used to compensate for these differences because it is easier to reduce pressure to the rear brakes than to increase pressure to the front brakes.

The proportioning valve does not work at all times. During light or moderate braking, there is insufficient weight transfer to make rear wheel locking a problem. Before proportioning action will begin, brake system hydraulic pressure must reach a minimum level called the **split point.** Below the split point full system pressure is supplied to the rear brakes. ● **SEE FIGURE 95–10.**

Above the split point, the proportioning valve allows only a portion of the pressure through to the rear brakes.

The proportioning valve gets its name from the fact that it regulates pressure to the rear brakes *in proportion* to the pressure applied to the front brakes. Once system hydraulic pressure exceeds the split point, the rear brakes receive a fixed percentage of any further increase in pressure. Brake engineers refer to the ratio of front to rear brake pressure proportioning as the **slope.** Full system pressure to the rear brakes equals a slope of 1, but if only half the pressure is allowed to reach the rear brakes, the proportioning valve is said to have a slope of 0.50. The proportioning valves on most vehicles have a slope between 0.25 and 0.50. ● **SEE FIGURES 95–11 AND 95–12.**

PROPORTIONING VALVE OPERATION

A simple proportioning valve consists of a spring-loaded piston that slides in a stepped bore. ● **SEE FIGURE 95–13.** The piston is exposed to pressure on both sides. The smaller end of the piston is acted on by pressure from the master cylinder, while the larger end reacts to pressure in the rear brake circuit. The actual proportioning valve is located in the center of the piston and is opened or closed depending on the position of the piston in the stepped bore.

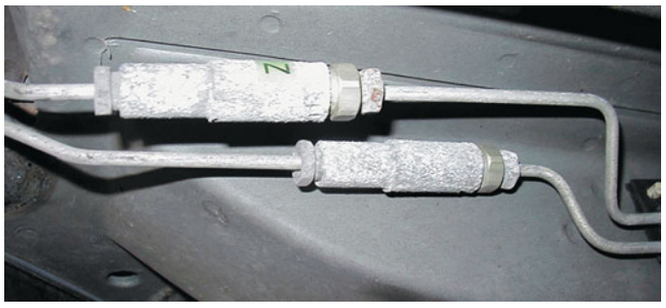


FIGURE 95–12 These two proportioning valves are found under the vehicle on this Dodge minivan.

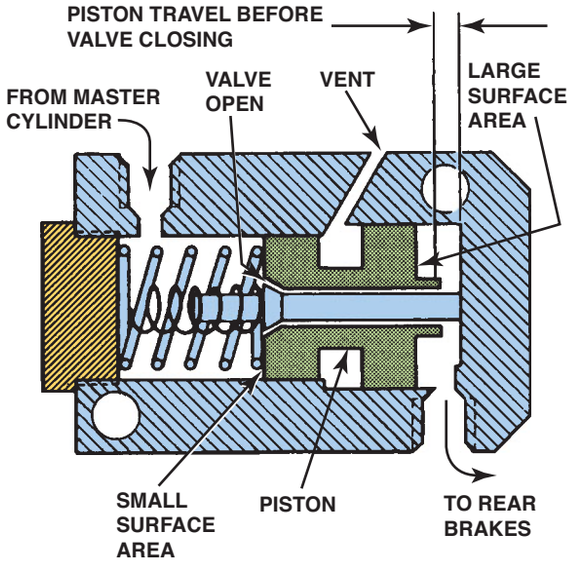


FIGURE 95–13 The proportioning valve piston can travel within the range shown without reducing pressure to the rear brakes.

When the brakes are first applied, hydraulic pressure passes through the proportioning valve to the rear brakes. Hydraulic pressure is the same on both sides of the piston, but because the side facing the rear brakes has more surface area than the side facing the master cylinder, greater force is developed and the piston moves to the left against the spring tension. At pressures below the split point, the proportioning valve is open, and pressure to both the front and rear brakes is the same.

As the vehicle is braked harder, increased system pressure forces the piston so far to the left that the proportioning valve is closed. ● **SEE FIGURE 95–14.** This seals off the brake line and prevents any additional pressure from reaching the rear brakes. The pressure at the moment the proportioning valve first closes is the split point of the valve. From this point on, the rear brakes receive only a portion of the pressure supplied to the front brakes.

As system pressure (the pressure to the front brakes) increases, enough force is developed on the master cylinder side of the piston to overcome the pressure trapped in the rear brake circuit. This forces the piston back to the right and opens the proportioning valve. Some of the higher pressure enters the rear brake circuit, but before pressure in the two circuits can equalize, the force developed on the larger piston area in the rear circuit moves the piston back to the left and closes the valve. The difference in surface area between the two ends of the piston determines the slope of the valve, and

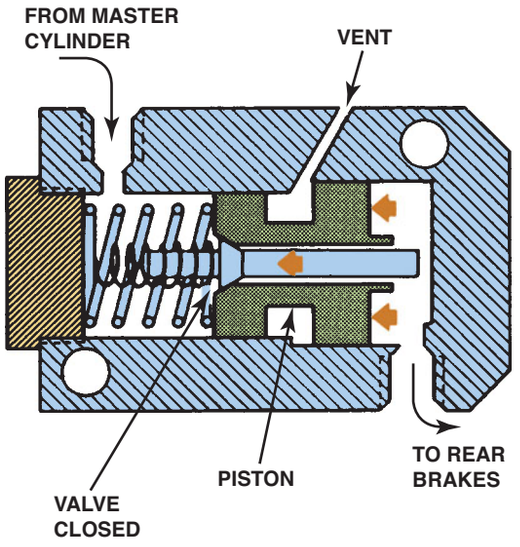


FIGURE 95–14 At the split point, the proportioning valve piston closes the fluid passage through the valve.

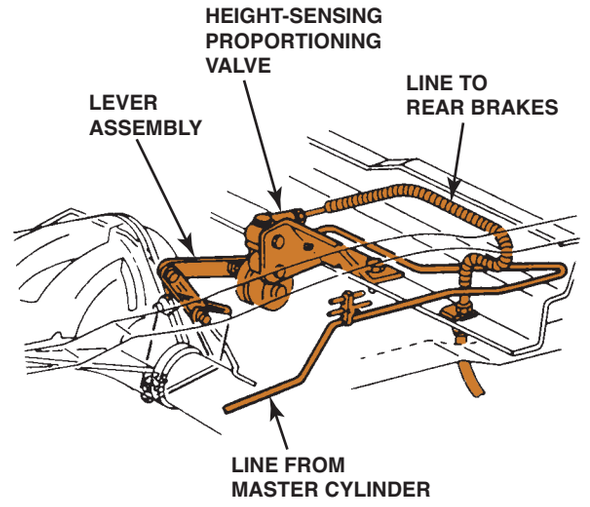


FIGURE 95–15 A height-sensing proportioning valve provides the vehicle with variable brake balance. The valve allows higher pressure to be applied to the rear brakes when the vehicle is heavily loaded and less pressure when the vehicle is lightly loaded.

TECH TIP

Always Inspect Both Front and Rear Brakes

If a vehicle tends to lock up the rear brakes during a stop, many technicians may try to repair the problem by replacing the proportioning valve or servicing the rear brakes. Proportioning valves are simple spring-loaded devices that are usually trouble free. If the rear brakes lock up during braking, carefully inspect the rear brakes looking for contaminated linings or other problems that can cause the rear brakes to grab. Do not stop there—always inspect the front brakes, too. If the front brakes are rusted or corroded, they cannot operate efficiently and greater force must be exerted by the driver to stop the vehicle. Even if the proportioning valve is functioning correctly, the higher brake pedal pressure by the driver could easily cause the rear brakes to lock up.

A locked wheel has less traction with the road than a rotating wheel. As a result, if the rear wheels become locked, the rear of the vehicle often "comes around" or "fishtails," causing the vehicle to skid. Careful inspection of the *entire* braking system is required to be assured of a safe vehicle.

thus the percentage of system pressure allowed to reach the rear brakes.

As long as system pressure continues to increase, the piston will repeatedly cycle back and forth, opening and closing the proportioning valve, and maintaining a fixed proportion of full system pressure to the rear brakes. When the brakes are released, the spring returns the piston all the way to the right, which opens the valve and allows fluid to pass in both directions.

HEIGHT-SENSING PROPORTIONING VALVES

Many vehicles use a proportioning valve that varies the amount of pressure that can be sent to the rear brakes depending on the height of the rear suspension. This type of valve is called a **height-sensing proportioning valve.** If the vehicle is lightly loaded, the rear suspension is high, especially during braking. In this case, the amount of pressure allowed to the rear brakes is reduced. This *helps* prevent rear-wheel lockup and possible skidding. Besides, a lightly loaded vehicle requires less braking force to stop than a heavily loaded vehicle.

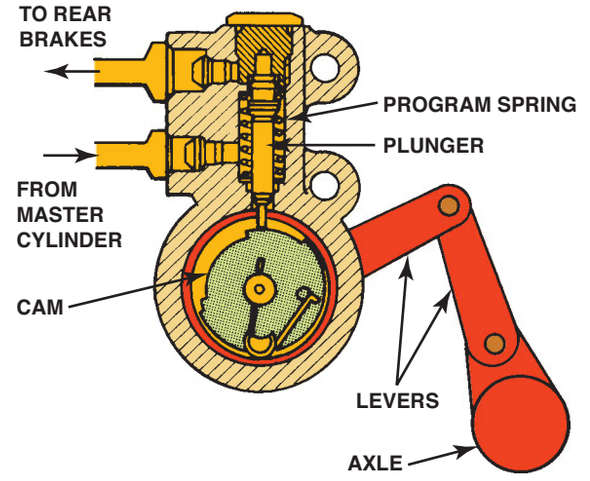


FIGURE 95–16 A stepped cam is used to alter the split point of this height-sensing proportioning valve.

When the vehicle is loaded, the rear suspension is forced downward. The lever on the proportioning valve moves and allows a greater pressure to be sent to the rear brakes. ● **SEE FIGURES 95–15 AND 95–16.** This greater pressure allows the rear brakes to achieve more braking force, helping to slow a heavier vehicle. When a vehicle is heavily loaded in the rear, the chances of rear-wheel lockup are reduced.

CAUTION: Some vehicle manufacturers warn that service technicians should never install replacement air lift shock absorbers or springs that may result in a vehicle height different than specified by the vehicle manufacturer. If the ride height is increased, the front to rear brake proportional relationship will be changed and could reduce stopping distances.

PROPORTIONING VALVE ADJUSTMENT. Height-sensing proportioning valves should be adjusted when replaced. The proper adjustment

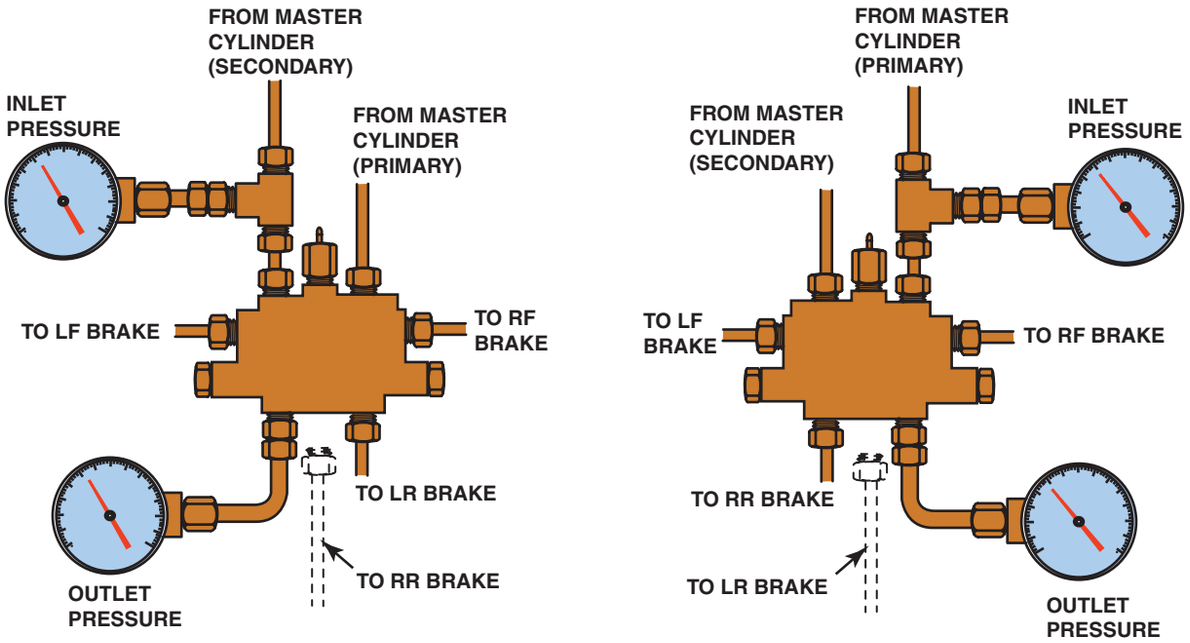


FIGURE 95–17 A proportioning valve pressure test can be performed using two pressure gauges—one to register the pressure from the master cylinder and the other gauge to read the pressure being applied to the rear brakes. This test has to be repeated in order to read the pressure to each rear wheel.

ensures that the proper pressure is applied to the rear brakes in relation to the loading of the vehicle.

Procedures vary from one vehicle to another. Always consult the factory service information for the exact procedure. Some trucks require the use of special plastic gauges available from the dealer.

PROPORTIONING VALVE DIAGNOSIS AND TESTING A defective proportioning valve usually allows rear brake pressure to increase too rapidly, causing the rear wheels to lock up during hard braking. When the rear brakes become locked, the traction with the road surface decreases and the vehicle often skids. Whenever rear brakes tend to lock during braking, the proportioning valve should be checked for proper operation. If the proportioning valve is height sensing, verify the proper vehicle ride (trim) height and adjustment of the operating lever. ● **SEE FIGURE 95–17.**

Pressure gauges can also be used to check for proper operation. Install one gauge into the brake line from the master cylinder and the second gauge to the rear brake outlet of the proportioning valve. While an assistant depresses the brake pedal, observe the two gauges. Both gauges should register an increasing pressure as the brake pedal is depressed until the split point. After the split point, the gauge connected to the proportioning valve (rear brakes) should increase at a slower rate than the reading on the gauge connected to the master cylinder.

If the pressures do not react as described, the proportioning valve should be *replaced.* The same procedure can be performed on a diagonal split-type system as used on most front-wheel-drive vehicles.

ELECTRONIC BRAKE PROPORTIONING

PURPOSE AND FUNCTION Many newer antilock braking systems eliminate the need for a conventional brake proportioning valve. A proportioning valve is usually necessary to reduce pressure to the rear brakes to keep them from locking up. This is because there is less weight over the rear wheels, and weight shifts forward when braking. Proportioning is needed most when a vehicle is lightly loaded or braking from a high speed. Most proportioning valves are calibrated to reduce pressure to the rear brakes by a fixed amount, which may increase the risk of rear-wheel lockup if the vehicle is loaded differently or is braking on a wet or slick surface. Dynamic rear proportioning is overcome by adjusting brake balance to match the need of the vehicle to changing road and load conditions.

PARTS AND OPERATION **Electronic brake proportioning (EBP)** in the antilock braking system is accomplished by monitoring front- and rear-wheel speeds, and reducing pressure to the rear brakes as needed using the ABS solenoids when there is a difference in wheel deceleration rates. The controller energizes the inlet valve solenoids for both rear brakes to hold pressure in the lines, and then energizes both rear outlet valve solenoids to release pressure as needed.

The dynamic rear proportioning function is enabled at all times unless there is a failure of the antilock brake controller or two wheel speed sensors on the same axle both fail at the same time. But as long as there is at least one functional speed sensor on the front and rear axles, the antilock brake controller can compare the relative speeds of the front and rear wheels.

METERING VALVE (HOLD-OFF) OPERATION

PURPOSE AND FUNCTION A **metering valve** is used on all front-disc, rear-drum-brake-equipped vehicles. The metering valve prevents the full operation of (holds off) the disc brakes until between 75 to 125 PSI is sent to the rear drum brakes to overcome rear-brake return spring pressure. This allows the front and rear brakes to apply at the same time for even stopping. Most metering valves also allow for the pressure to the front brakes to be gradually blended up to the

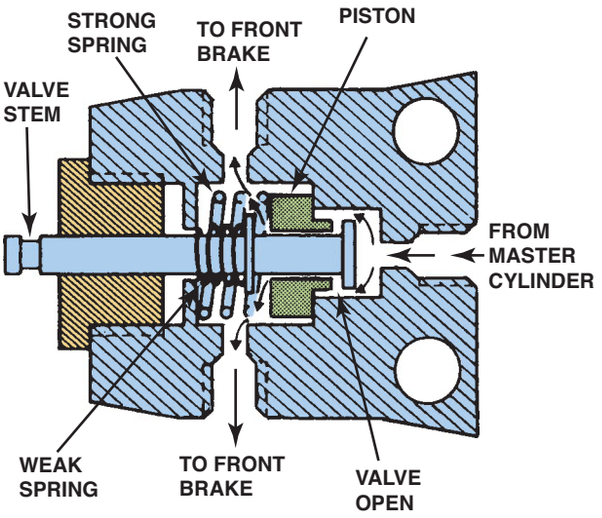


FIGURE 95–18 A metering valve when the brakes are not applied. Notice the brake fluid can flow through the metering valve to compensate for brake fluid expansion and contraction that occurs with changes in temperature.

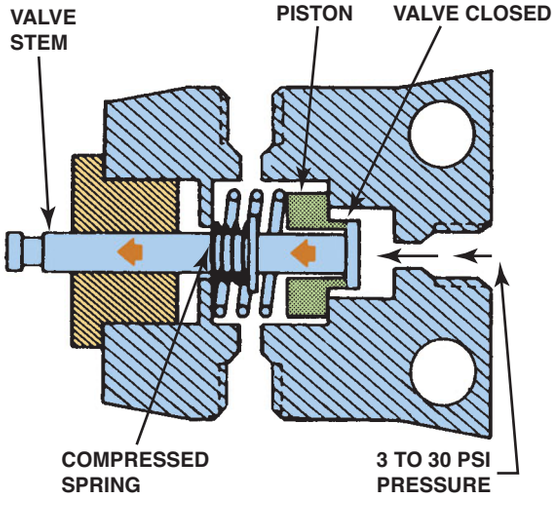


FIGURE 95–19 A metering valve under light brake pedal application.

metering valve pressure to prevent front brake locking under light pedal pressures on icy surfaces.

PARTS AND OPERATION

A metering valve consists of a piston controlled by a strong spring and a valve stem controlled by a weak spring. ● **SEE FIGURE 95–18.** When the brakes are not applied, the strong spring seats the piston and prevents fluid flow around it. At the same time, the weak spring holds the valve stem to the right and opens a passage through the center of the piston. Brake fluid is free to flow through this passage to compensate for changes in system fluid volume.

When the brakes are applied and pressure in the front brake line reaches 3 to 30 PSI (20 to 200 kPa), the tension of the weak spring is overcome and the metering valve stem moves to the left, which closes the passage through the piston and prevents fluid flow to the front brakes. ● **SEE FIGURE 95–19.**

The small amount of pressure applied to the calipers before the metering valve closes is enough to take up any clearance, but not enough to generate braking force.

While the fluid flow to the front calipers is shut off, the rear brake shoes move into contact with the drums, braking begins, and hydraulic pressure throughout the brake system increases. When

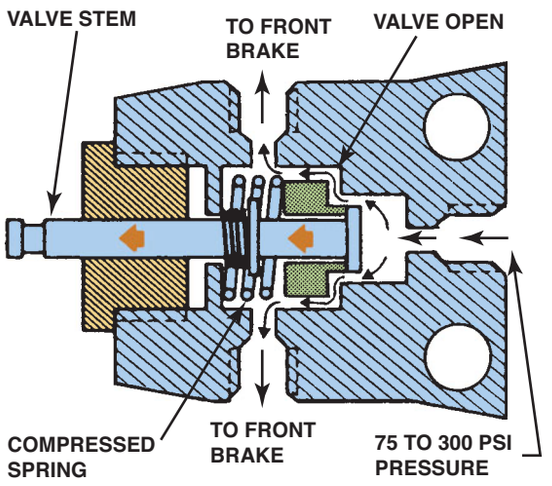


FIGURE 95–20 A metering valve during a normal brake application.

the pressure at the metering valve reaches 75 to 300 PSI, the tension of the strong spring is overcome and the valve stem and piston move farther to the left. ● **SEE FIGURE 95–20.** This opens a passage around the outside of the piston and allows fluid to flow through the valve to the front brake calipers.

When the brakes are released, the strong spring seats the piston and prevents fluid flow around it. At the same time, the weak spring opens the fluid passage through the center of the piston. Excess fluid returns to the master cylinder through this passage and the valve is ready for another brake application.

SYSTEMS WITHOUT METERING VALVES

Braking systems that are diagonal split, such as those found on most front-wheel-drive vehicles, do *not* use a metering valve. A metering valve is only used on front/rear split braking systems such as those found on most rear-wheel-drive vehicles.

There are three reasons why front-wheel-drive vehicles do not use metering valves.

1. Front-wheel-drive vehicles usually have a diagonally split dual braking system that would require a separate metering valve for each hydraulic circuit. This would make the brake system more costly and complicated.
2. Front-wheel-drive vehicles have a forward weight bias that requires the front brakes to supply up to 80% of the total braking power. Since the front brakes do most of the work, it is desirable to apply them as soon as possible when the brake pedal is depressed. A metering valve would create a slight delay.
3. Until all the clearance in the brake system is taken up, there will not be enough pressure in the brake hydraulic system for the front disc brakes to overcome the engine torque applied to the driven front wheels.

Engine torque and a heavy front weight bias help prevent front-wheel lockup from being a problem during light braking or when the brakes are first applied.

Most rear-wheel-drive vehicles without metering valves are equipped with four-wheel disc brakes. Because the clearance between the pads and rotors is approximately the same at all four wheels, there is no need to delay front brake actuation. Some of these vehicles also have antilock brake systems that prevent the wheels from locking at any time.

METERING VALVE DIAGNOSIS AND TESTING

A defective metering valve can leak brake fluid and/or cause the front brakes

TECH TIP

Push-In or Pull-Out Metering Valve?

Whenever bleeding the air out of the hydraulic brake system, the metering valve should be bypassed. The metering valve stops the passage of brake fluid to the front wheels until pressure exceeds about 125 PSI (860 kPa). It is important not to push the brake pedal down with a great force so as to keep from dispersing any trapped air into small and hard-to-bleed bubbles. To bypass the metering valve, the service technician has to push or pull a small button located on the metering valve. An easy way to remember whether to push in or to pull out is to inspect the button itself. *If the button is rubber coated, then you push in. If the button is steel, then pull out.*

Special tools allow the metering valve to be held in the bypass position. Failure to remove the tool after bleeding the brakes can result in premature application of the front brakes before the rear drum brakes have enough pressure to operate.

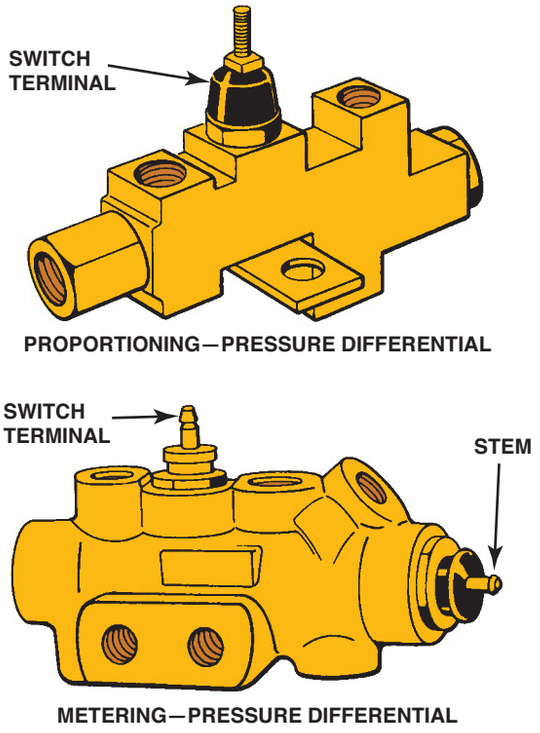


FIGURE 95–21 Typical two-function combination valves.

to apply before the rear brakes. This is most commonly noticed on slippery surfaces such as on snow or ice or on rain-slick roads. If the front brakes lock up during these conditions, the front wheels cannot be steered. Inspect the metering valve for these two conditions:

1. Look around the bottom of the metering valve for brake fluid leakage. (Ignore slight dampness.) Replace the metering valve assembly if it is leaking.
2. As the pressure builds to the front brakes, the metering valve stem should move. If it does not, replace the valve.

More accurate testing of the metering valve can be accomplished using pressure gauges. Install two gauges, one in the pressure line coming from the master cylinder and the other in the outlet line leading to the front brakes. When depressing the brake pedal, both gauges should read the same until about 3 to 30 PSI (20 to 200 kPa) when the metering valve shuts, thereby delaying the operation of the front brakes. The master cylinder outlet gauge should show an increase in pressure as the brake pedal is depressed further.

Once 75 to 300 PSI is reached, the gauge showing pressure to the front brakes should match the pressure from the master cylinder. If the pressures do not match these ranges, the metering valve assembly should be replaced.

TECH TIP

No Valves Can Cause a Pull

When diagnosing a pull to one side during braking, some technicians tend to blame the metering valve, proportional valve, the pressure-differential switch, or the master cylinder itself.

Just remember that if a vehicle pulls during braking that the problem *has* to be due to an individual wheel brake or brake line. The master cylinder and all the valves control front or rear brakes together or diagonal brakes and cannot cause a pull if not functioning correctly.

COMBINATION VALVE

Most vehicle manufacturers combine the function of a proportioning valve with one or more other valves into one unit called a **combination valve.** ● **SEE FIGURES 95–21 AND 95–22.**

On a typical rear-wheel-drive vehicle, a typical combination valve consists of the following components all in one replaceable unit:

- Metering valve
- Proportioning valve
- Pressure-differential switch

Some combination valves have only two functions and contain the pressure-differential and the metering valve, while others combine the pressure-differential with the proportioning valve.

BRAKE LIGHT SWITCH

The job of the **brake light switch** is to turn on the brake lights at the back of the vehicle when the brakes are applied. A properly adjusted light switch will activate the brake lights as soon as the brake pedal is applied and before braking action actually begins at the wheels. Depending on the make, model, and year of vehicle, a brake light switch can be called:

- Stop light switch
- Brake pedal position (BPP) switch
- Brake on/off (BOO) switch (Fords)

Mechanical switches that operate directly off the brake pedal arm are most often used. ● **SEE FIGURE 95–23.**

Brake light switches are normally open. When the brakes are applied, the switch closes, which completes the brake light circuit.

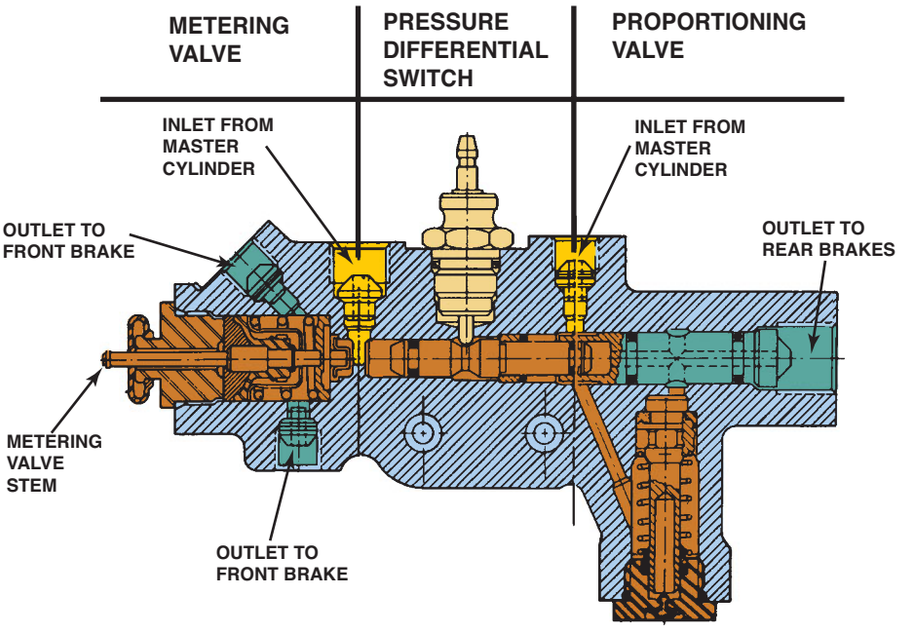


FIGURE 95–22 Combination valve containing metering, pressure-differential (warning switch), and proportioning valves all in one unit. This style is often called a "pistol grip" design because the proportioning valve section resembles the grip section of a handgun.

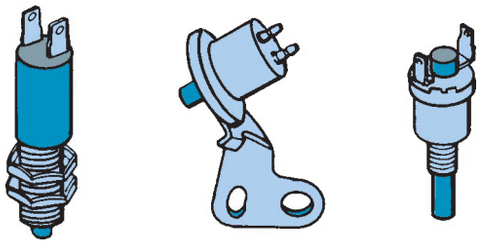


FIGURE 95–23 Typical brake light switches.

Most newer vehicles use the brake switch as an input to the body computer for many functions including:

- Brake lights
- Antilock brake system (ABS) input signal
- Traction control is disabled when the brake pedal is depressed
- Electronic stability control (ESC) system input signal

REVIEW QUESTIONS

1. Why are residual check valves not used in most vehicles?
2. List the three possible reasons that could cause the red brake warning lamp to come on during driving.
3. Explain why metering valves are not used on all vehicles.
4. Explain the split point and the slope of a proportioning valve.

CHAPTER QUIZ

1. Technician A says a pull to the right during braking could be caused by a defective metering valve. Technician B says a pull to the left could be caused by a defective proportioning valve. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
2. The rear brakes lock up during a regular brake application. Technician A says the metering valve could be the cause. Technician B says that stuck front disc brake calipers could be the cause. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
3. The rear wheels lock up during hard braking. Technician A says that a defective metering valve could be the cause. Technician B says that a defective proportioning valve could be the cause. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. A combination valve could include _____.
   a. Metering and proportioning valves
   b. Proportioning and pressure-differential valves
   c. Proportioning, metering, and pressure-differential valves
   d. Any of the above depending on the make and model of the vehicle
5. A residual check valve is used to _____.
   a. Maintain a slight pressure on the hydraulic system
   b. Prevent front-wheel lockup during hard braking
   c. Prevent rear-wheel lockup during hard braking
   d. Speed brake release to reduce brake wear
6. Technician A says that the red brake warning light can be turned on if a difference in pressure is detected by the pressure-differential switch. Technician B says that the red brake warning light can be turned on if the brake fluid level sensor detected low brake fluid level. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

7. Which type of vehicles most often do not use metering valves?
   a. Rear-wheel drive **c.** Front-wheel drive
   b. Four-wheel drive **d.** All-wheel drive
8. Technician A says that some proportioning valves are one part and used to control both rear brakes. Technician B says that some proportioning valves are two parts; one for each rear wheel brake.
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
9. The button on the _____ valve should be held when pressure bleeding the brakes.
   a. Metering
   b. Proportioning
   c. Pressure-differential
   d. Residual check
10. A typical brake light is electrically _____.
   a. Normally open
   b. Normally closed

chapter 96 BRAKE FLUID AND LINES

OBJECTIVES: **After studying Chapter 96, the reader will be able to:** • Prepare for the Brakes (A5) ASE certification test. • List the types of brake fluids. • Describe where armored brake line is used. • Discuss the differences between double-flare and ISO flare. • Explain how flexible brake lines should be handled during service. • List the precautions necessary when handling or disposing of brake fluid. • Discuss the types of rubber that are used in brake system components.

KEY TERMS: Armored brake line 1056 • Brake fluid 1050 • Brake lines 1054 • Brake pipes 1054 • Brake tubing 1054 • DOT 3 1051 • DOT 4 1051 • DOT 5 1052 • DOT 5.1 1051 • Double flare 1055 • Elastomers 1054 • Flexible brake hoses 1058 • Hydraulic system mineral oil (HSMO) 1052 • Hygroscopic 1051 • ISO 1055 • Nonhygroscopic 1052 • Polyglycol 1050 • Silicone brake fluid 1052

BRAKE FLUID

PURPOSE AND FUNCTION

Brake fluid is designed to function in the hydraulic brake system under all operating conditions. Brake fluid boiling point is one of the most critical aspects and ratings for brake fluid. As brake fluid ages, it absorbs moisture, which lowers its boiling point and causes increased corrosion of the brake system components.

All automotive experts agree that brake fluid should be changed regularly as part of normal routine service. Even through the driver may not notice an immediate improvement, the reduced corrosion will eventually result in less money being spent for brake system component replacement in the future. Getting the old low-boiling-point brake fluid out of the system could prevent a total loss of brakes due to brake fluid boiling.

All brake fluids must be able to pass tests for the following:

1. Fluidity at low temperatures
2. Controlled percentage loss due to evaporation at high temperatures (tested at 212°F [100°C])
3. Compatibility with other brake fluids
4. Resistance to oxidation
5. Specific effects on rubber, including:
   a. No disintegration
   b. No increase in hardness of the rubber tested
   c. Limited amount of decrease in hardness of the rubber

PHYSICAL PROPERTIES

Brake fluid is made from a combination of various types of glycol, a non-petroleum-based fluid. Brake fluid is a polyalkylene–glycol–ether mixture called **polyglycol** for short. All *polyglycol brake fluid is clear to amber in color.* Brake fluid has to have the following characteristics:

- A high boiling point
- A low freezing point
- Ability to not damage rubber parts in the brake system

BRAKE FLUID SPECIFICATIONS

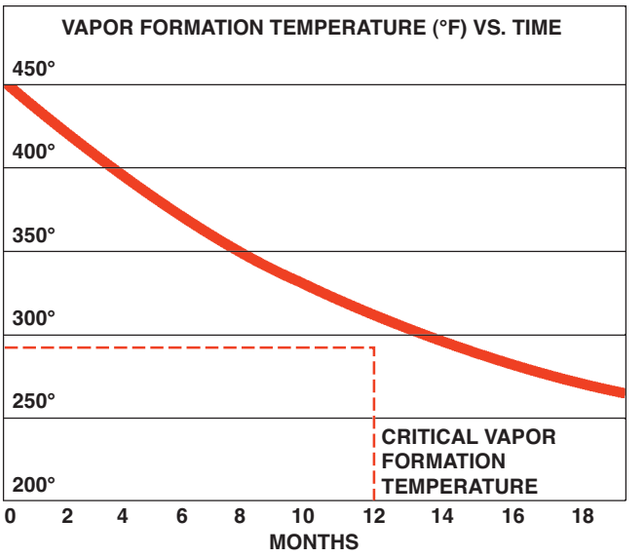
All automotive brake fluid must meet Federal Motor Vehicle Safety Standard (FMVSS) 116. The Society of Automotive Engineers (SAE) and the Department of Transportation (DOT) have established brake fluid specification standards as shown in the following chart.

	DOT 3	DOT 4	DOT 5.1	DOT 5
Dry boiling point				
°F	401	446	500	500
°C	205	230	260	260
Wet boiling point				
°F	284	311	356	356
°C	140	155	180	180

The wet boiling point is often referred to as “equilibrium reflux boiling point” (ERBP). ERBP refers to the method in the specification (SAE J1703) by which the fluid is exposed to moisture and tested.



FIGURE 96–1 Brake fluid can absorb moisture from the air even through plastic, so many experts recommend that brake fluid be purchased in metal containers, if possible.



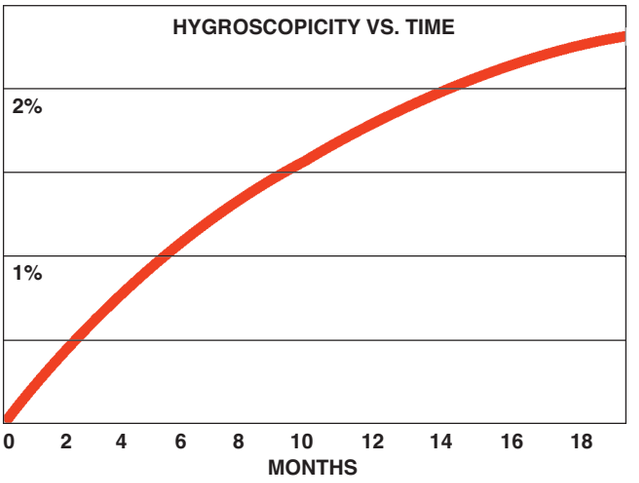


FIGURE 96–2 Brake fluid absorbs moisture from the air at the rate of about 2% per year. As the brake fluid absorbs water, its boiling temperature decreases.

FREQUENTLY ASKED QUESTION

What Is Blue Brake Fluid?

Some brake fluid vendors market a high-performance DOT 4 brake fluid that is dyed blue and is called super blue while others market a super DOT 4 that is yellow. These brake fluids are designed to be sold in Europe. The advertising states that the bright color of the brake fluid makes it easy to see when all of the old fluid has been purged from the system during a brake fluid replacement procedure.

DOT 3. **DOT 3** brake fluid is the type most often used. However, DOT 3 brake fluid has some important characteristics including:

1. DOT 3 absorbs moisture. According to the Society of Automotive Engineers (SAE), DOT 3 can absorb 2% of its volume in water per year. Moisture is absorbed by the brake fluid through microscopic seams in the brake system and around seals. Over time, the water will corrode the system and thicken the brake fluid. The moisture can also cause a spongy brake pedal, due to reduced vapor-lock temperature. ● **SEE FIGURES 96–1 AND 96–2.**
2. DOT 3 must be used from a sealed (capped) container. If allowed to remain open for any length of time, DOT 3 will absorb moisture from the surrounding air, which is called **hygroscopic.**
3. Always check the brake fluid recommendations on the top of the master cylinders of imported vehicles before adding DOT 3.

CAUTION: DOT 3 brake fluid is a very strong solvent and can remove paint! Care is required when working with DOT 3 brake fluid to avoid contact with the vehicle's painted surfaces. It also takes the color out of leather shoes.

DOT 4. **DOT 4** brake fluid is formulated for use by all vehicles, that are designed to use DOT 3 brake fluid. DOT 4 is polyglycol based but has borate esters added to provide an extra buffer for the fluid against acids that can form in the moisture that has been absorbed in the fluid when it is heated. DOT 4 is approximately double the cost of DOT 3. DOT 4 can often be used where DOT 3 is used and even though the two types of brake fluid are compatible and miscible (able to be mixed), some vehicle manufacturers recommend that DOT 3 and DOT 4 not be mixed. If DOT 4 is to be used, the system should be purged of all of the old DOT 3 and replaced with DOT 4.

NOTE: Because brake fluid absorbs moisture over time, many vehicle manufacturers recommend changing the brake fluid as part of the standard services to be performed routinely. The typical recommended brake fluid change interval is every two years or every 30,000 miles (48,000 km), whichever comes first. This is particularly important for vehicles equipped with an antilock braking system (ABS) because of the problem of expensive brake component wear or corrosion caused by contaminated brake fluid.

DOT 5.1. **DOT 5.1** brake fluid is a non-silicone-based polyglycol fluid and is clear to amber in color. This severe duty fluid has a boiling point of over 500°F equal to the boiling point of silicone-based DOT 5 fluid. Unlike DOT 5, DOT 5.1 can be mixed with either DOT 3 or DOT 4 according to brake fluid manufacturers' recommendations.

CAUTION: Some vehicle manufacturers such as Chrysler do not recommend the use of or the mixing of other types of polyglycol brake fluid and specify the use of DOT 3 brake fluid only. Always follow the vehicle manufacturer's recommendation.



FIGURE 96–3 DOT 5 brake fluid is used mostly in motorcycles because if spilled, it will not hurt painted surfaces.

DOT 5. **DOT 5** brake fluid is commonly called **silicone brake fluid** and is made from polydimethylsiloxanes. DOT 5 brake fluid is purple (violet) in color to distinguish it from DOT 3 or DOT 4 brake fluid. It does not absorb any water, and is therefore called **nonhygroscopic.** Even though DOT 5 does not normally absorb water, it is still tested using standardized SAE procedures in a humidity chamber. After a fixed amount of time, the brake fluid is measured for boiling point. Since it has had a chance to absorb moisture, the boiling point after this sequence is called the minimum wet boiling point.

Silicones have about three times the amount of dissolved air as glycol fluids (about 15% of dissolved air versus only about 5% for standard glycol brake fluid). It is this characteristic of silicone brake fluid that causes the most concern about its use.

1. Silicone brake fluid has an affinity for air; therefore, it is more difficult to bleed the hydraulic system of trapped air.
2. The trapped air expands with increasing temperature. This causes the brake pedal to feel "mushy" because the pressure exerted on the hydraulic system simply compresses the air in the system and does not transfer the force to the wheel cylinders and calipers as it should.

   NOTE: The characteristic of DOT 5 silicone brake fluid to absorb air is one of the major reasons why it is not recommended for use with an antilock braking system (ABS). In an ABS, valves and pumps are used which can aerate the brake fluid. Brake fluid filled with air bubbles cannot properly lubricate the ABS components and will cause a low, soft brake pedal.
3. The air trapped in the silicone brake fluid can also "off-gas" at high altitudes, causing a mushy brake pedal and reduced braking performance. DOT 5 brake fluid has been known to create a braking problem during high-altitude (over 5,000 ft [1,500 m]) and high-temperature driving. The high altitude tends to vaporize (off-gassing) some parts of the liquid, creating bubbles in the brake system, similar to having air in the brake system.
4. DOT 5 brake fluid should not be mixed with any other type of brake fluid. Therefore, the entire braking system must be completely flushed and refilled with DOT 5.
5. DOT 5 does not affect rubber parts and will not cause corrosion.
6. DOT 5 is expensive. It is approximately four times the cost of DOT 3 brake fluid. ● **SEE FIGURE 96–3.**



FIGURE 96–4 Both rubber sealing cups were exactly the same size. The cup on the left was exposed to mineral oil. Notice how the seal greatly expanded.

? **FREQUENTLY ASKED QUESTION**

What Is Hydraulic Brake System Mineral Oil?

Some French-built Citroen and British-designed Rolls-Royce vehicles use **hydraulic system mineral oil (HSMO)** as part of their hydraulic control systems. The systems in these vehicles use a hydraulic pump to pressurize hydraulic oil for use in the suspension leveling and braking systems.

CAUTION: Mineral hydraulic oil should never be used in a braking system that requires DOT 3 or DOT 4 polyglycol-based brake fluid. If any mineral oil, such as engine oil, transmission oil, or automatic transmission fluid (ATF), gets into a braking system that requires glycol brake fluid, every rubber part in the entire braking system must be replaced. Mineral oil causes the rubber compounds that are used in glycol brake fluid systems to swell (● SEE FIGURE 96–4).

To help prevent hydraulic system mineral oil from being mixed with glycol brake fluid, *hydraulic mineral oils are green.*

BRAKE FLUID INSPECTION AND TESTING

The brake fluid should be inspected regularly, including the following items:

1. **Proper Level.** The brake fluid level should be above the minimum level (labeled MIN) and below the maximum (labeled MAX) on the side of the master cylinder reservoir. Do not add brake fluid unless the entire brake system is carefully inspected for worn brake pads and shoes and for signs of any external leakage.
2. **Color/Condition.** New brake fluid is clear or amber in color. If the brake fluid is black or discolored like black coffee or coffee with cream, the fluid should be changed. ● **SEE FIGURE 96–5.**
3. **Tested Using a Tester or Test Strips.** Often, brake fluid does not look as if it is bad but has absorbed moisture enough to reduce its effectiveness. Test strips can be used to measure copper ions that increase as the brake fluid becomes deteriorated. The copper comes from sealing washers and other brass or copper brake system components.

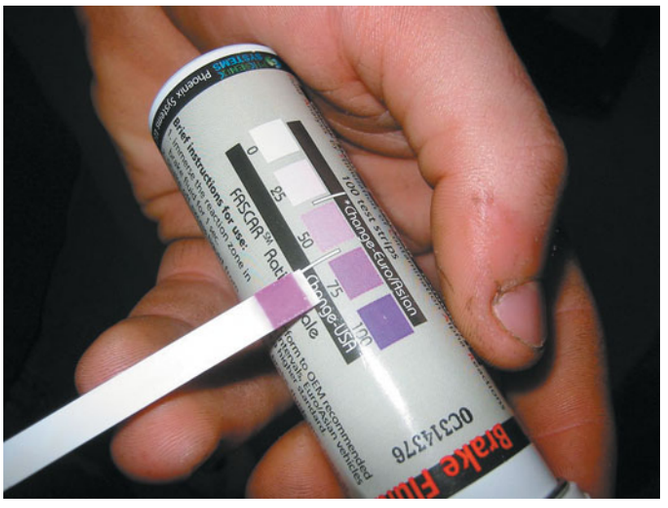
   ● **SEE FIGURE 96–6.**
4. **Boiling Point Tester.** An electronic tester can be used to measure the actual boiling temperature of the brake fluid. The tester probe is inserted into the brake fluid and then a button



FIGURE 96–5 If the brake fluid is black in color, it should be replaced.



(a)



(b)

FIGURE 96–6 (a) A brake fluid test strip is being used to test the condition of the brake fluid. (b) The color of the test strip is then compared with a chart on the package, which indicates the condition and if the fluid should be replaced.



FIGURE 96–7 An electronic tester that measures the boiling temperature of the brake fluid is useful to help determine if the brake fluid needs to be replaced.

REAL WORLD FIX

The Sinking Brake Pedal

This author has experienced what happens when brake fluid is not changed regularly. Just as many technicians will tell you, we do not always do what we know should be done to our own vehicles.

While driving a four-year-old vehicle on vacation in very hot weather in mountainous country, the brake pedal sank to the floor. When the vehicle was cold, the brakes were fine. But after several brake applications, the pedal became soft and spongy and sank slowly to the floor if pressure was maintained on the brake pedal. Because the brakes were okay when cold, I knew it had to be boiling brake fluid. Old brake fluid (four years old) often has a boiling point under 300°F (150°C). With the air temperature near 100°F (38°C), it does not take much more heat to start boiling the brake fluid. After bleeding over a quart (1 liter) of new brake fluid through the system, the brakes worked normally. I'll never again forget to replace the brake fluid as recommended by the vehicle manufacturer.

is pushed and the boiling temperature is displayed. ● **SEE FIGURE 96–7.**

5. **Brake Fluid Contamination Test.** If brake fluid is mixed with any mineral oil, such as engine oil, power steering fluid, or automatic transmission fluid, rubber components will swell and cause brake system failure. To check for possible contamination, remove the reservoir cover from the master cylinder. If the rubber diaphragm is swelled or distorted, brake fluid contamination is likely. To check the brake fluid, use a Styrofoam cup filled with water.
   - Place a teaspoon (1 ml) of brake fluid from the master cylinder into the water.
   - Pure brake fluid will completely dissolve in the water. Petroleum or mineral oil fluids will float on the surface of

REAL WORLD FIX

The Pike's Peak Brake Inspection

All vehicles must stop about halfway down Pike's Peak Mountain in Colorado (14,110 ft [4,300 m]) for a "brake inspection." When this author stopped at the inspection station, a uniformed inspector simply looked at the right front wheel and waved us on. I pulled over and asked the inspector what he was checking. He said that when linings and drums/rotors get hot, the vehicle loses brake effectiveness. But if the brake fluid boils, the vehicle loses its brakes entirely. The inspector was listening for boiling brake fluid at the front wheel and feeling for heat about 1 ft (30 cm) from the wheel. The inspector used an infrared pyrometer to measure the front wheel brakes and if the brakes were too hot to continue, you would be instructed to pull over and wait for the brakes to cool. The inspector recommended placing the transmission into a lower gear, which uses the engine to slow the vehicle during the descent without having to rely entirely on the brakes.

the water and retain their color. Petroleum fluids will also dissolve the Styrofoam cup at the waterline.

- If the brake fluid is contaminated, the entire braking system must be drained and flushed and all rubber components replaced.

BRAKE FLUID SERVICE PROCEDURES AND PRECAUTIONS

1. Store brake fluid only in its original container.
   - To help prevent possible contamination with moisture, air, or other products, purchase brake fluid in small containers.
   - Keep all brake fluid containers tightly closed to prevent air (containing moisture) from being absorbed.
2. Before opening a brake fluid container, remove any dirt, moisture, or other contamination from the top and outside of the container.
3. When a brake fluid container is empty, it should be discarded—the container should never be used for anything except brake fluid.
4. Do not transfer brake fluid to any other container that may have contained oil, kerosene, gasoline, antifreeze, water, cleaners, or any other liquids or chemicals.
5. Do not reuse brake fluid that has been siphoned from another vehicle or drawn out during a brake bleeding operation. (Brake bleeding means to open special bleeder valves in the hydraulic system to rid the system of any trapped air.)
6. Use only fresh, new brake fluid for flushing the hydraulic brake system.

CAUTION: Alcohol or flushing fluids should not be used because they cannot be totally removed from a closed hydraulic brake system and will contaminate the system. Disassembled parts, however, can and should be cleaned with denatured alcohol or spray brake cleaner where the parts can be visually inspected to be free of cleaning solutions.

BRAKE FLUID HANDLING AND DISPOSAL

Polyglycol brake fluid presents little toxicity hazard, but for some individuals, brake fluid may produce moderate eye and skin irritation. For good safety practice, protective clothing and safety glasses or goggles should be worn.

Brake fluid becomes a hazardous waste if spilled onto open ground, where it can seep into groundwater. The disposal requirements for brake fluid spilled onto open ground vary with the exact amount spilled and other factors. Refer to local EPA guidelines and requirements for the exact rules and regulations in your area.

RUBBER TYPES

Vehicles use a wide variety of rubber in the braking system, suspension system, steering system, and engine. Rubber products are called **elastomers.** Some are oil- and grease-resistant elastomers and can be harmed by brake fluid, while others are brake-fluid resistant and can swell or expand if they come in contact with oil or grease. ● **SEE CHART 96–1** for types and compatible fluids.

● **SEE FIGURES 96–8 THROUGH 96–10** for examples of where rubber is used in the braking system.

Brake fluid (DOT 3 or DOT 4 glycol brake fluid) affects all elastomers and causes a slight swelling effect (about 5%). This swelling action is necessary for the seals to withstand high hydraulic pressures. Silicone (DOT 5) brake fluid does not cause rubber to swell; therefore, a rubber swell additive is used in silicone brake fluid. While these additives work well for EPDM rubber, it can cause SBR rubber to swell too much. Although most seals today use EPDM, many drum brakes still use SBR seals. This is a major reason that DOT 5 brake fluid is not recommended by many vehicle manufacturers.

BRAKE LINES

TERMINOLOGY

High-pressure double-walled steel brake lines or high-strength flexible lines are used to connect the master cylinder to each wheel. The steel **brake lines** are also called **brake pipes** or **brake tubing.** Brake lines carry brake fluid from the master cylinder to the ABS hydraulic control unit, wheel cylinders, and brake calipers. The brake lines contain and direct the pressure of the brake hydraulic system.

Most of the total length of the brake line consists of rigid tubing. For maximum strength and durability, all brake systems use double-walled brake tubing made from plated steel sheet. There are two types of double-walled tubing:

- Seamless
- Multiple ply

● **SEE FIGURE 96–11.**

All double-walled brake tubing is plated with tin, zinc, or other similar substances for protection against rust and corrosion. The Society of Automotive Engineers (SAE) has guidelines for brake tubing. SAE Standard J1047 specifies that a sample section of brake line must be able to withstand 8,000 PSI (55,000 kPa) plus other standards for resistance to fatigue, heat, rust, and corrosion.

CAUTION: Copper tubing should *never* be used for brake lines. Copper tends to burst at a lower pressure than steel.

RUBBER COMPATIBILITY CHART

NAME	ABBREVIATIONS	OK	NOT OK	USES
Ethylene propylene diene (developed in 1963)	EPM, EPDM, EPR	Brake fluid, silicone fluids	Petroleum fluids	Most brake system seals and parts
Styrene, butadiene (developed in 1920s)	SBR, BUNA S, GRS	Brake fluid, silicone fluids, alcohols	Petroleum fluids	Some drum brake seals, O-rings
Nitrile (nitrile butadiene rubber)	NBR, BUNA N	Petroleum fluids, ethylene glycol (antifreeze)	Brake fluid	Engine seals, O-rings
Neoprene (polychloroprene)	CR	Refrigerants (Freons: R-12 and R-134a), petroleum fluids	Brake fluids	Refrigerant, O-rings
Polyacrylate	ACM	Petroleum fluids, automatic transmission fluids	Brake fluids	Automatic transmission and engine seals
Viton (fluorocarbon)	FKM	Petroleum fluids	Brake fluid, 134a refrigerant	Engine seals, fuel system parts
Natural rubber	NR	Water, brake fluid	Petroleum fluids	Tires

CHART 96–1

Notice that if a rubber is OK to use for brake fluid it is not OK to use for oil or grease.

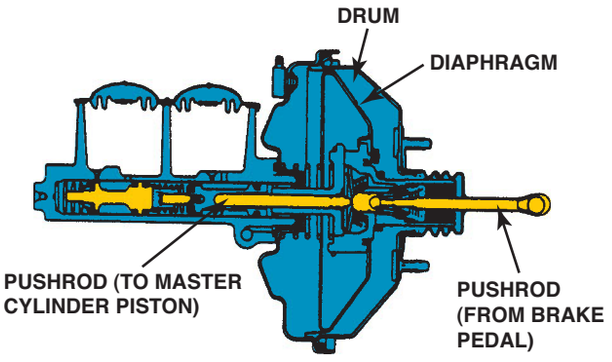


FIGURE 96–8 The master cylinder piston seals are usually constructed from EPDM rubber, and the diaphragm of the vacuum power brake booster is usually made from SBR.

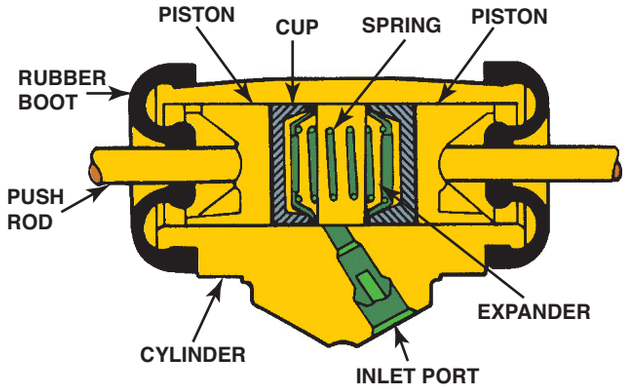


FIGURE 96–9 Cross-sectional view of a typical drum brake wheel cylinder. Most wheel cylinder boots and cups are either SBR or EPDM rubber.

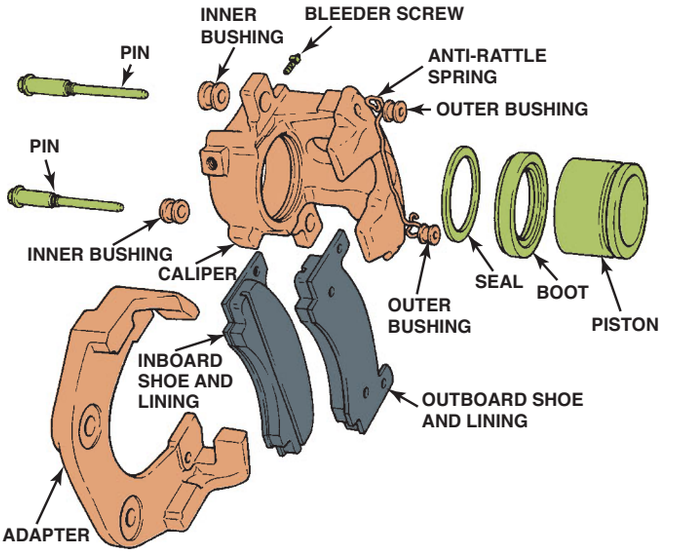


FIGURE 96–10 Exploded view of a typical disc brake caliper. Both the caliper seal and dust boot are constructed of EPDM rubber.

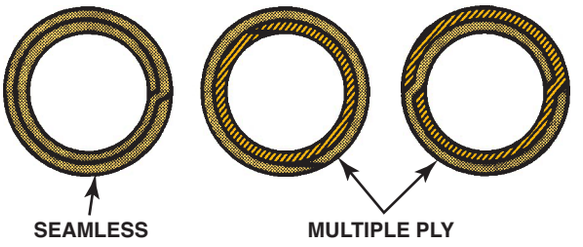


FIGURE 96–11 Steel brake tubing is double-walled for strength and plated for corrosion resistance.

All steel brake lines have one of two basic types of ends:

- **Double Flare.** This type of flare is a 45 degree flare that meets SAE standard J533 and is also called an *SAE flare* for that reason. ● **SEE FIGURE 96–12.**
- **ISO,** which means **International Standards Organization** (also called a *ball flare* or *bubble flare*). ● **SEE FIGURE 96–13.**

BRAKE LINE REPLACEMENT Always use a tubing cutter instead of a hacksaw when cutting brake line. A hacksaw will leave a rough and uneven end that will not flare properly. Always check the instructions that came with the flaring tool for the exact procedure to follow. ● **SEE FIGURE 96-14.**

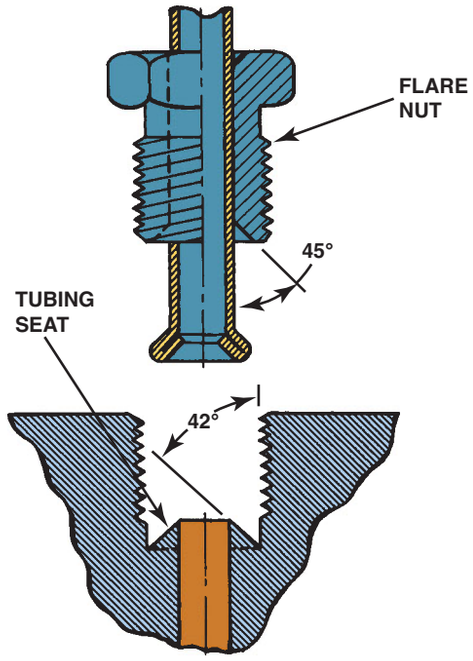


FIGURE 96–12 An SAE flare brake line fitting. Because of the slight difference in flare angle, double-flare fitting seals cause a wedging action.

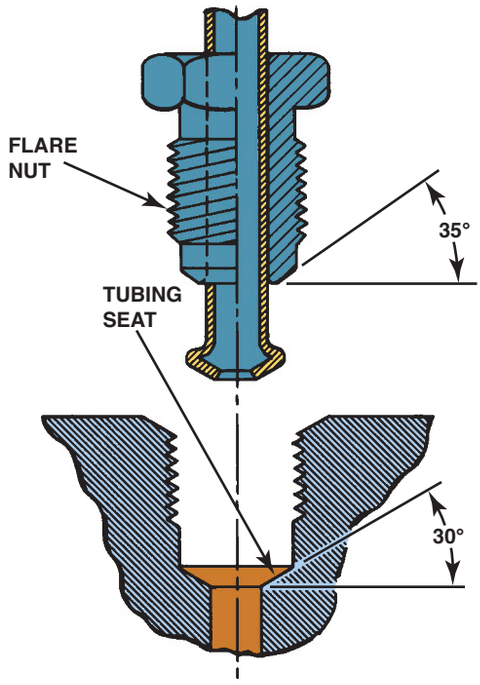


FIGURE 96–13 An ISO fitting, also called a bubble or ball-type flare.

FLARING BRAKE LINE When replacing steel brake line, new steel tubing should be used and a double flare or an ISO flare completed at each end using a special flaring tool. ● **SEE FIGURES 96–15 AND 96–16.**

Brake line can also be purchased in selected lengths already correctly flared. They are available in different diameters, the most commonly used being 3/16 in. (4.8 mm), 1/4 in. (6.4 mm), and 5/16 in. (7.9 mm) outside diameter (O.D.).

CAUTION: According to vehicle manufacturers' recommended procedures, compression fittings should never be used to join two pieces of steel brake line. Only use double-flare ends and connections, if necessary, when replacing damaged steel brake lines.

Always use two line wrenches when disconnecting or reattaching brake lines. ● **SEE FIGURE 96–17** on page 1058.

COILED BRAKE LINE Steel brake line is often coiled, ● **SEE FIGURE 96–18** on page 1058. The purpose of the coils is to allow movement between the brake components without stress that could lead to metal fatigue and brake line breakage. The typical master cylinder attaches to the bulkhead of the vehicle and the combination valve is often attached to the frame. Because the body and frame are usually insulated from each other using rubber isolators, some movement occurs while driving.

ARMORED BRAKE LINE In many areas of the brake system, the steel brake line is covered with a wire coil wrap, as shown in ● **FIGURE 96–19** on page 1058. This type of brake line is called **armored brake line.** This armor is designed to prevent damage from stones and other debris that could dent or damage the brake line. If a section of armored brake line is to be replaced, armored replacement line should be installed.

TECH TIP

Bend It Right the First Time

Replacing rusted or damaged brake line can be a difficult job. It is important that the replacement brake line be located in the same location as the original to prevent possible damage from road debris or heat from the exhaust. Often this means bending the brake line with many angles and turns. To make the job a lot easier, use a stiff length of wire and bend the wire into the exact shape necessary. Then use the wire as a pattern to bend the brake line. Always use a tubing bender to avoid kinking the brake line. A kink not only restricts the flow of brake fluid, but also weakens the line. To bend brake line without a tubing bender tool, use an old V-belt pulley. Clamp the pulley in a vise, lay the tubing in the groove, and smoothly bend the tubing. Different diameter pulleys will create various radius bends. ● **SEE FIGURE 96–20** on page 1059.

NOTE: Always use a tubing cutter instead of a hacksaw when cutting brake line. A hacksaw will leave a rough and uneven end that will not flare properly except when forming an ISO flare. A hacksaw is used to provide a rough surface to allow the flaring tool to grip the line during the procedure. Always check the instructions that came with the flaring tool for the exact procedure to follow.

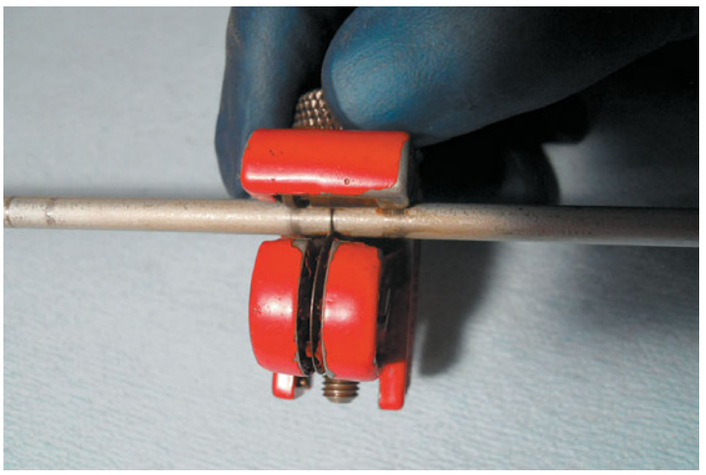


FIGURE 96–14 A tubing cutter is the preferred tool to use to cut brake line because it leaves a clean edge.



(a)



(c)



(b)

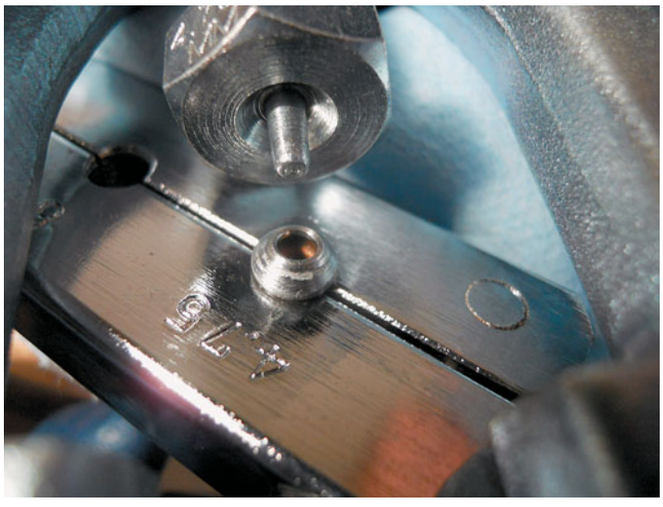


(d)

FIGURE 96–15 Double flaring the end of a brake line. (a) Clamp the line at the correct height above the surface of the clamping tool using the shoulder of the insert as a gauge. (b) The insert is pressed into the end of the tubing. This creates the first bend. (c) Remove the insert and use the pointed tool to complete the overlap double flare. (d) The completed operation as it appears while still in the clamp.



(a)



(b)

FIGURE 96–16 Making an ISO flare requires a special tool. (a) Position the brake line into the two-part tool at the correct height using the gauge end of the tool. (b) Assemble the two blocks of the tool together and clamp in a vise. Turn the tool around and thread it into the tool block. The end of the threaded part of the tool forms the "bubble" or ISO flare.

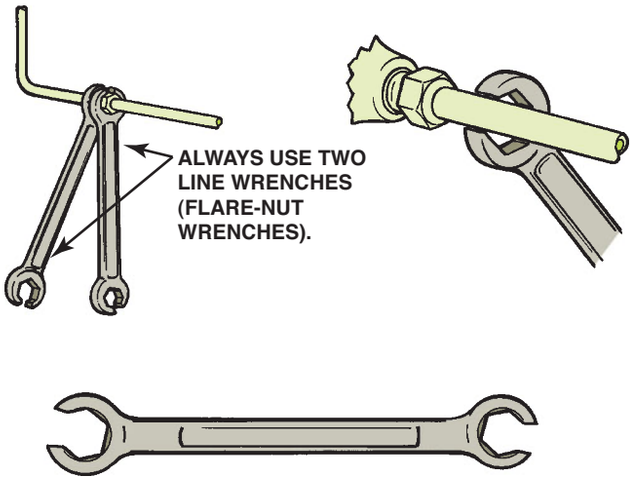


FIGURE 96–17 Whenever disconnecting or tightening a brake line, always use the correct size flare-nut wrench. A flare-nut wrench is also called a tube-nut wrench or a line wrench.

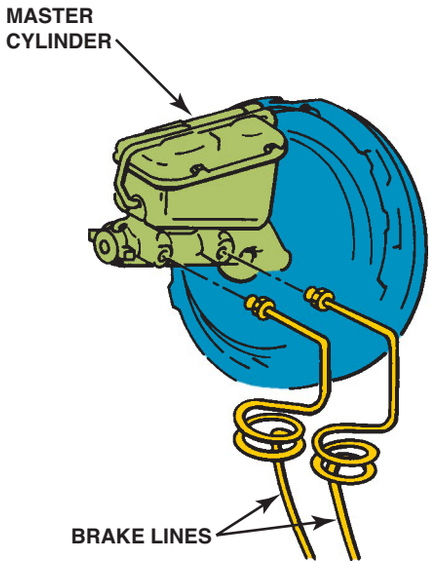


FIGURE 96–18 The coils in the brake line help prevent cracks caused by vibration.

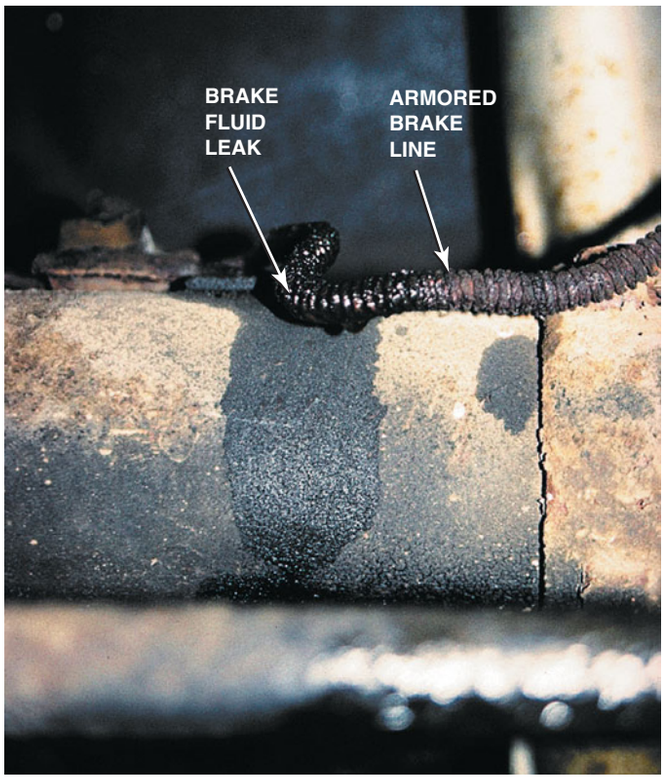


FIGURE 96–19 Armored brake line is usually used in the location where the line may be exposed to rock or road debris damage. Even armored brake line can leak and a visual inspection is an important part of any brake service.

FLEXIBLE BRAKE HOSE

Flexible brake hoses are used on each front wheel to allow for steering and suspension movement and at the rear to allow for rear suspension travel. ● **SEE FIGURE 96–21.** These rubber high-strength hoses can crack, blister, or leak, and should be inspected at least every six months. ● **SEE FIGURE 96–22.**

Flexible brake hose is made from synthetic yarn (poly vinyl alcohol, abbreviated PVA) that is braided into position from multi-end yarn spindles. By braiding the yarn, all of the strands operate



FIGURE 96–20 A tube bender being used to bend a brake line.

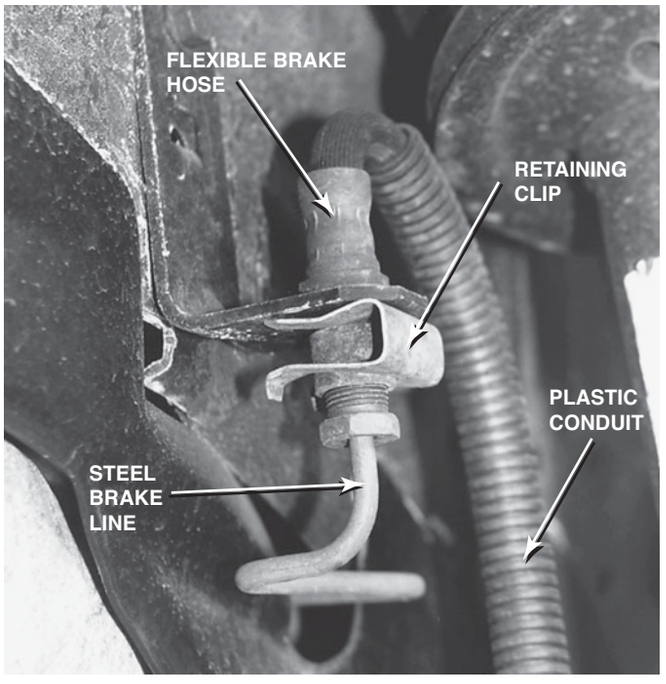
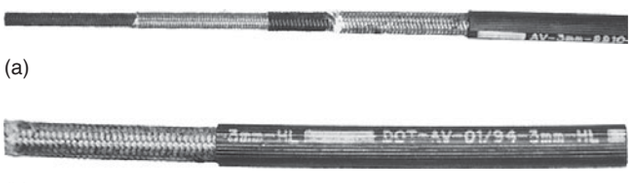


FIGURE 96–21 Flexible brake hoses are used between the frame or body of the vehicle and the wheel brakes. Because of suspension and/or steering movement, these flexible brake lines must be strong enough to handle high brake fluid pressures, yet remain flexible. Note that this flexible brake hose is further protected against road debris with a plastic conduit covering.



(a)

(b)

FIGURE 96–22 (a) Typical flexible brake hose showing the multiple layers of rubber and fabric. (b) The inside diameter (ID) is printed on the hose (3 mm).

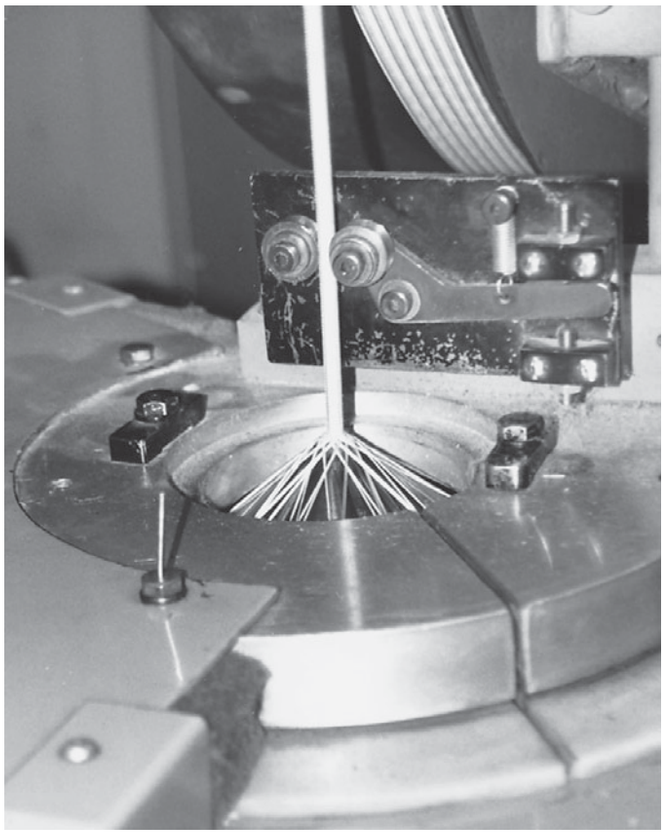


FIGURE 96–23 Brake hose fabric being woven at the factory.

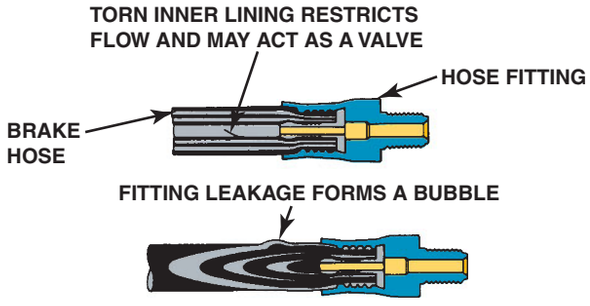


FIGURE 96–24 Typical flexible brake hose faults. Many faults cannot be seen, yet can cause the brakes to remain applied after the brake pedal is released.

in tension and, therefore, have great strength to withstand braking system pressure over 1,000 PSI (6,900 kPa). ● **SEE FIGURE 96–23.**

A typical brake hose has an inner tube for conveying the brake fluid and a cushion liner that is between the braided layers to prevent the braids from chafing. All three layers use ethylene-propylene-diene-monomer (EPDM)-type thermosetting polymers, which help prevent the hose from absorbing moisture from the outside air. An outside jacket is made from rubber and protects the reinforcement fabric from moisture and abrasion. The outside covering is also ribbed as part of the manufacturing process to hide surface blemishes. These ribs also make it easy for the technician to see if the hose is twisted. It is not unusual for flexible brake lines to become turned around and twisted when the disc brake caliper is removed and then replaced during a brake pad change. ● **SEE FIGURE 96–24.**

A constricted brake hose can cause the brakes to remain applied, thereby causing excessive brake pad wear and unequal braking. A constricted flexible brake line can also cause the vehicle to pull to one side. ● **SEE FIGURE 96–25.**



FIGURE 96–25 Flexible brake hose should be carefully inspected for cuts or other damage, especially near sections where the brake hose is attached to the vehicle. Notice the crack and cut hose next to the mounting bracket.

CAUTION: Never allow a disc brake caliper to hang by the flexible brake hose. Damage to the line can result. Always use a wire to support the weight of the caliper.

Always replace flexible brake hoses in pairs. If one side is found to be defective the other side may be close to failing too. Both brake hoses have been subjected to the same weather and operating conditions so it is always wise to replace all of the flexible brake lines including the rear hose or hoses depending on vehicle design.

REVIEW QUESTIONS

1. What is the difference between DOT 3, DOT 4, DOT 5.1, and DOT 5 brake fluid?
2. List four things that should be done during a thorough inspection of the brake fluid.
3. List four precautions that should be followed when handling brake fluid.
4. What are the two types of flares used on brake lines?
5. Why are some brake lines coiled?

CHAPTER QUIZ

1. The type of brake fluid most often recommended by vehicle manufacturers is _____.
   a. DOT 3 **c.** DOT 5
   b. DOT 4 **d.** DOT 5.1
2. Which of the following is *not* a characteristic of conventional brake fluid?
   a. Absorbs moisture from the air
   b. Removes paint if spilled on vehicle surfaces
   c. Lasts the life of the vehicle unless there is a leak
   d. Is clear or amber in color
3. Technician A says that DOT 5 brake fluid can be added to DOT 3 brake fluid. Technician B says that it is wise to purchase brake fluid that is in metal rather than plastic containers. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
4. As brake fluid ages, what happens?
   a. The boiling temperature decreases
   b. The boiling temperature increases
   c. The viscosity (thickness) decreases
   d. The color changes to purple
5. Technician A says that glycol-based brake fluid causes the seals to swell slightly. Technician B says the DOT 5 (silicone-based) brake fluid causes rubber seals to swell slightly. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. The two types of flares used on brake lines are _____.
   a. SAE and DOT **c.** Ball flare and bubble flare
   b. Double flare and ISO **d.** SAE and double flare
7. Two technicians are discussing why the brake lines are coiled near the master cylinder on many vehicles. Technician A says that these coils help prevent moisture from flowing from the master cylinder to the calipers. Technician B says that they help prevent cracks that could be caused by vibrations. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. Flexible brake hose should be inspected for all of the following *except:*
   a. Cracks **c.** Twisted
   b. Leakage **d.** Worn outer ribs
9. Why should brake calipers be supported by a wire during brake service and not allowed to hang by the flexible brake hose?
   a. To keep air from getting into the system
   b. To help prevent damage to the brake hose
   c. To hold the caliper higher than the master cylinder to prevent fluid loss
   d. To prevent bending the hose support bracket
10. Used brake fluid should be _____.
    a. Mixed with and recycled with used oil
    b. Poured down the drain
    c. Dispose of properly according to State and local laws
    d. Poured onto open ground to reduce dust

chapter 97

BRAKE BLEEDING METHODS AND PROCEDURES

OBJECTIVES: **After studying Chapter 97, the reader will be able to:** • Prepare to take the Brakes (A5) ASE certification test content area "A" (Hydraulic System Diagnosis and Repair). • Explain how to bench bleed a master cylinder. • Describe the proper brake bleeding sequence. • Describe the single stroke manual brake bleeding procedure. • Discuss how to gravity bleed the hydraulic brake system. • List the steps needed to perform a pressure bleed procedure. • Discuss how to vacuum bleed a hydraulic brake system.

KEY TERMS: Bleeder valve 1061 • Brake bleeding 1061 • Gravity bleeding 1065 • Power bleeding 1066 • Pressure bleeding 1066 • Single stroke bleeding method 1063 • Vacuum bleeding 1064

BRAKE BLEEDING

THE NEED FOR BRAKE BLEEDING

Brake bleeding is removing any trapped air from the hydraulic system. If air is the brake hydraulic system, the brake pedal will often feel "spongy". The brake pedal will also travel farther (lower than normal brake pedal) before the brakes start to apply. Air can get into the hydraulic system whenever any hydraulic brake line or unit is opened. Air can also be drawn into the hydraulic system through small holes or loose brake line connections during the release of the brake pedal. A common source of air in the brake system of this type can occur through very small holes in rubber flexible brake lines. Another source of air in the braking system is through the absorption of moisture by the brake fluid. When moisture is absorbed, the boiling point of the brake fluid is reduced. During severe braking, the heat generated can cause the brake fluid to boil and create air bubbles in the hydraulic brake system. Air eventually travels to the highest part of the brake system, if not restricted by pressure control valves.

If air is in the brake hydraulic system, the following conditions will likely occur:

1. A lower than normal brake pedal
2. A "spongy" or soft feeling brake pedal
3. A need to "pump up" the brake pedal before they stop the vehicle

BENCH BLEEDING THE MASTER CYLINDER

Whenever the master cylinder is replaced or the hydraulic system has been left opened for several hours, the air may have to be bled from the master cylinder. The master cylinder is located in the highest section of the hydraulic braking system. Some master cylinders are equipped with bleeder valves. If the master cylinder is not equipped with bleeder valves, it can be bled by loosening the brake line fittings at the master cylinder. Bleed the master cylinder "on the bench" before installing it on the vehicle. ● **SEE FIGURE 97–1.**



FIGURE 97–1 Bench bleeding a master cylinder. Always clamp a master cylinder in a vise by the mounting flange to prevent distortion of the cylinder bore. Bench bleeding tubes can also be used that route the fluid back into the reservoir.

ON-VEHICLE MASTER CYLINDER BLEEDING

If bleeding the master cylinder after working on the hydraulic system, follow these steps:

STEP 1 Fill the master cylinder with clean brake fluid from a sealed container up to the recommended "full" level.

STEP 2 Have an assistant slowly depress the brake pedal as you "crack open" the master cylinder bleed screw starting with the section closest to the brake pedal. It is very important that the primary section of the master cylinder be bled before attempting to bleed the air out of the secondary section of the master cylinder. Before the brake pedal reaches the floor, close the bleeder valve.

NOTE: A proper manual bleeding of the hydraulic system requires that accurate communications occur between the person depressing the brake pedal and the person opening and closing the bleeder valve(s). The bleeder valve (also called a *bleed valve*) should be open only when the brake pedal is being depressed. The valve *must* be closed when the brake pedal is released to prevent air from being drawn into the system.

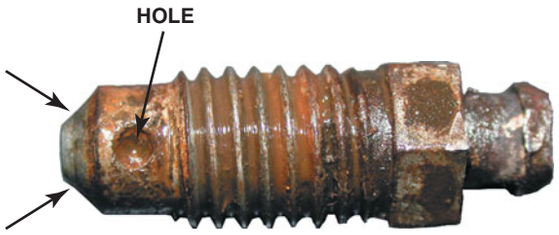


FIGURE 97–2 Typical bleeder valve from a disc brake caliper. The arrows point to the taper section that does the actual sealing. It is this taper that requires a shock to loosen. If the bleeder is simply turned with a wrench, the bleeder usually breaks off because the tapered part at the bottom remains adhered to the caliper or wheel cylinder. Once loosened, brake fluid flows around the taper and out through the hole in the side of the bleeder valve. The hole is clogged in this example and needs to be cleaned out.

TECH TIP

Check That All Bleeder Valves Are Pointing Up

Make certain all the brake components such as calipers and wheel cylinders are correctly installed with the bleeder valve located on the highest section of the part. Some wheel cylinders and calipers (such as many Ford calipers) can be installed upside down!

This usually occurs whenever both front calipers are off the vehicle and they accidentally get reversed left to right. If this occurs, the air will never be completely bled from the caliper.

STEP 3 Repeat the procedure several times until a solid flow of brake fluid is observed leaving the bleeder valve. If the master cylinder is not equipped with bleeder valves, the outlet tube nuts can be loosened instead.

BRAKE BLEEDER VALVE LOOSENING METHODS

Attempting to loosen a bleeder valve often results in breaking (shearing off) the bleeder valve. Several of these service procedures can be tried that help prevent the *possibility* of breaking a bleeder valve. Bleeder valves are tapered and become wedged in the caliper on the wheel cylinder housing. ● **SEE FIGURES 97–2 AND 97–3.** All of these methods use shock to "break the taper" and to loosen the stuck valve.

HIT AND TAP METHOD

STEP 1 Tap on the end of the bleeder valve with a steel hammer after applying a penetrating oil to help lubricate the threads of the bleeder valve. This shock often "breaks the taper" at the base of the bleeder valve. The shock also breaks loose any rust or corrosion on the threads.

STEP 2 Using a 6-point wrench or socket, *tap* the bleeder valve in the clockwise direction (tighten).

STEP 3 Using the same 6-point socket or wrench, *tap* the bleeder valve counter-clockwise to loosen and remove the bleeder valve.

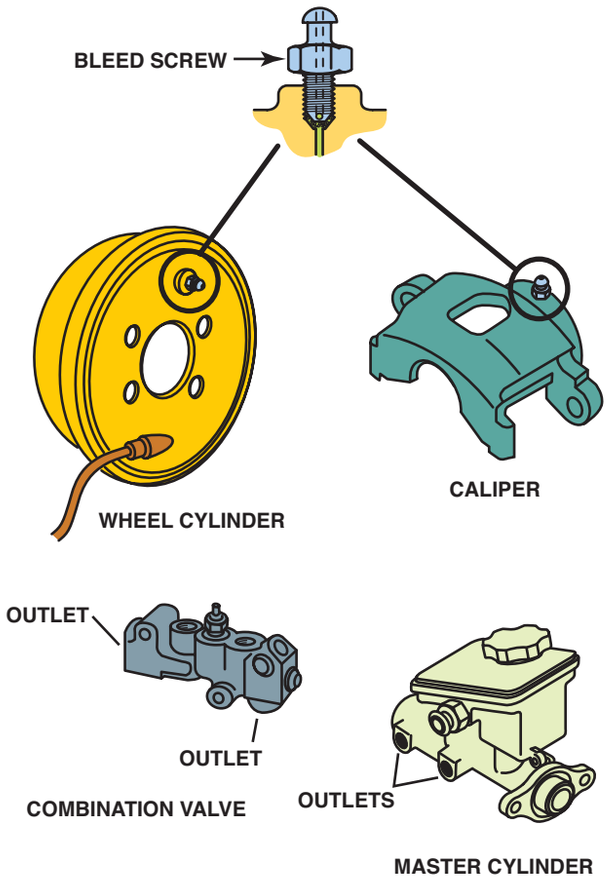


FIGURE 97–3 Typical bleeder locations. Note that the combination valve and master cylinder shown do not have bleeder valves; therefore, bleeding is accomplished by loosening the brake line at the outlet ports.



FIGURE 97–4 Using an air punch next to the bleeder valve to help "break the taper" on the bleeder valve.

NOTE: It is the *shock* of the tap on the wrench that breaks loose the bleeder valve. Simply pulling on the wrench often results in breaking off the bleeder.

STEP 4 If the valve is still stuck (frozen), repeat Step 1 through Step 3.

AIR PUNCH METHOD After using a penetrating oil, use an air punch near the bleeder valve while attempting to loosen the bleeder valve at the same time. ● **SEE FIGURE 97–4.**

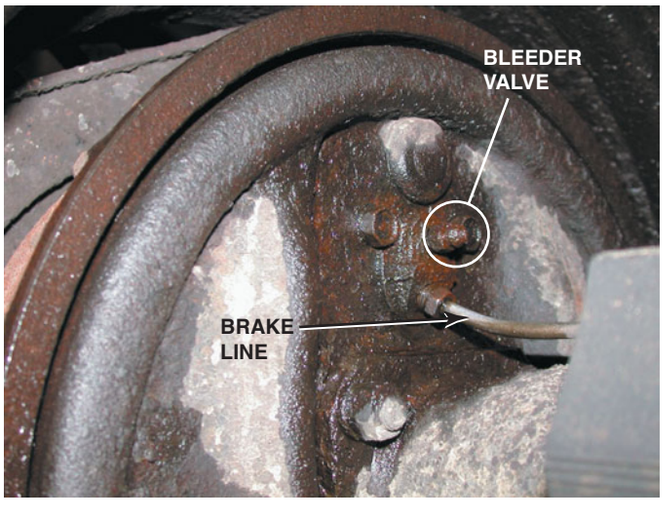


FIGURE 97–5 Most vehicle manufacturers recommend starting the brake bleeding process at the rear wheel farthest from the master cylinder.

The air punch creates a shock motion that often loosens the taper and threads of the bleeder valve from the caliper or wheel cylinder. It is also helpful to first attempt to turn the bleeder valve in the clockwise (tightening) direction, then turn the bleeder in the counter-clockwise direction to loosen and remove the bleeder valve.

HEAT AND TAP METHOD

Heat the area around the bleeder valve with a torch. The heat expands the size of the hole and usually allows the bleeder to be loosened and removed.

CAUTION: The heat from a torch will damage the rubber seals inside the caliper or wheel cylinder. Using heat to free a stuck bleeder valve will *require* that all internal rubber parts be replaced.

WAX METHOD

STEP 1 Heat the bleeder valve itself with a torch. The heat causes the valve itself to expand.

STEP 2 Remove the heat from the bleeder valve. As the valve is cooling, touch paraffin wax or candle wax to the hot valve. The wax will melt and run down around the threads of the bleeder valve.

STEP 3 Allow the bleeder valve to cool until it can be safely touched with your hand. This assures that the temperature is low enough for the wax to return to a solid and provide the lubricating properties necessary for the easy removal of the bleeder valve. Again, turn the bleeder valve clockwise before turning the valve counterclockwise to remove.

BLEEDING SEQUENCE

After bleeding the master cylinder, the combination valve should be bled if equipped. Check the level in the master cylinder frequently being careful not to allow the master cylinder to run dry and keep it filled with clean brake fluid throughout the brake bleeding procedure.

For most rear-wheel-drive vehicles equipped with a front/rear split system, start the bleeding with the wheel farthest from the master cylinder and work toward the closest. ● **SEE FIGURE 97–5.**

For most vehicles, this sequence is as follows:

1. Right rear
2. Left rear
3. Right front
4. Left front

NOTE: If the vehicle has two wheel cylinders on one brake, bleed the upper wheel cylinder first.

For vehicles equipped with a diagonal split section or equipped with ABS, follow the brake bleeding procedure recommended in the service information for the vehicle.

The two most commonly specified brake bleeding order for diagonal-split brake system vehicles include:

RR, LR, RF and then LF

RF, LF, RR and then LR

MANUAL BLEEDING

Manual bleeding is the most commonly used method and uses hydraulic pressure created by the master cylinder to pump fresh fluid through the brake system. This method is also called the **single stroke bleeding method.**

ITEMS NEEDED FOR MANUAL BLEEDING

The manual method of brake bleeding is the most common. Manual bleeding requires the following:

- An assistant to apply and release the brake pedal
- A bleeder screw wrench
- Approximately 2 feet of clear, plastic hose with an inside diameter small enough to fit snugly over the bleeder screws
- A clear jar partially filled with clean brake fluid

MANUAL BLEEDING PROCEDURE

To manually bleed the brake system, follow these steps:

STEP 1 Discharge the vacuum or hydraulic power booster (if equipped) by pumping the brake pedal with the ignition OFF until the pedal feels hard.

STEP 2 Fill the master cylinder reservoir with new brake fluid and make sure it remains at least half full throughout the bleeding procedure.

STEP 3 Attach the plastic hose over the bleeder screw of the first wheel cylinder or caliper in the bleeding sequence, and submerge the end of the tube in the jar of brake fluid. ● **SEE FIGURE 97–6.**

STEP 4 Have the assistant lightly depress the brake pedal, then open the bleeder valve about one half turn. It is extremely important when manually bleeding a brake system that the pedal be applied and released slowly and gently. Rapid pedal pumping can churn up the fluid and reduce the size of trapped air bubbles, making them more difficult to bleed from the system. Air bubbles leaving the bleeder screw will be visible in the hose to the jar.

STEP 5 Tighten the bleeder screw, then have your assistant slowly release the brake pedal.



FIGURE 97–6 Bleeding brakes using clear plastic tubing makes it easy to see air bubbles. Submerging the hose in a container of clean brake fluid helps ensure that all of the air will be purged by the system.

TECH TIP

Tiny Bubbles

Do not use excessive brake pedal force while bleeding and never bleed the brake with the engine running! The extra assist from the power brake unit greatly increases the force exerted on the brake fluid in the master cylinder. The trapped air bubbles may be dispersed into tiny bubbles that often cling to the inside surface of the brake lines. These tiny air bubbles may not be able to be bled from the hydraulic system until enough time has allowed the bubbles to re-form. If the dispersal of the air into tiny bubbles is suspected, try tapping the calipers or wheel cylinders with a plastic hammer. After this tapping, simply waiting for a period of time will cause the bubbles to re-form into larger and easier-to-bleed air pockets. Most brake experts recommend waiting *15 seconds or longer* between attempts to bleed each wheel. This waiting period is critical and allows time for the air bubbles to form.

NOTE: To help prevent depressing the brake pedal down too far, some experts recommend placing a 2 × 4 in. board under the brake pedal. This helps prevent the seals inside the master cylinder from traveling over unused sections inside the bore that may be corroded or rusty.

STEP 6 Wait at least 15 seconds to allow time for any small bubbles to form into larger bubbles. See the Tech Tip called, "Tiny Bubbles."

STEP 7 Repeat steps 4 and 5 until no more air bubbles emerge from the bleeder.



FIGURE 97–7 Using a compressed air-powered vacuum bleeder.

STEP 8 Transfer the plastic hose to the bleeder screw of the next wheel cylinder or caliper in the bleeding sequence, and repeat steps 4 through 7. Continue around the vehicle in the specified order until the brakes at all four wheels have been bled.

VACUUM BLEEDING

Vacuum bleeding uses a special suction pump that attaches to the bleeder screw. The pump creates a low-pressure area at the bleeder screw, which allows atmospheric pressure to force brake fluid through the system when the bleeder screw is opened.

ADVANTAGES OF VACUUM BLEEDING

Vacuum bleeding requires only one technician. It is easy and the required equipment can be purchased at low cost.

DISADVANTAGES OF VACUUM BLEEDING

The disadvantage of using a vacuum bleeding method is that a vacuum tool must be used and often air can be drawn into the line between the bleeder valve and the hose creating some bubbles that can be interpreted by the technician as air in the system.

VACUUM BLEEDING PROCEDURE

To vacuum bleed a brake system, use the following steps:

STEP 1 Fill the master cylinder reservoir with new brake fluid and make sure it remains at least half full throughout the bleeding procedure.

STEP 2 Attach the plastic tube from the vacuum bleeder to the bleeder screw of the first wheel cylinder or caliper in the bleeding sequence. ● **SEE FIGURES 97–7 AND 97–8.** If necessary, use one of the adapters provided with the vacuum in the catch bottle.

STEP 3 Operate the bleeder to create a partial vacuum in the catch bottle.

STEP 4 Loosen the bleeder screw approximately one-half turn. Brake fluid and air bubbles will flow into the bottle. When the fluid is free of bubbles, tighten the bleeder screw.

STEP 5 Repeat steps 3 and 4 until no more air bubbles emerge from the bleeder.

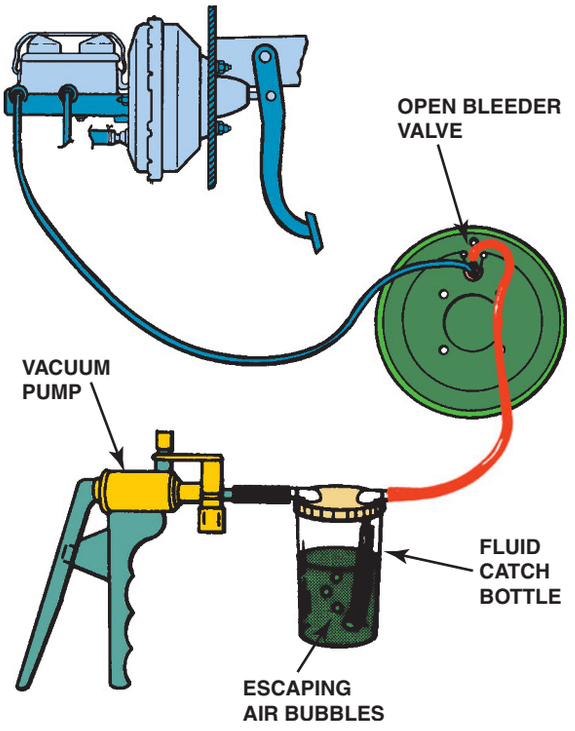


FIGURE 97–8 Vacuum bleeding uses atmospheric pressure to force brake fluid through the hydraulic system.

STEP 6 Transfer the vacuum bleeder to the bleeder screw of the next wheel cylinder or caliper in the bleeding sequence, and repeat steps 3 and 4. Continue around the vehicle in the specified order until the brakes at all four wheels have been bled.

GRAVITY BLEEDING

Gravity bleeding is a slow, but effective, method that will work on many vehicles to rid the hydraulic system of air. The procedure involves simply opening the bleeder valve and waiting until brake fluid flows from the open valve. Any air trapped in the part being bled will rise and escape from the port when the valve is opened. It may take several minutes before brake fluid escapes. Gravity bleeding works because any liquid tends to seek its own level. This means that the brake fluid in the master cylinder tends to flow downward toward the wheel cylinders or calipers. As long as the brake fluid level in the master cylinder is higher than the bleeder valve, the brake fluid will flow downward and out the open bleeder valve, as shown in ● **FIGURE 97–9.**

This flow of brake fluid can even get past the metering valve and proportioning valve. The proportioning valve is normally open to the rear brakes until the pressure reaches a predetermined level when it starts to limit increasing pressure to the rear brakes. The metering valve used to control or delay the operation of the front brakes is open to the front wheels until the pressure exceeds 10 to 15 PSI (70 to 100 kPa). Therefore, as long as no one is pushing on the brake pedal, the metering valve remains open to the front wheels and the brake fluid from the master cylinder can easily flow downward through the valve and out the open bleeder valve.

Since no pressure is exerted on the brake fluid, the large air bubbles remain large air bubbles and are not separated into smaller, harder-to-bleed air bubbles that can occur with manual bleeding.



FIGURE 97–9 Gravity bleeding is simply opening the bleeder valve and allowing gravity to force the brake fluid out of the bleeder valve. Because air is lighter than brake fluid all of the air escapes before the brake fluid runs out.

ADVANTAGES OF GRAVITY BLEEDING

All four wheel brakes can be bled at one time using the gravity method. In this process, the bleeder screws at all four wheels are opened at the same time, and the system is allowed to drain naturally until the fluid coming out of the bleeders is free of air. Gravity bleeding can be done by a single technician, who is freed to attend to other jobs while the brakes bleed.

DISADVANTAGES OF GRAVITY BLEEDING

Gravity bleeding is a slow process that can take an hour or more. In addition, this procedure cannot be used on brake systems with residual pressure check valves because the valves restrict the fluid flow. When other bleeding procedures fail, gravity bleeding can sometimes be effective on brake systems that trap small pockets of air.

GRAVITY BLEEDING PROCEDURE

Gravity bleeding requires:

- A bleeder wrench
- Four lengths of plastic hose that fit snugly over the bleeder screws
- Four jars to catch the dripping fluid—one for each wheel brake

Unless a plastic hose is used to "start a siphon" at each bleeder screw, it is possible that air may enter the system rather than be bled from it. This can occur because the total open area of the four bleeder screws is somewhat larger than that of the two compensating ports through which the fluid must enter the system. To gravity bleed the brake system, follow these steps:

STEP 1 Fill the master cylinder reservoir with new brake fluid. During the bleeding process, check the fluid level periodically to ensure that the reservoir remains at least half full.

STEP 2 Attach a length of plastic tubing to each bleeder screw, and place the ends of the tubes in jars to catch the drainage. Open each bleeder screw approximately one full turn and make sure that fluid begins to drain. Allow the system to drain until the fluid flowing from the bleeder screws is free of air bubbles. If no brake fluid comes out, remove the bleeder valve entirely—it may be clogged. Nothing but air and brake fluid will be *slowly* coming out of the wheel cylinder or caliper when the bleeder valve is removed. *Do not press on the brake pedal with the bleeder valve out while gravity bleeding.*

STEP 3 Close the bleeder screws and fill the brake fluid in the master cylinder reservoir to the maximum level mark.

TECH TIP

The Master Cylinder One-Drip-Per-Second Test

Excessive brake wear is often caused by misadjusted brake linkage or brake light switches keeping the brake pedal from fully releasing. If the brake pedal is not fully released, the primary piston sealing cup blocks the compensating port from the brake fluid reservoir. To test if this is the problem, loosen both lines from the master cylinder. Brake fluid should drip out of both lines about one drip per second. This is why this test is also called the "Master Cylinder Drip Test." If the master cylinder does not drip, the brake pedal may not be allowing the master cylinder to fully release. Have an assistant pull up on the brake pedal. If the dripping starts, the problem is due to a misadjusted brake light or speed (cruise) control switch or pedal stop. If the master cylinder still does not drip, loosen the master cylinder from the power booster. If the master cylinder now starts to drip, the pushrod adjustment is too long.

If the master cylinder still does not drip, the problem is in the master cylinder itself. Check for brake fluid contamination. If mineral oil, such as engine oil, power steering fluid, or automatic transmission fluid (ATF), has been used in the system, the rubber sealing cups swell and can block off the compensating port. If contamination is discovered, *every* brake component that contains rubber *must* be replaced.

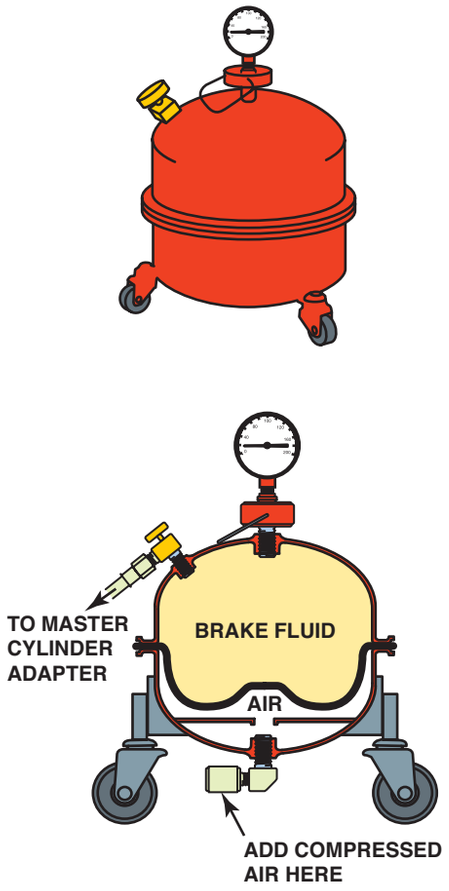


FIGURE 97–10 A typical pressure bleeder. The brake fluid inside is pressurized with air pressure in the air chamber. This air pressure is applied to the brake fluid in the upper section. A rubber diaphragm separates the air from the brake fluid.

PRESSURE BLEEDING

Pressure bleeding, sometimes called **power bleeding,** is a common method used to bleed the brake hydraulic system. In this process, a pressure bleeder attached to the master cylinder forces brake fluid through the system under pressure to purge any trapped air. Once the hydraulic system is pressurized, the technician simply opens the bleeder screws in the prescribed order and allows fluid to flow until it is free of air bubbles.

The tools required for pressure bleeding include a plastic hose and fluid catch jar as used in manual bleeding, as well as a pressure bleeder, a source of air pressure to charge the bleeder, and an adapter to attach the pressure bleeder to the master cylinder fluid reservoir. Cast-metal cylinders with integral reservoirs commonly use a flat, plate-type adapter that seals against the same surface as the reservoir cover. ● **SEE FIGURE 97–10.**

Some plastic master cylinder reservoirs also use plate-type adapters, but others require adapters that seal against the bottom of the reservoir. ● **SEE FIGURE 97–11.** Pressure bleeder manufacturers offer many adapters to fit specific applications.

METERING VALVE OVERRIDE TOOLS In addition to the tools previously described, a metering valve override tool is required when pressure bleeding the front brakes of certain vehicles. The override tool is used to deactivate the metering valve because the operating pressure of power bleeders is within the range where the metering valve blocks fluid flow to the front brakes. Metering valves that require an override tool have a stem or button on one



FIGURE 97–11 Brake fluid under pressure from the power bleeder is applied to the top of the master cylinder. It is very important that the proper adapter be used for the master cylinder. Failure to use the correct adapter or failure to release the pressure on the brake fluid before removing the adapter can cause fluid to escape under pressure.

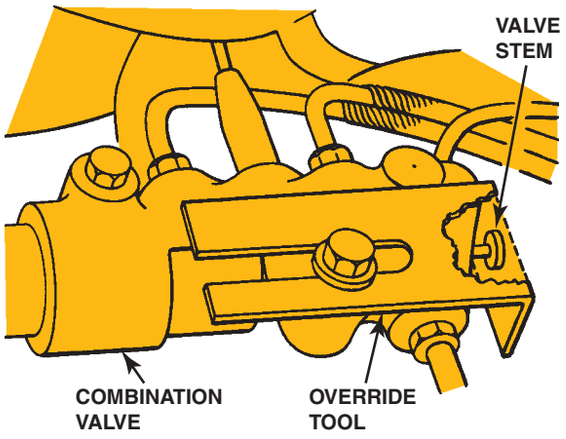


FIGURE 97–12 Metering valve override tool on a General Motors vehicle.

end that is either pushed in or pulled out to hold the valve open. The override tool performs this service.

To install the override tool used on General Motors vehicles, loosen the combination valve mounting bolt and slip the slot in the tool under the bolt head.

Push the end of the tool toward the valve body until it depresses the valve plunger, then tighten the mounting bolt to hold the tool in place.

Some full-size Ford vehicles have a metering valve with a stem that must be pushed in to bleed the front brakes, but Ford does not offer a special tool for this purpose. An assistant is needed to override the valve when the front brakes are being bled.

To install the override tool used on older Chrysler and Ford vehicles, slip one fork of the tool under the rubber boot, and the other fork under the valve stem head. ● **SEE FIGURE 97–12.**

The spring tension of the tool holds the valve open, but allows the valve stem to move slightly when the system is pressurized. If the valve is held rigidly open, internal damage will result.

PRESSURE BLEEDING PROCEDURE Just as in manual bleeding, it is important to follow the proper sequence when pressure bleeding a brake system. Some manufacturers recommend one sequence for manual bleeding and another for pressure bleeding. To pressure bleed a brake system, follow these steps:

STEP 1 If it has not already been done, consult the equipment manufacturer's instructions and fill the pressure bleeder with the proper type of brake fluid.

STEP 2 Make sure the bleeder is properly sealed and the fluid supply valve is closed, then use compressed air to pressurize the bleeder until approximately 30 PSI (207 kPa) is indicated on the bleeder gauge.

STEP 3 If the vehicle is equipped with a metering valve, override it with the appropriate tool. ● **SEE FIGURE 97–13.**

STEP 4 Clean the top of the master cylinder, then remove the master cylinder cover and clean around the gasket surface. Be careful not to allow any dirt to fall into the reservoir.

STEP 5 Fill the reservoir about half full with new brake fluid, then install the proper pressure bleeder adapter on the master cylinder.

STEP 6 Connect the pressure bleeder fluid supply hose to the adapter, making sure the hose fitting is securely engaged.

STEP 7 Open the fluid supply valve on the pressure bleeder to allow pressurized brake fluid to enter the system. Check carefully for fluid leaks that can damage the vehicle finish.

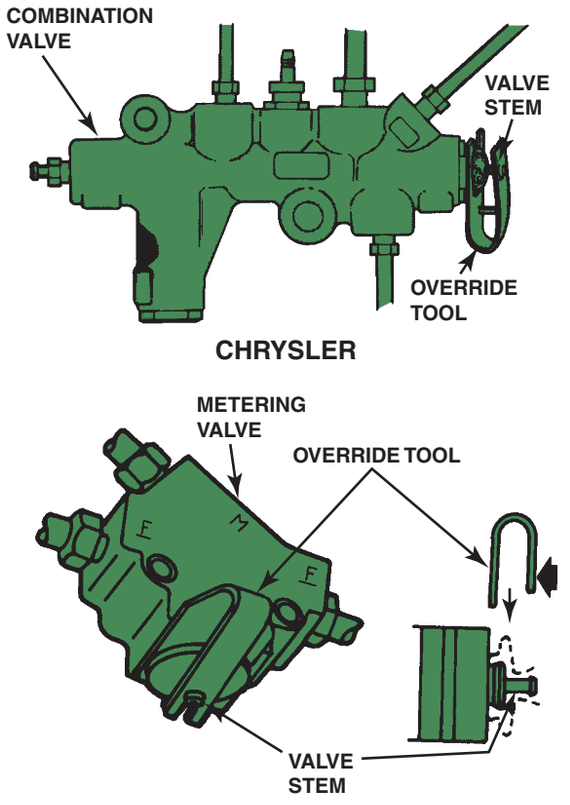


FIGURE 97–13 Pull-out-type metering valves being held out using a special override tool.

STEP 8 Slip the plastic hose over the bleeder screw of the first wheel cylinder or caliper to be bled, and submerge the end of the tube in the jar of brake fluid.

STEP 9 Open the bleeder screw approximately one-half turn, and let the fluid run until air bubbles no longer emerge from the tube. Close the bleeder screw.

STEP 10 Transfer the plastic hose to the bleeder screw of the next wheel cylinder or caliper in the bleeding sequence, and repeat steps 8 and 9. Continue around the vehicle in the specified order until the brakes at all four wheels have been bled.

STEP 11 Remove the metering valve override tool.

STEP 12 Close the fluid supply valve on the pressure bleeder.

STEP 13 Shut off or disconnect shop air supply before removing master cylinder adapter.

STEP 14 Wrap the end of the fluid supply hose in a shop towel, and disconnect it from the master cylinder adapter. Be careful to avoid spilling brake fluid.

STEP 15 Remove the master cylinder adapter, adjust the fluid level to the full point, and install the fluid reservoir cover.

HYDRAULIC ABS SERVICE

CHECK SERVICE INFORMATION Before doing any brake work on a vehicle equipped with antilock brakes, always consult the appropriate service information for the exact vehicle being serviced. For example, some manufacturers recommend discharging the hydraulic accumulator by depressing the brake pedal many times

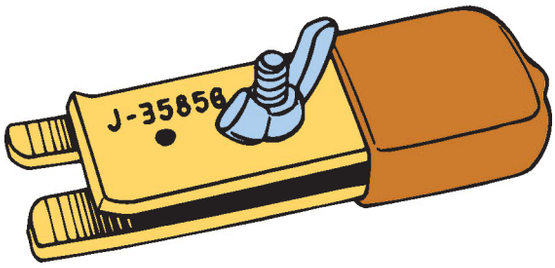


FIGURE 97–14 Special bleed valve tools are often required when bleeding some ABS units such as the Kelsey-Hayes 4WAL system.

before opening bleeder valves. Many service checks require that a pressure gauge be installed in the system.

BLEEDING THE ELECTRONIC-HYDRAULIC ASSEMBLY

Air can easily get trapped in the ABS electronic-hydraulic (E-H) assembly whenever the hydraulic system is opened. Even though the master cylinder and all four wheel cylinders/calipers have been bled, sometimes the brake pedal will still feel spongy. Some E-H units can be bled through the use of a scan tool where the valves are pulsed in sequence by the electronic brake controller (computer). Some units are equipped with bleeder valves while others must be bled by loosening the brake lines. Bleeding the E-H unit also purges out the older brake fluid, which can cause rust and corrosion damage. Only DOT 3 brake fluid is specified for use in an antilock braking system. Always check the label on the brake fluid reservoir and/or service manual or owner's manual.

CAUTION: Some ABS units require that the brake pedal be depressed as many as 40 times to discharge brake fluid fully from the accumulator. Failure to discharge the accumulator fully can show that the brake fluid level is too low. If additional brake fluid is added, the fluid could overflow the reservoir during an ABS stop when the accumulator discharges brake fluid back into the reservoir.

MANUALLY BLEEDING ABS WHEEL BRAKES

During routine brake service, attempt to keep the air from entering the hydraulic system by doing the following:

1. Do not allow the brake system to run dry. Use a brake pedal depressor or plug any open brake line to keep brake fluid from flowing out of the brake master cylinder reservoir.
2. Do not allow the master cylinder to run dry during the bleeding operation. Check the master cylinder reservoir often and keep it filled with fresh brake fluid from a sealed container.
3. Always bench bleed a replacement master cylinder to help prevent against introducing air into the hydraulic system.

After depressing the unit as per manufacturer's recommended procedures, the brakes can be bled using the same procedure as for a vehicle without ABS. Air trapped in the ABS hydraulic unit may require that a scan tool be used to cycle the valves. ● **SEE FIGURES 97–14 AND 97–15.**

The bleeding procedure for vehicles equipped with antilock brakes is often different than vehicles without ABS. Consult the service information for the specified bleeding procedure and sequence.

SCAN TOOL BLEEDING

To bleed the system using a scan tool use the following steps:

STEP 1 Check service information and determine the specified procedure to follow. This usually involves manually bleeding the wheel brakes before using a scan tool.

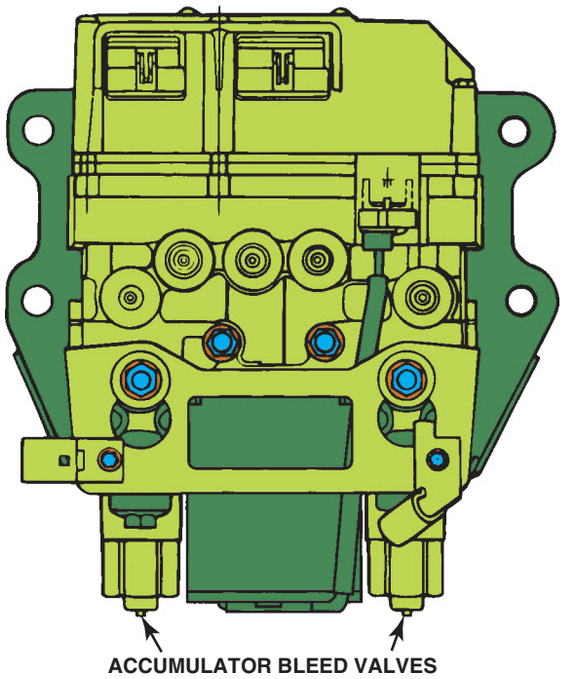


FIGURE 97–15 Two bleed valve tools are needed to bleed the Kelsey-Hayes 4WAL system, which attaches to the bleeder valves on the accumulator.



FIGURE 97–16 To perform an automated brake bleed procedure on an antilock braking system, first connect a factory or enhanced scan tool to the data link connector (DLC) located under the dash on this vehicle.

STEP 2 Use a factory scan tool or one that is capable of performing an automated bleed procedure.

STEP 3 Connect the scan tool to the data link connector (DLC). This connector can be located under the dash or in the center console or even covered by a panel. Check service information for the exact location of the DLC for the vehicle being serviced. ● **SEE FIGURE 97–16.**

STEP 4 Enter vehicle information as shown on the display of the scan tool and locate the antilock brake system (ABS) function area. ● **SEE FIGURE 97–17.**



FIGURE 97–17 Access the menu that includes antilock brake system (ABS) functions.

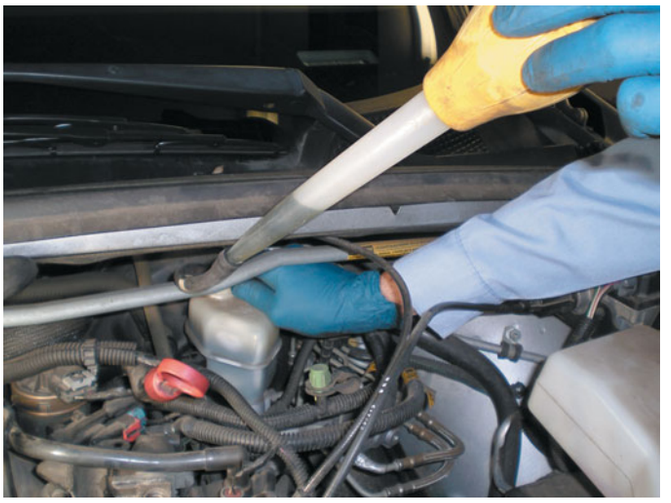


FIGURE 97–19 A turkey baster can be used to remove the old brake fluid from the master cylinder reservoir. A rubber hose was attached to the end of the turkey baster to get access to the brake fluid.

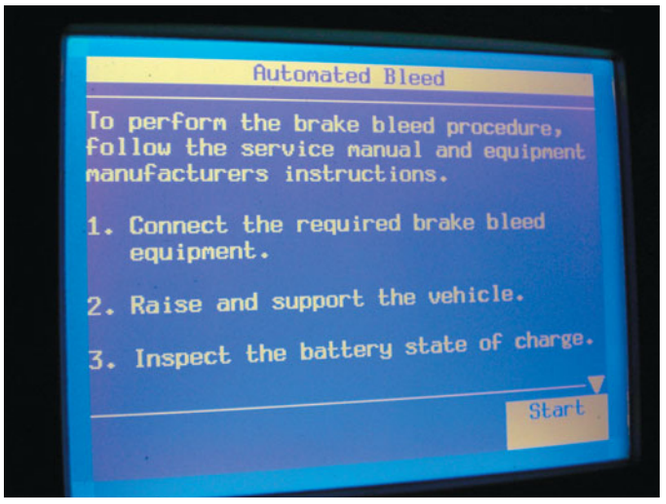


FIGURE 97–18 Scroll through the menus and select automated bleed procedure and follow the on-screen instructions.

STEP 5 Select ABS automated bleed from the ABS menu. The instructions on the scan tool could include several steps including manually bleeding the system, then allowing the scan tool to cycle the hydraulic ABS solenoid valves and then bleeding again. ● **SEE FIGURE 97–18**.

BRAKE FLUID REPLACEMENT/FLUSHING

Brake fluid flushing is a procedure where the old brake fluid is removed and new brake fluid is added to the hydraulic system.

FLUSHING PROCEDURE The brake fluid flushing procedure usually requires the following:

- An assistant to pump the brake pedal
- A bleeder screw wrench
- Approximately 2 feet of clear, plastic hose with an inside diameter small enough to fit snugly over the bleeder screw
- A jar partially filled with clean brake fluid

To flush a brake system, use the following steps:

STEP 1 Using a turkey baster or similar tool, remove the old brake fluid from the master cylinder reservoir. ● **SEE FIGURE 97–19**.

STEP 2 Fill the master cylinder reservoir with new brake fluid from a sealed container.

STEP 3 Slip the plastic hose over the bleeder screw of the wheel cylinder or caliper to be bled and submerge the end of the tube in the jar of brake fluid.

STEP 4 Open the bleeder screw approximately one-half turn.

STEP 5 With the bleeder screw *open,* have your assistant slowly depress the brake pedal.

STEP 6 While your assistant holds the brake pedal down, close the bleeder screw.

STEP 7 Continue to bleed at each wheel until the fluid that emerges from the bleeder screw is free of any discoloration and contamination.

STEP 8 Repeat steps 4 through 7 at each bleeder screw in the recommended order.

STEP 9 Check the brakes for proper operation and re-bleed the system if needed.

TECH TIP

ABS Bleeding Made Easy

To avoid having to bleed the hydraulic unit, use a brake pedal depressor during brake service to avoid losing brake fluid. This simple precaution keeps air from getting into the hard-to-bleed passages of the hydraulic unit.

REVIEW QUESTIONS

1. Describe how to bench bleed a master cylinder.
2. List the steps necessary to manually bleed a brake hydraulic system.
3. Discuss the equipment and the procedures needed to pressure bleed a brake hydraulic system.
4. Explain how to gravity bleed a brake hydraulic system.
5. Describe how to vacuum bleed a brake hydraulic system.

CHAPTER QUIZ

1. The button on the _____ valve should be held when pressure bleeding the brakes.
   a. Metering **c.** Pressure-differential
   b. Proportioning **d.** Residual check
2. The brake bleeding procedure usually specified for a rear-wheel vehicle with a dual split master cylinder is _____.
   a. RR, LR, RF, LF **c.** RF, LR, LF, RR
   b. LF, RF, LR, RR **d.** LR, RR, LF, RF
3. Two technicians are discussing bench bleeding a master cylinder. Technician A says that the front (nose end) of the master cylinder should be bled first. Technician B says that the rear (brake pedal end) should be bled first. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
4. Two technicians are discussing how to loosen bleeder valves. Technician A says that a shock is usually necessary to break the taper at the base of the valve. Technician B says to apply steady, loosening torque to the bleeder valve using a 6-point wrench. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
5. Technician A says that the brake pedal should be depressed with as much force as possible during the normal bleeding procedure. Technician B says that the brake pedal should be pumped rapidly during this manual bleeding procedure to force the air down toward the bleeder valve(s). Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
6. Vacuum is applied where during vacuum bleeding?
   a. At each wheel brake bleeder valve
   c. At the master cylinder reservoir
   c. At the vacuum booster check valve
   d. At the metering valve end of the combination valve
7. The bleeder is opened at a caliper and no brake fluid flows out. Technician A says that this is normal and that brake fluid should not flow or drip out of an open bleeder valve. Technician B says that the vent port in the master cylinder may be blocked. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
8. The usual maximum pressure that should be used when pressure bleeding a brake system is _____.
   a. 20 PSI **c.** 50 PSI
   b. 30 PSI **d.** 70 PSI
9. How does a bleeder valve seal?
   a. O-ring **c.** Lip seal
   b. By the threads **d.** Tapered end
10. Air in the brake hydraulic system can cause all *except* _____.
    a. Spongy brake pedal
    b. Hard brake pedal
    c. Lower than normal brake pedal
    d. May require the driver to "pump up" the brakes before they will stop the vehicle

chapter 98

WHEEL BEARINGS AND SERVICE

OBJECTIVES: After studying Chapter 98, the reader will be able to: • Prepare for Suspension and Steering (A4) ASE certification test content area "C" (Related Suspension and Steering Service). • Discuss the various types, designs, and parts of automotive antifriction wheel bearings. • Describe the symptoms of defective wheel bearings. • Explain wheel bearing inspection procedures and causes of spalling and brinelling. • List the installation and adjustment procedures for front wheel bearings. • Explain how to inspect, service, and replace rear wheel bearings and seals.

KEY TERMS: Antifriction bearings 1071 • Axial load 1071 • Ball bearings 1071 • Brinelling 1084 • Cage 1071 • C-Lock (C-clip) type 1080 • Cone (inner ring) 1071 • Cup (outer ring) 1071 • Dynamic seals 1074 • Garter spring 1074 • GC-LB 1073 • Grease 1072 • Grease seal 1078 • Needle rollers 1071 • NLGI 1073 • Radial load 1071 • Retainer plate (flange) type 1080 • Roller bearings 1071 • Spalling 1082 • Static seal 1074 • Tapered roller bearings 1071

ANTIFRICTION BEARINGS

PURPOSE AND FUNCTION Bearings allow the wheels of a vehicle to rotate and still support the weight of the entire vehicle. **Antifriction bearings** use rolling parts inside the bearing to reduce friction. Four styles of rolling contact bearings include ball, roller, needle, and tapered roller bearings, as shown in ● **FIGURE 98–1.** All four styles convert sliding friction into rolling motion. All of the weight of a vehicle or load on the bearing is transferred through the rolling part. In a ball bearing, the entire load is concentrated into small spots where the ball contacts the *inner and outer race (rings).* ● **SEE FIGURE 98–2.**

BALL BEARINGS **Ball bearings** use hardened steel balls between the inner and outer race to reduce friction. While ball bearings cannot support the same weight as roller bearings, there is less friction in ball bearings and they generally operate at higher speeds. Ball bearings can control thrust movement of an axle shaft because the balls ride in grooves on the inner and outer races. The groove walls resist lateral movement of the wheel on the spindle. The front hub bearings of front wheel drive (FWD) and four wheel drive (4WD) vehicles with front hub assemblies. Many front-wheel-drive vehicles use sealed double-row ball bearings as a complete sealed unit and are nonserviceable except as an assembly. ● **SEE FIGURE 98–3.**

ROLLER BEARINGS **Roller bearings** use rollers between the inner and outer race to reduce friction. A roller bearing having a greater (longer) contact area can support heavier loads than a ball bearing. ● **SEE FIGURE 98–4.**



FIGURE 98–1 Rolling contact bearings include (left to right) ball, roller, needle, and tapered roller.

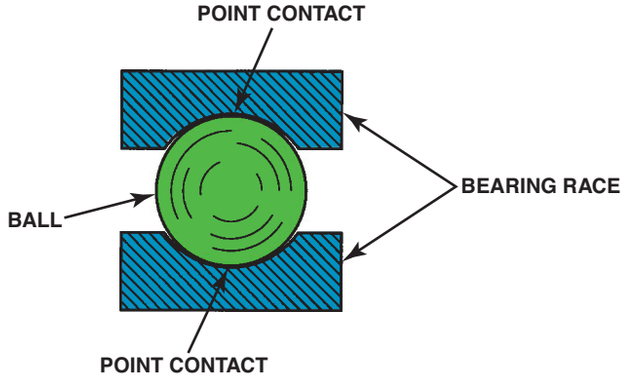


FIGURE 98–2 Ball bearing point contact.

A needle bearing is a type of roller bearing that uses smaller rollers called **needle rollers.** The clearance between the diameter of the straight roller is manufactured into the bearing to provide the proper *radial clearance* and is *not adjustable.*

TAPERED ROLLER BEARINGS The most commonly used automotive wheel bearing is the **tapered roller bearing.** Not only is the bearing itself tapered, but the rollers are also tapered. By design, this type of bearing can withstand **radial loads** (up and down) as well as **axial loads** (thrust) in one direction. ● **SEE FIGURE 98–5.**

Many non-drive-wheel bearings use tapered roller bearings. The taper allows more weight to be handled by the friction-reducing bearings because the weight is directed over the entire length of each roller rather than concentrated on a small spot, as with ball bearings. The rollers are held in place by a **cage** between the inner race (also called the **inner ring** or **cone** assembly) and the outer race (also called the **outer ring** or **cup**). Tapered roller bearings must be loose in the cage to allow for heat expansion. Tapered roller bearings should always be adjusted for a certain amount of free play to allow for heat expansion. On non-drive-axle vehicle wheels, the cup is tightly fitted to the wheel hub and the cone is loosely fitted to the

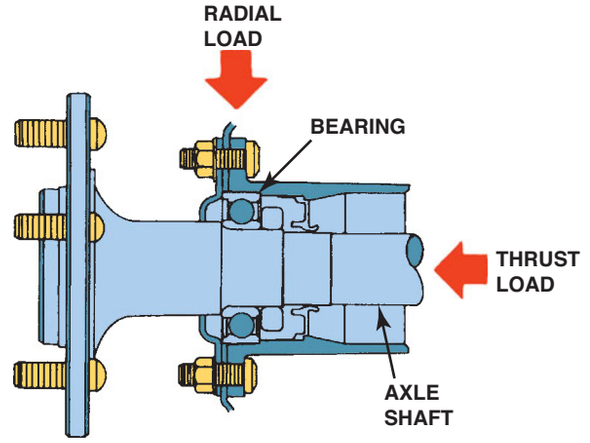


FIGURE 98–3 Radial load is the vehicle weight pressing on the wheels. The thrust load occurs as the chassis components exert a side force during cornering.

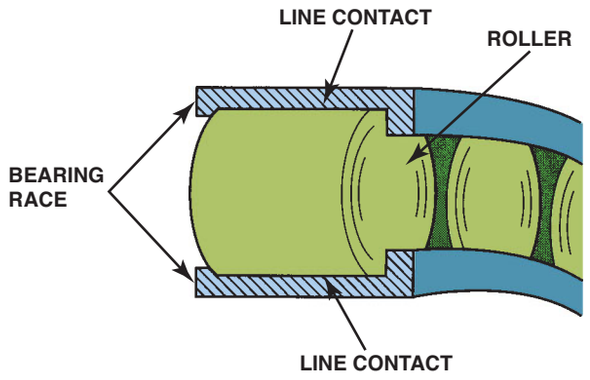


FIGURE 98–4 Roller bearing line contact.

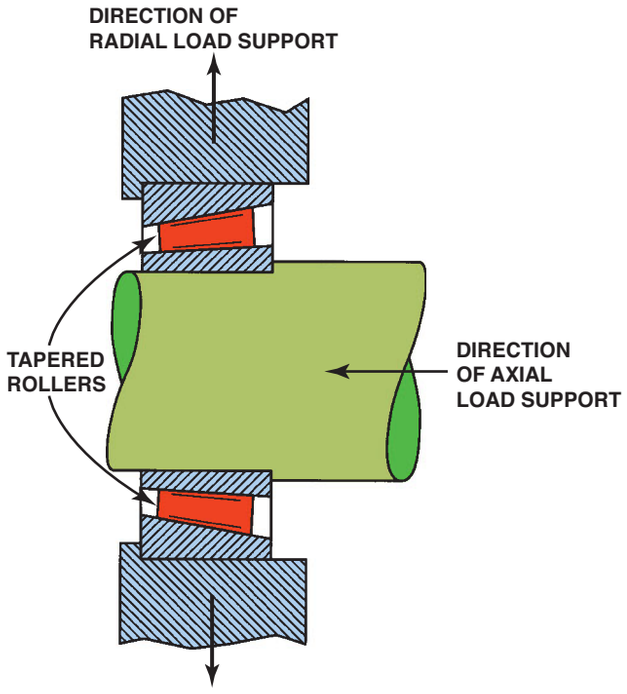


FIGURE 98–5 A tapered roller bearing will support a radial load and an axial load in only one direction.



FIGURE 98–6 Many tapered roller bearings use a plastic cage to retain the rollers.

wheel spindle. New bearings come packaged with the rollers, cage, and inner race assembled together with the outer race wrapped with moisture-resistant paper. ● **SEE FIGURE 98–6.**

INNER AND OUTER WHEEL BEARINGS

Many rear-wheel-drive vehicles use an inner and an outer wheel bearing on the front wheels. The inner wheel bearing is always the larger bearing because it is designed to carry most of the vehicle weight and transmit the weight to the suspension through to the spindle. Between the inner wheel bearing and the spindle, there is a grease seal, which prevents grease from getting onto the braking surface and prevents dirt and moisture from entering the bearing. ● **SEE FIGURE 98–7.**

STANDARD BEARING SIZES

Bearings use standard dimensions for inside diameter, width, and outside diameter. The standardization of bearing sizes helps interchangeability. The dimensions that are standardized include bearing bore size (inside diameter),

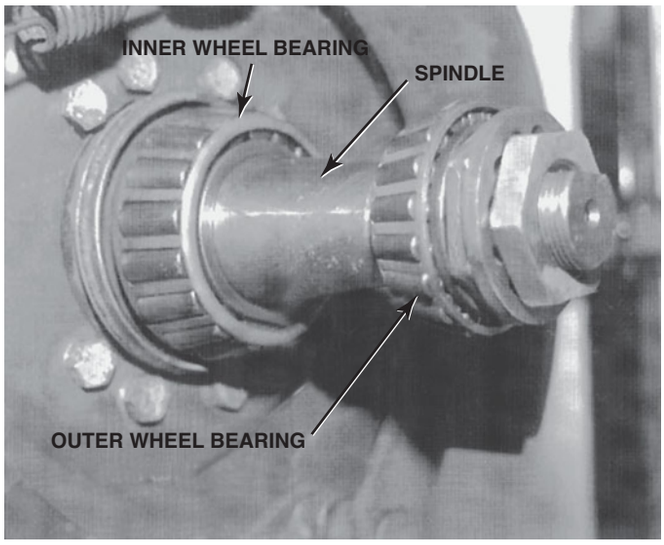


FIGURE 98–7 Non-drive-wheel hub with inner and outer tapered roller bearings. By angling the inner and outer in opposite directions, axial (thrust) loads are supported in both directions.

bearing series (light to heavy usage), and external dimensions. When replacing a wheel bearing, note the original bearing brand name and number. Replacement bearing catalogs usually have cross-over charts from one brand to another. The bearing number is usually the same because of the interchangeability and standardization within the wheel bearing industry.

SEALED FRONT-WHEEL-DRIVE BEARINGS

Most front-wheel-drive (FWD) vehicles use a sealed nonadjustable front wheel bearing. This type of bearing can include either two preloaded tapered roller bearings or a double-row ball bearing. This type of sealed bearing is also used on the rear of many front-wheel-drive vehicles and are usually called *hub assemblies*.

Double-row ball bearings are often used because of their reduced friction and greater seize resistance. ● **SEE FIGURES 98–8 AND 98–9.**

BEARING GREASES

DEFINITION OF GREASE

Vehicle manufacturers specify the type and consistency of grease for each application. The technician should know what these specifications mean. **Grease** is oil with a thickening agent to allow it to be installed in places where a liquid lubricant would not stay. Greases are named for their thickening agent, such as aluminum, barium, calcium, lithium, or sodium.

GREASE ADDITIVES

Commonly used additives in grease include the following:

- Antioxidants
- Antiwear agents
- Rust inhibitors
- Extreme pressure (EP) additives such as sulfurized fatty oil or chlorine

Grease also contains a dye to not only provide product identification but also to give the grease a consistent color.

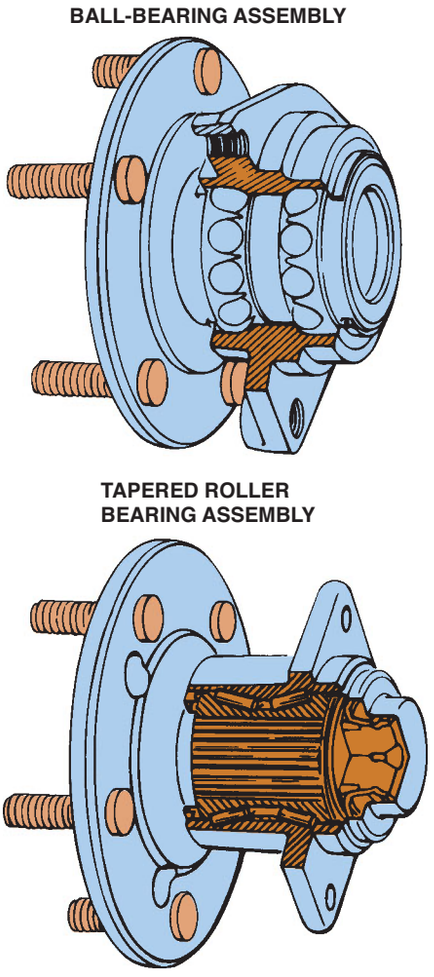


FIGURE 98–8 Sealed bearing and hub assemblies are used on the front and rear wheels of many vehicles.

The grease contains a solid such as graphite or molybdenum disulfide (moly), which acts as an antiseize additive.

NLGI CLASSIFICATION The **National Lubricating Grease Institute (NLGI)** uses the penetration test as a guide to assign the grease a number. Low numbers are very fluid and higher numbers are more firm or hard. Number 2 grease is the most commonly used. See the chart.

NATIONAL LUBRICATING GREASE INSTITUTE (NLGI) NUMBERS

NLGI NUMBER	RELATIVE CONSISTENCY
000	Very fluid
00	Fluid
0	Semi-fluid
1	Very soft
2	Soft (typically used for wheel bearings)
3	Semi-firm
4	Firm
5	Very firm
6	Hard

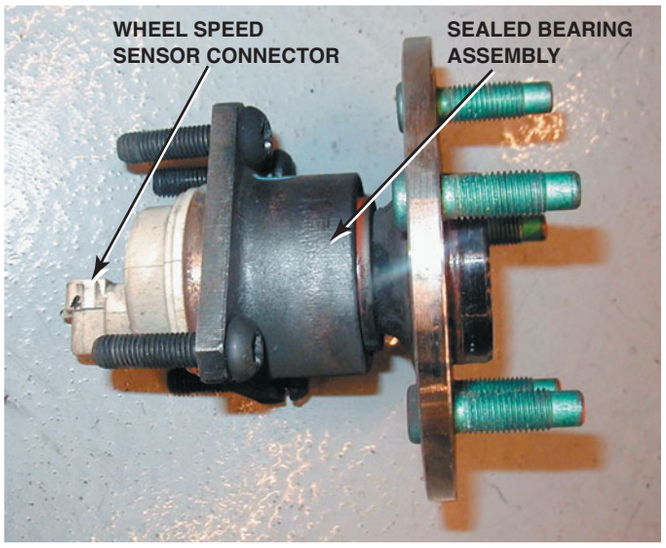


FIGURE 98–9 Sealed bearing and hub assemblies are serviced as a complete unit as shown. This assembly includes the wheel speed sensor.

FREQUENTLY ASKED QUESTION

What Do Different Grease Colors Mean?

Nothing. According to grease manufacturers, grease is colored for identification, marketing, and for consistency of color reasons.

- **Identification.** The color is often used to distinguish one type of grease from another within the same company. The blue grease from one company may be totally different from the blue grease produced or marketed by another company.
- **Marketing.** According to grease manufacturers, customers tend to be attracted to a particular color of grease and associate that color with quality.
- **Consistency of color.** All greases are produced in batches, and the color of the finished product often varies in color from one batch to another. By adding color to the grease, the color can be made consistent.

Always use the grease recommended for the service being performed.

Grease is also classified according to quality. Wheel bearing classifications include the following:

- GA—mild duty
- GB—moderate duty
- GC—severe duty, high temperature (frequent stop-and-go service)

GC indicates the highest quality. Chassis grease, such as is used to lubricate steering and suspension components, includes the following classifications:

- LA—mild duty (frequent relubrication)
- LB—high loads (infrequent relubrication)

LB indicates the highest quality. Most multipurpose greases are labeled with both wheel bearing and chassis grease classifications such as **GC-LB.**



FIGURE 98–10 Typical lip seal with a garter spring.

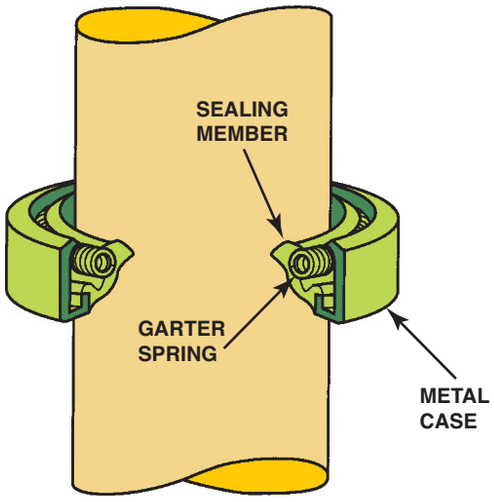


FIGURE 98–11 A garter spring helps hold the sharp lip edge of the seal tight against the shaft.

SAFETY TIP

Smoking Can Kill You

Some greases contain polymers such as Teflon® that turn to a deadly gas when burned. Always wash your hands thoroughly after handling grease that contains these ingredients before smoking. If some of the grease is on the cigarette paper and is burned, these polymers turn into nitrofluoric acid—a deadly toxin.

More rolling bearings are destroyed by overlubrication than by underlubrication because the heat generated in the bearings cannot be transferred easily to the air through the excessive grease. Bearings should never be filled beyond one-third to one-half of their grease capacity by volume.

SEALS

PURPOSE AND FUNCTION

Seals are used in all vehicles to keep lubricant, such as grease, from leaking out and to prevent dirt, dust, or water from getting into the bearing or lubricant.

TYPES OF SEALS

Two general applications of seals are static and dynamic.

- **Static seals** are used between two surfaces that do not move.
- **Dynamic seals** are used to seal between two surfaces where one or both is moving.

Wheel bearing seals are dynamic-type seals that must seal between rotating axle hubs and the stationary spindles or axle housing. Most dynamic seals use a synthetic rubber lip seal encased in metal. The lip is often held in contact with the moving part with the aid of a **garter spring,** as seen in ● **FIGURE 98–10.** The sealing lip should be installed toward the grease or fluid being contained. ● **SEE FIGURE 98–11.**

BEARING DIAGNOSIS

SYMPTOMS OF A DEFECTIVE BEARING

Wheel bearings control the positioning and reduce the rolling resistance of vehicle wheels. Whenever a bearing fails, the wheel may not be kept in position and noise is usually heard. Symptoms of defective wheel bearings include the following:

1. A hum, rumbling, or growling noise that increases with vehicle speed
2. Roughness felt in the steering wheel that changes with the vehicle speed or cornering
3. Looseness or excessive play in the steering wheel especially while driving over rough road surfaces
4. A loud grinding noise in severe cases, indicating a defective front wheel bearing
5. Pulling during braking

DETERMINING BEARING NOISE FROM TIRE NOISE

A defective wheel bearing is often difficult to diagnose because the noise is similar to a noisy winter tire or a severely cupped tire. Customers often request that tires be replaced as a result of the noise when the real problem is a bad wheel bearing. To help determine if the noise is caused by a wheel bearing or a tire, try these tests:

TEST 1 Drive the vehicle over a variety of road surfaces. If the noise changes with a change in road surface, then the noise is caused by a tire(s). If the noise remains the same, then the cause is a defective wheel bearing.

TEST 2 Try temporarily overinflating the tires. If the noise changes, then the tires are the cause. If the noise is the same, then defective wheel bearings are the cause.

TEST 3 A defective wheel bearing will change in noise level when turning. For example a defective left front wheel bearing will usually make more noise when the vehicle is turning toward the right which places more of the vehicle weight onto the left front wheel bearing.

TESTING A WHEEL BEARING

With the vehicle off the ground, rotate the wheel by hand, listening and feeling carefully for bearing roughness. Grasp the wheel at the top and bottom and wiggle it back and forth, checking for bearing looseness.



FIGURE 98–12 Removing the grease cap with grease cap pliers.



FIGURE 98–13 Using a seal puller to remove the grease seal.



FIGURE 98–14 Cleaning a wheel bearing with a parts brush and solvent.

TECH TIP

Easy Wheel Bearing Looseness Test

Looseness in a front wheel bearing can allow the rotor to move whenever the front wheel hits a bump, forcing the caliper piston in, which causes the brake pedal to kick back and creates the feeling that the brakes are locking up. Loose wheel bearings are easily diagnosed by removing the cover of the master cylinder reservoir and watching the brake fluid as the front wheels are turned left and right with the steering wheel. If the brake fluid moves while the front wheels are being turned, caliper piston(s) are moving in and out, caused by loose wheel bearing(s). If everything is OK, the brake fluid should not move. Loose wheel bearings can also cause the brake pedal to sink due to movement of the rotor, causing the caliper piston to move. This sinking brake pedal is usually caused by a defective master cylinder. Before replacing a master cylinder, check the wheel bearings.

WHEEL BEARING SERVICE

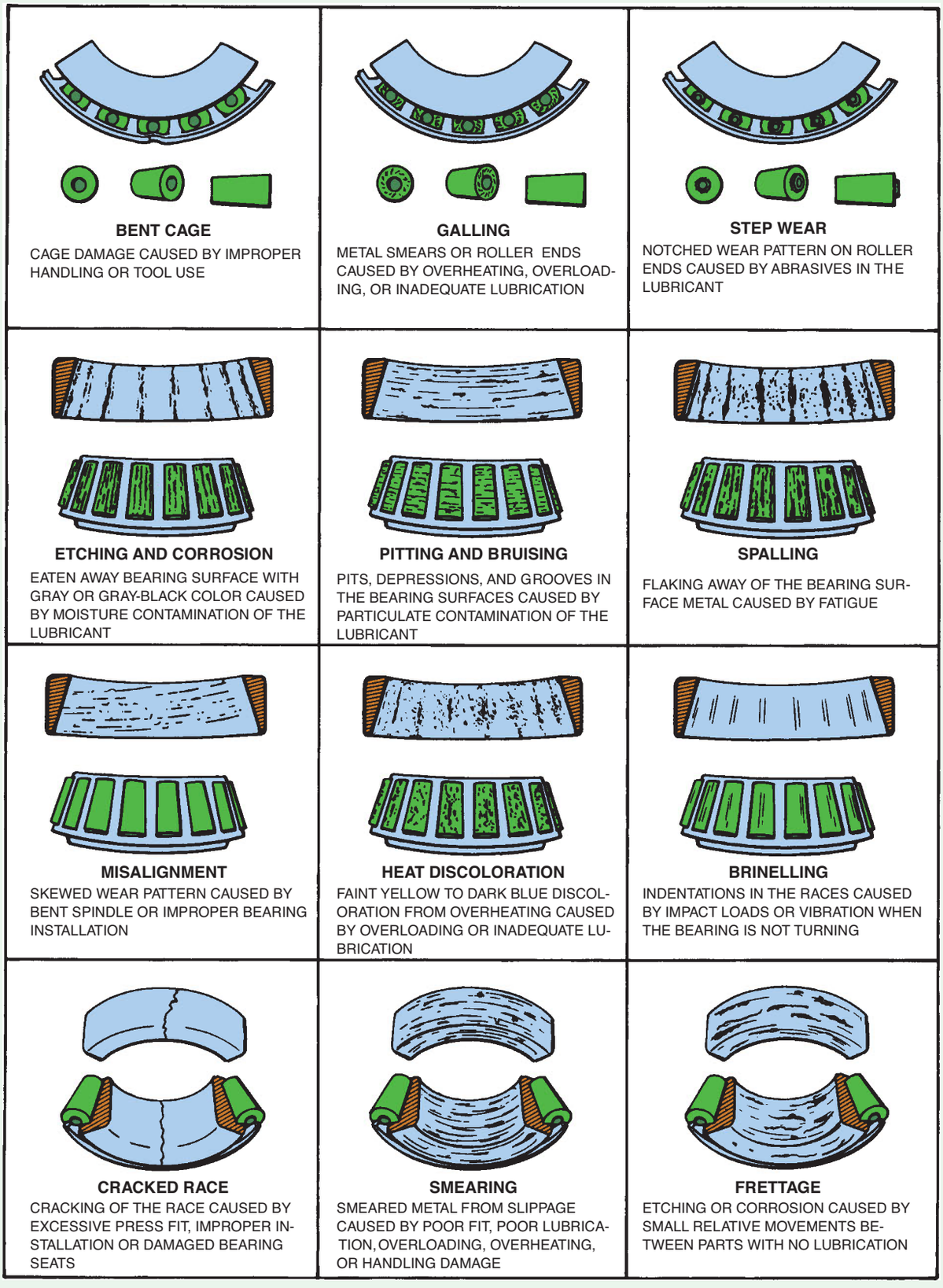
The steps in a non-drive-wheel bearing inspection include the following:

1. Hoist the vehicle safely.
2. Remove the wheel.
3. Remove the brake caliper assembly and support it with a coat hanger or other suitable hook to avoid allowing the caliper to hang by the brake hose.
4. Remove the grease cap (dust cap). ● **SEE FIGURE 98–12.**
5. Remove the old cotter key and discard.

NOTE: The term *cotter,* as in cotter key or cotter pin, is derived from the Old English verb meaning "to close or fasten."

6. Remove the spindle nut (castle nut).
7. Remove the washer and the outer wheel bearing. ● **SEE FIGURE 98–13.** Remove the bearing hub from the spindle. The inner bearing will remain in the hub and may be removed (simply lifted out) after the grease seal is pried out.
8. Most vehicle and bearing manufacturers recommend cleaning the bearing thoroughly in solvent or acetone. ● **SEE FIGURE 98–14.** If there is no acetone, clean the solvent off the bearings with denatured alcohol or brake cleaner to make certain that the thin solvent layer is completely washed off and dry. *All solvent must be removed or allowed to dry from the bearing because the new grease will not stick to a layer of solvent.*
9. Carefully inspect the bearings and the races for the following:
   a. The outer race for lines, scratches, or pits.
   b. The cage should be round. If the round cage has straight sections, this is an indication of an overtightened adjustment or a dropped cage. ● **SEE CHART 98–1.**

If either of the above is observed, then the bearing, including the outer race, must be replaced. Failure to replace the outer race (which is included when purchasing a bearing) could lead to rapid failure of the new bearing. ● **SEE FIGURES 98–15 AND 98–16.** Pack the cleaned or new bearing thoroughly with



BENT CAGE

CAGE DAMAGE CAUSED BY IMPROPER HANDLING OR TOOL USE

GALLING

METAL SMEARS OR ROLLER ENDS CAUSED BY OVERHEATING, OVERLOADING, OR INADEQUATE LUBRICATION

STEP WEAR

NOTCHED WEAR PATTERN ON ROLLER ENDS CAUSED BY ABRASIVES IN THE LUBRICANT

ETCHING AND CORROSION

EATEN AWAY BEARING SURFACE WITH GRAY OR GRAY-BLACK COLOR CAUSED BY MOISTURE CONTAMINATION OF THE LUBRICANT

PITTING AND BRUISING

PITS, DEPRESSIONS, AND GROOVES IN THE BEARING SURFACES CAUSED BY PARTICULATE CONTAMINATION OF THE LUBRICANT

SPALLING

FLAKING AWAY OF THE BEARING SURFACE METAL CAUSED BY FATIGUE

MISALIGNMENT

SKEWED WEAR PATTERN CAUSED BY BENT SPINDLE OR IMPROPER BEARING INSTALLATION

HEAT DISCOLORATION

FAINT YELLOW TO DARK BLUE DISCOLORATION FROM OVERHEATING CAUSED BY OVERLOADING OR INADEQUATE LUBRICATION

BRINELLING

INDENTATIONS IN THE RACES CAUSED BY IMPACT LOADS OR VIBRATION WHEN THE BEARING IS NOT TURNING

CRACKED RACE

CRACKING OF THE RACE CAUSED BY EXCESSIVE PRESS FIT, IMPROPER INSTALLATION OR DAMAGED BEARING SEATS

SMEARING

SMEARED METAL FROM SLIPPAGE CAUSED BY POOR FIT, POOR LUBRICATION, OVERLOADING, OVERHEATING, OR HANDLING DAMAGE

FRETTAGE

ETCHING OR CORROSION CAUSED BY SMALL RELATIVE MOVEMENTS BETWEEN PARTS WITH NO LUBRICATION

CHART 98–1

Wheel bearing inspection chart. Replace the bearing if it has any of the faults shown.

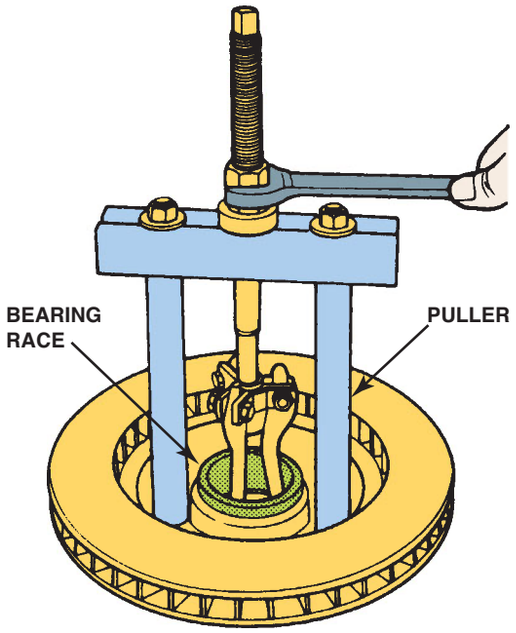


FIGURE 98–15 A wheel bearing race puller.

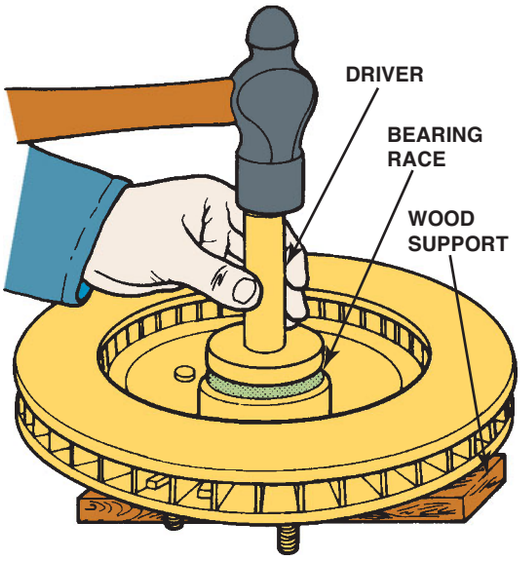


FIGURE 98–16 Installing a bearing race with a driver.

clean, new, approved wheel bearing grease. Always clean out all of the old grease before applying the recommended type of new grease. *Because of compatibility problems, it is not recommended that greases be mixed.* There are several different ways to pack wheel bearings including:

- **By hand.** Place some grease in the palm of the hand and then force the grease through the bearing until grease can be seen out the other side. ● **SEE FIGURE 98–17.**
- **By hand-operated bearing packer.** A hand-operated bearing packer is faster to use and produces excellent results. ● **SEE FIGURE 98–18.**
- **Grease gun-type bearing packer.** This type of bearing packer uses a grease gun to fill the bearing with grease. The grease gun can be hand-operated or powered by electric or air. ● **SEE FIGURE 98–19.**

10. Place a thin layer of grease on the outer race.

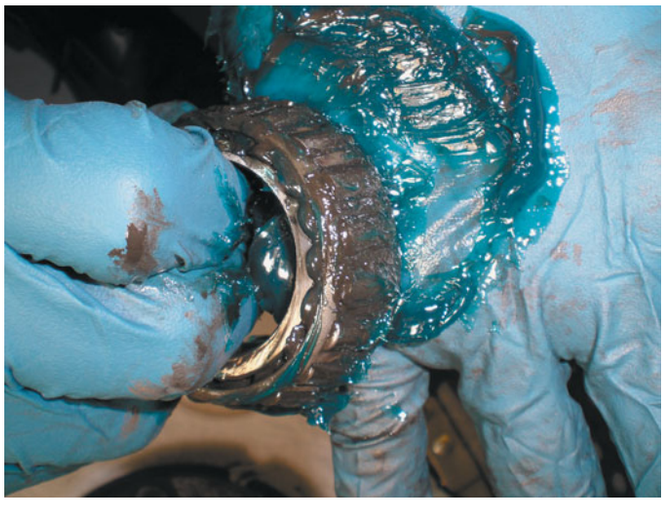


FIGURE 98–17 Notice the new blue grease has been forced through the bearing.



FIGURE 98–18 A commonly used hand-operated bearing packer.



FIGURE 98–19 The wheel bearing is placed between two nylon cones and then a grease gun is used to inject grease into the center of the bearing.

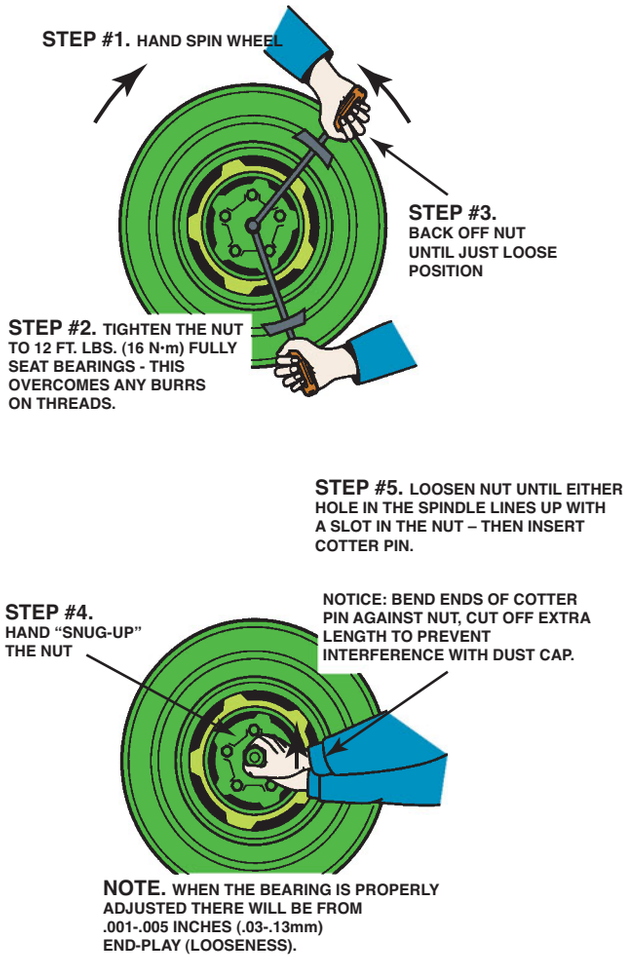


FIGURE 98–20 The wheel bearing adjustment procedure as specified for rear-wheel-drive vehicles. Always check service information for the exact specified procedure for the vehicle being serviced.

11. Apply a thin layer of grease to the spindle, being sure to cover the outer bearing seat, inner bearing seat, and shoulder at the grease seal seat.
12. Install a new **grease seal** (also called a *grease retainer*) flush with the hub using a seal driver.
13. Place approximately 3 tablespoons of grease into the grease cavity of the wheel hub. Excessive grease could cause the inner grease seal to fail, with the possibility of grease getting on the brakes. Place the rotor with the inner bearing and seal in place over the spindle until the grease seal rests on the grease seal shoulder.
14. Install the outer bearing and the bearing washer.
15. Install the spindle nut and, while rotating the tire assembly, tighten to about 12 to 30 lb-ft with a wrench to "seat" the bearing correctly in the race (cup) and on the spindle. ● **SEE FIGURE 98–20.**
16. While still rotating the tire assembly, loosen the nut approximately one-half turn and then *hand tighten only* (about 5 lb-in.).

    NOTE: If the wheel bearing is properly adjusted, the wheel will still have about 0.001 to 0.005 in. (0.03 to 0.13 mm) end play. This looseness is necessary to allow the tapered roller bearing to expand when hot and not bind or cause the wheel to lock up.

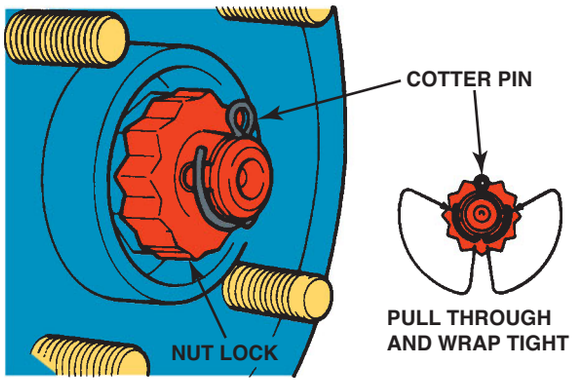


FIGURE 98–21 A properly secured wheel bearing adjustment nut.

17. Install a new cotter key. (An old cotter key could break a part off where it was bent and lodge in the bearing, causing major damage.)

    NOTE: Most vehicles use a cotter key that is 1/8 in. in diameter by 1 1/2 in. long.
18. If the cotter key does not line up with the hole in the spindle, loosen slightly (no more than 1/16 in. of a turn) until the hole lines up. Never tighten more than hand tight.
19. Bend the cotter key ends up and around the nut, not over the end of the spindle where the end of the cotter key could rub on the grease cap, causing noise. ● **SEE FIGURE 98–21.**
20. Install the grease cap (dust cap) with a rubber mallet or soft-faced hammer to help prevent denting or distorting the grease cap. Install the wheel cover or hub cap.
21. Clean grease off the disc brake rotors or drums after servicing the wheel bearings. Use a brake cleaner and a shop cloth. Even a slight amount of grease on the friction surfaces of the brakes can harm the friction lining and/or cause brake noise.

SEALED BEARING REPLACEMENT

Diagnosing a defective front bearing on a front-wheel-drive vehicle is sometimes confusing. A defective wheel bearing is usually noisy while driving straight, and the noise increases with vehicle speed (wheel speed). A drive axle shaft U-joint (CV joint) can also be the cause of noise on a front-wheel-drive vehicle, but usually makes *more noise* while turning and accelerating. Most front-wheel-drive vehicles use a sealed bearing assembly that is bolted to the steering knuckle and supports the drive axle or the rear, as shown in ● **FIGURE 98–22.**

Many front-wheel-drive vehicles use a bearing that must be pressed off the steering knuckle. Special aftermarket tools are also available to remove many of the bearings without removing the knuckle from the vehicle. Check the service information for the exact procedures to follow for the vehicle being serviced. ● **SEE FIGURES 98–23 AND 98–24.**

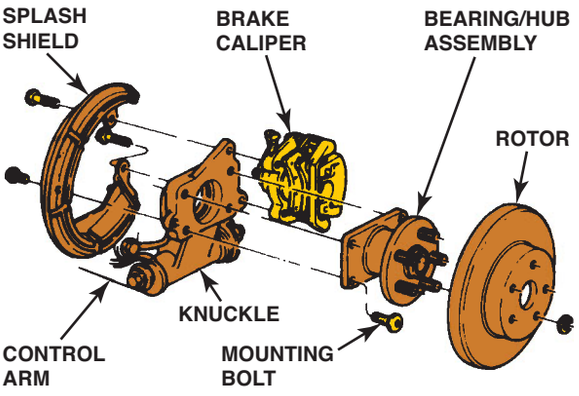


FIGURE 98–22 A rear wheel sealed bearing hub assembly.

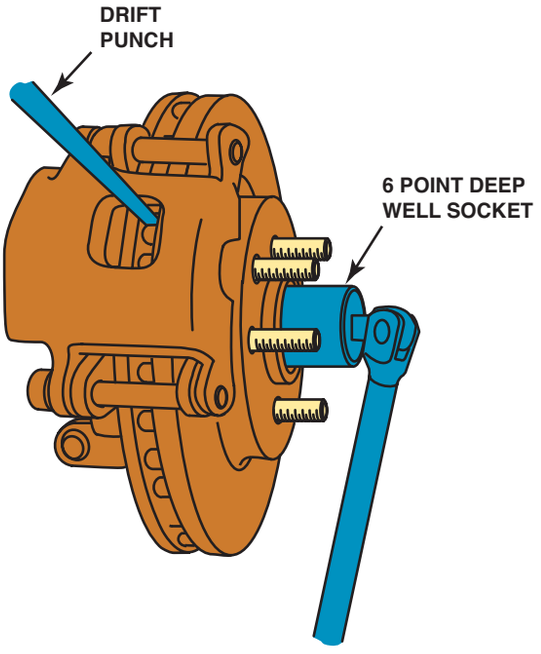


FIGURE 98–23 Removing the drive axle shaft hub nut. This nut is usually very tight and the drift (tapered) punch wedged into the cooling fins of the brake rotor keeps the hub from revolving when the nut is loosened. Never use an impact to remove or install a drive axle shaft hub nut because the hammering action can damage the bearing.

REAR DRIVE AXLE CLASSIFICATIONS

There are three rear drive axle classifications:

- Full-floating
- Three-quarter-floating
- Semi-floating

These classifications indicate whether the axle shafts or the axle housing supports the wheel. The category of a rear drive axle is determined by how the wheel and wheel bearing mount to the axle or housing.

FULL-FLOATING AXLE On a full-floating axle, the bearings are mounted and retained in the hub of the brake drum or rotor. The hub and bearing mount onto the axle housing, and are held in place by a bearing retainer or adjustment nuts and safety locks. The flanged end of the drive axle is attached to the hub by bolts or nuts. The inner end of the axle splines into the differential side gears.

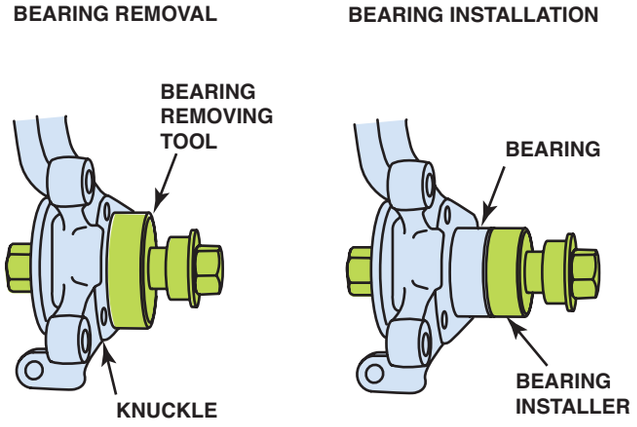


FIGURE 98–24 A special puller makes the job of removing the hub bearing from the knuckle easy without damaging any component.

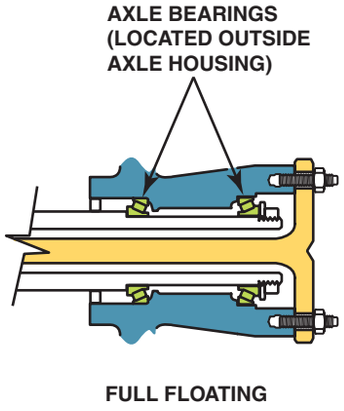


FIGURE 98–25 A typical full-floating rear axle assembly.

The wheel mounts onto the hub, and lug bolts or nuts retain it. In this design, the axle shafts "float" in the axle housing and drive the wheels without supporting their weight. Because the axle shafts do not retain the wheel, the axle shafts can usually be removed from the vehicle while it is standing on the wheels. Many three-quarter-ton pickups, all heavy-duty truck tractors, and trailers use full-floating axles. ● **SEE FIGURE 98–25.**

THREE-QUARTER-FLOATING AXLE The bearings in a three-quarter-floating axle are mounted and retained in the brake drum or rotor hub, which mounts onto the axle housing. The outer extension of the hub fits onto the end of the axle, which is usually splined and tapered, and a nut and cotter pin secure the hub to the axle. The axle shaft splines to the side gears inside the differential. The wheels are mounted on the hub and retained by lug bolts or nuts. As in the full-floating axle, the axle housing and bearings in the hub support the weight in a three-quarter-floating axle. Because of the construction of a three-quarter-floating axle, the wheel must be removed before removing the axle shaft from the vehicle.

SEMI-FLOATING AXLE The wheel bearings in a semi-floating axle either press onto the axle shaft or are installed in the outer end of the axle housing. A retainer plate at the outer end of the axle shaft or a C-clip inside the differential at the other end keeps the axle shaft in the housing. The brake drum or rotor fits onto the end of the axle, and lug bolts or nuts fasten the wheel to the drum or rotor and to the axle. These axles are called "semi-floating" because only the inboard ends of the axle shaft "float" in the housing. The outboard end of the shaft retains the wheel and transmits the weight of the wheel to the housing. Most solid-axle rear-wheel-drive cars and light trucks use a semi-floating type of axle. ● **SEE FIGURE 98–26.**

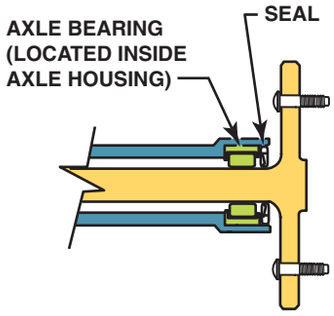


FIGURE 98–26 A semi-floating rear axle housing is the most commonly used in light rear-wheel-drive vehicles.

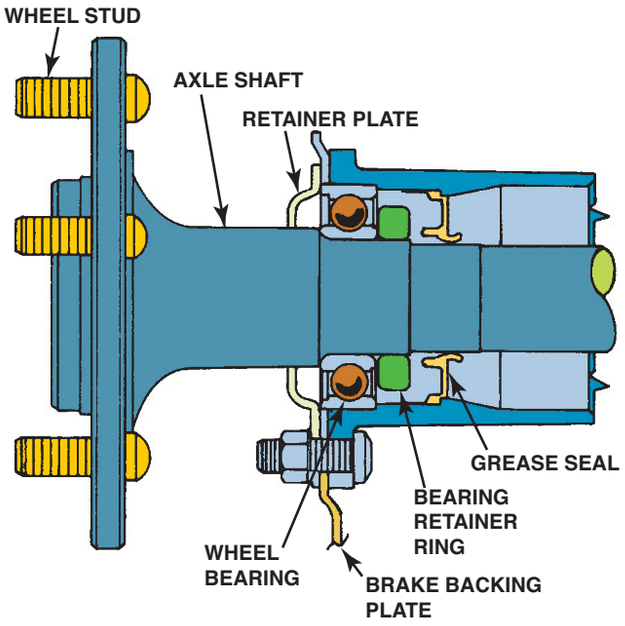


FIGURE 98–27 A retainer plate-type rear axle bearing. Access to the fasteners is through a hole in the axle flange.

REAR AXLE BEARING AND SEAL REPLACEMENT

The rear bearings used on rear-wheel-drive vehicles are constructed and serviced differently from other types of wheel bearings. Rear axle bearings are either sealed or lubricated by the rear-end lubricant. The rear axle must be removed from the vehicle to replace the rear axle bearing. There are two basic types of axle retaining methods:

- **Retainer plate (flange) type**
- **C-Lock (C-clip) type**

RETAINER PLATE-TYPE REAR AXLES

The retainer plate-type rear axle uses four fasteners that retain the axle in the axle housing. To remove the axle shaft and the rear axle bearing and seal, the retainer bolts or nuts must be removed.

The hole or holes in the wheel flange permit a socket wrench access to the fasteners. After the fasteners have been removed, the axle shaft must be removed from the rear axle housing. With the retainer plate-type rear axle, the bearing and the retaining ring are press fit onto the axle and the bearing cup (outer race) is also tightly fitted into the axle housing tube. The retaining ring should be removed by using a cold chisel to notch the ring in several places so it can be removed before pressing off the bearing. ● **SEE FIGURE 98–27.** ● **SEE FIGURE 98–28** for one way to remove the axle shaft using a rear axle puller.

C-LOCK-TYPE AXLES

Vehicles that use C-locks (clips) use a straight roller bearing supporting a semi-floating axle shaft inside the axle housing. The straight rollers do not have an inner race. The rollers ride on the axle itself. If a bearing fails, both the axle and the bearing usually need to be replaced. The outer bearing race holding the rollers is pressed into the rear axle housing. The axle bearing is usually lubricated by the rear-end lubricant and a grease seal is located on the outside of the bearing.

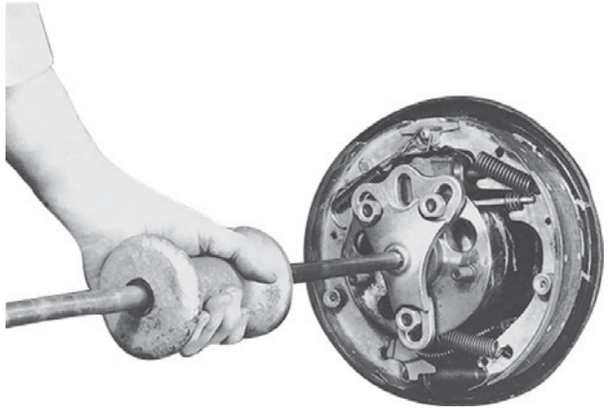


FIGURE 98–28 A slide hammer-type axle puller can also be used.

TECH TIP

The Brake Drum Slide Hammer Trick

To remove the axle from a vehicle equipped with a retainer plate-type rear axle, simply use the brake drum as a slide hammer to remove the axle from the axle housing. ● **SEE FIGURE 98–29.** If the brake drum does not provide enough force, a slide hammer can also be used to remove the axle shaft.

NOTE: Some replacement bearings are available that are designed to ride on a fresh, unworn section of the old axle. These bearings allow the use of the original axle, saving the cost of a replacement axle.

The C-lock-type rear axle retaining method requires that the differential cover plate be removed. After removal of the cover, the

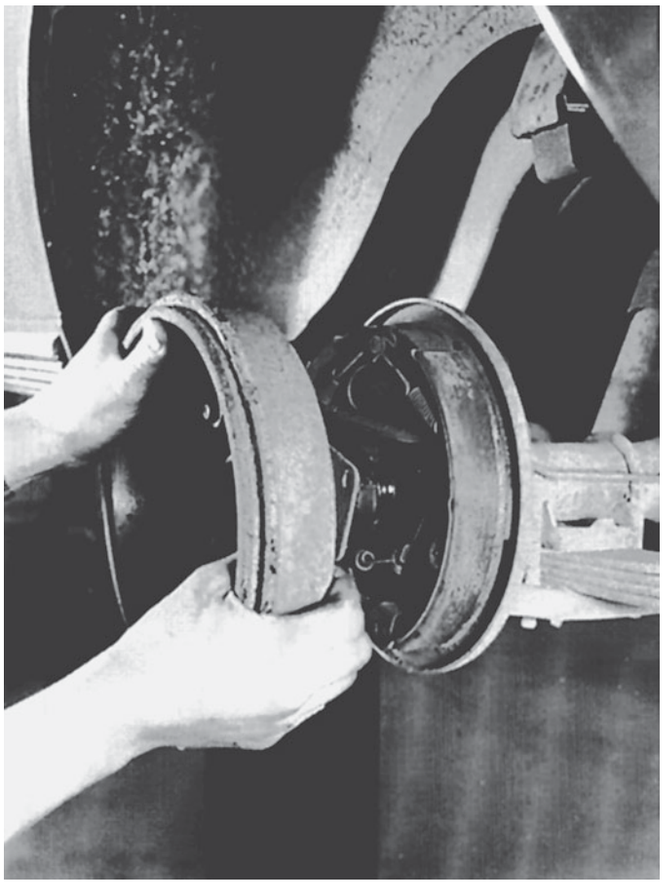


FIGURE 98–29 To remove the axle from this vehicle equipped with a retainer-plate rear axle, the brake drum was placed back onto the axle studs backward so that the drum itself can be used as a slide hammer to pull the axle out of the axle housing. A couple of pulls and the rear axle is pulled out of the axle housing.

differential pinion shaft has to be removed before the C-lock that retains the axle can be removed. ● **SEE FIGURES 98–30 AND 98–31.**

NOTE: When removing the differential cover, rear axle lubricant will flow from between the housing and the cover. Be sure to dispose of the old rear axle lubricant in the environmentally approved way, and refill with the proper type and viscosity (thickness) of rear-end lubricant. Check the vehicle specifications for the recommended grade.

Once the C-lock has been removed, the axle simply is pulled out of the axle tube. Axle bearings with inner races are pressed onto the axle shaft and must be pressed off using a hydraulic press. A bearing retaining collar should be chiseled or drilled into to expand the collar, allowing it to be removed. ● **SEE FIGURE 98–32.**

Always follow the manufacturer's recommended bearing removal and replacement procedures. Always replace the rear axle seal whenever replacing a rear axle bearing. ● **SEE FIGURE 98–33** for an example of seal removal.

DIFFERENTIAL VENTS

All differential use a vent to allow for pressure to equalize inside the differential due to heating and cooling of the part and the rear axle fluid.

Always check the differential vent to make sure it is clear. A clogged vent can cause excessive pressure to build up inside the differential and cause the rear axle seals to leak. If rear-end lubricant gets on the brake linings, the brakes will not have the proper friction and the linings themselves are ruined and must be replaced.

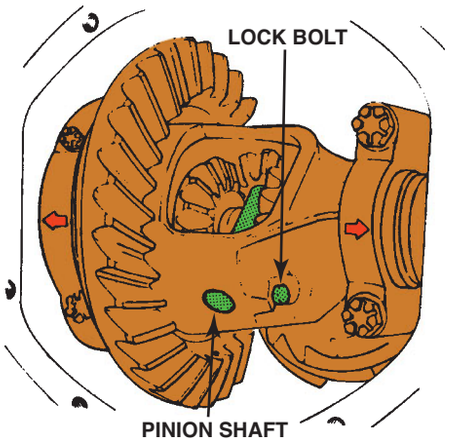


FIGURE 98–30 To remove the C-lock (clip), the lock bolt has to be moved before the pinion shaft.

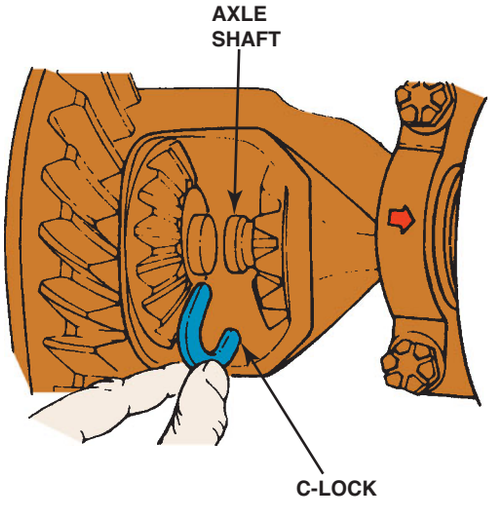


FIGURE 98–31 The axle must be pushed inward slightly to allow the C-lock to be removed. After the C-lock has been removed, the axle can be easily pulled out of the axle housing.

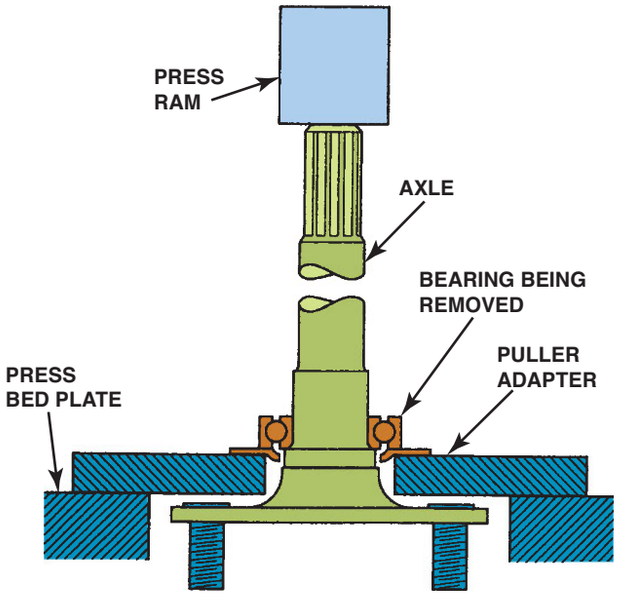


FIGURE 98–32 Using a hydraulic press to press an axle bearing from the axle. When pressing a new bearing back onto the axle, pressure should only be on the inner bearing race to prevent damaging the bearing.

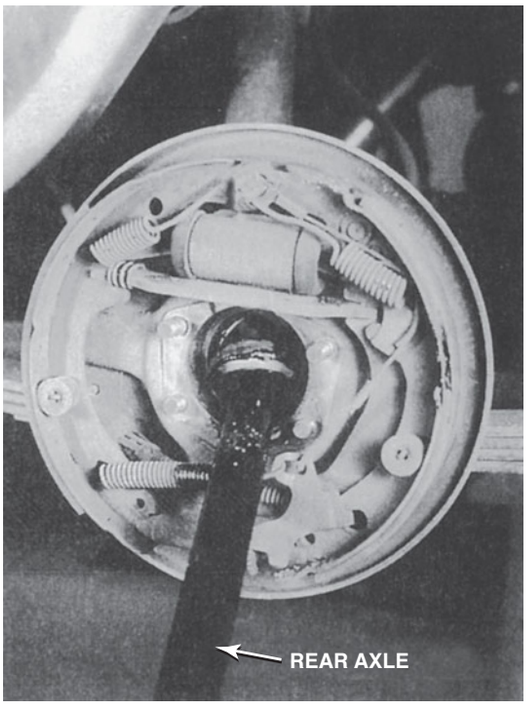


FIGURE 98–33 Removing an axle seal using the axle shaft as the tool.

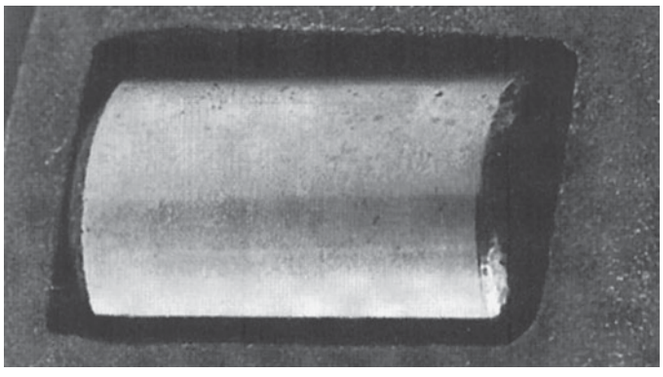


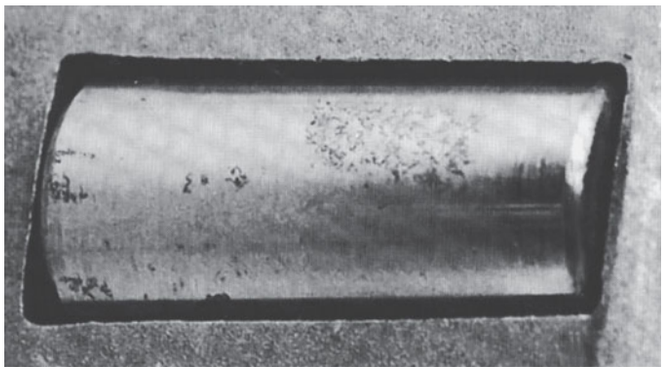
FIGURE 98–34 This is a normally worn bearing. If it does not have too much play, it can be reused. (*Courtesy SKF USA Inc.*)

BEARING FAILURE ANALYSIS

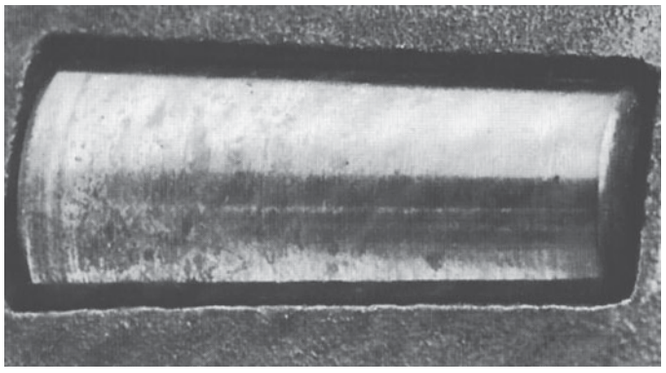
Whenever a bearing is replaced, the old bearing must be inspected and the cause of the failure eliminated. ● **SEE FIGURES 98–34 THROUGH 98–40** for examples of normal and abnormal bearing wear.

A wheel bearing may also fail for reasons that include the following.

METAL FATIGUE Long vehicle usage, even under normal driving conditions, causes metal to fatigue. Cracks often appear, and eventually these cracks expand downward into the metal from the surface. The metal between the cracks can break out into small chips, slabs, or scales of metal. This process of breaking up is called **spalling.** ● **SEE FIGURE 98–41.**

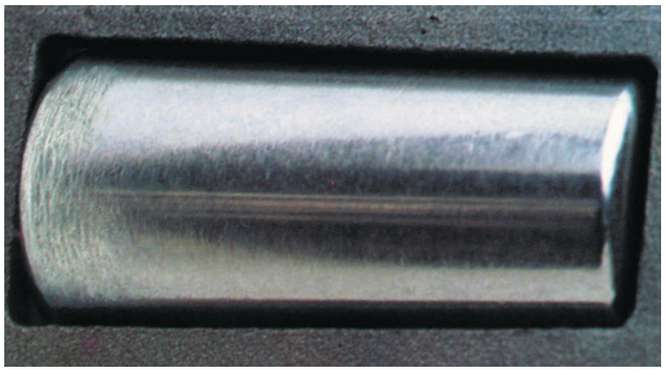


(a)

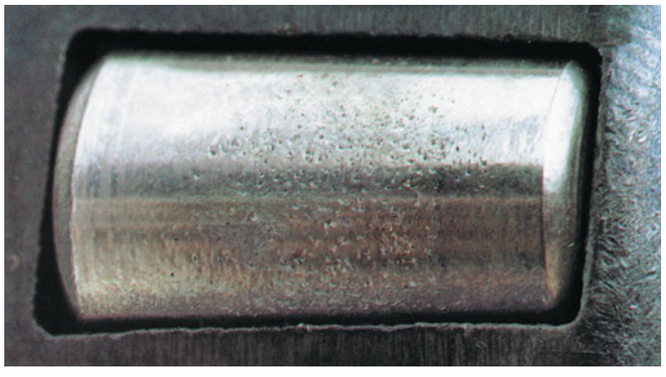


(b)

FIGURE 98–35 (a) When corrosion etches into the surface of a roller or race, the bearing should be discarded. (b) If light corrosion stains can be removed with an oil-soaked cloth, the bearing can be reused. (*Courtesy SKF USA Inc.*)



(a)

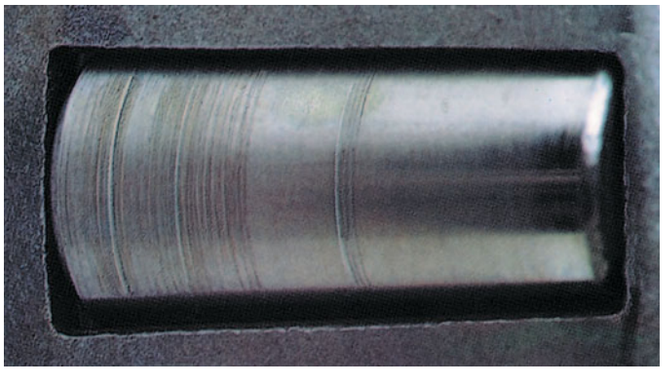


(b)

FIGURE 98–36 (a) When just the end of a roller is scored, it is because of excessive preload. Discard the bearing. (b) This is a more advanced case of pitting. Under load, it will rapidly lead to spalling. (*Courtesy SKF USA Inc.*)

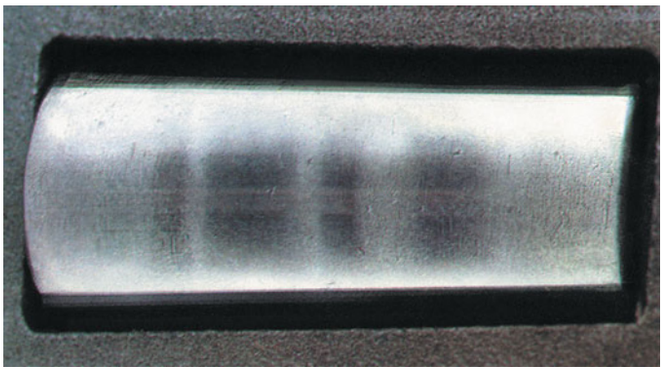


(a)

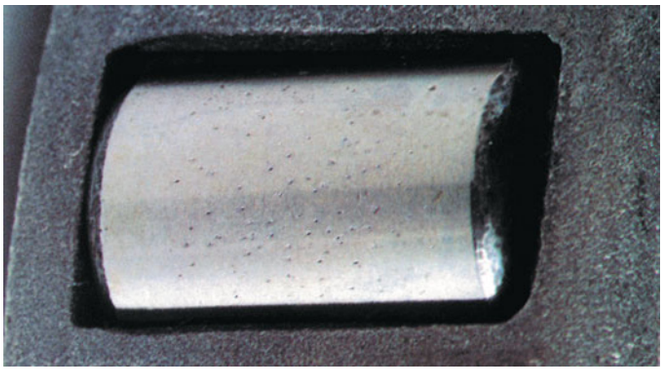


(b)

FIGURE 98–37 (a) Always check for faint grooves in the race. This bearing should not be reused. (b) Grooves like this are often matched by grooves in the race (above). Discard the bearing. (*Courtesy SKF USA Inc.*)



(a)



(b)

FIGURE 98–39 (a) This bearing is worn unevenly. Notice the stripes. It should not be reused. (b) Any damage that causes low spots in the metal renders the bearing useless. (*Courtesy SKF USA Inc.*)

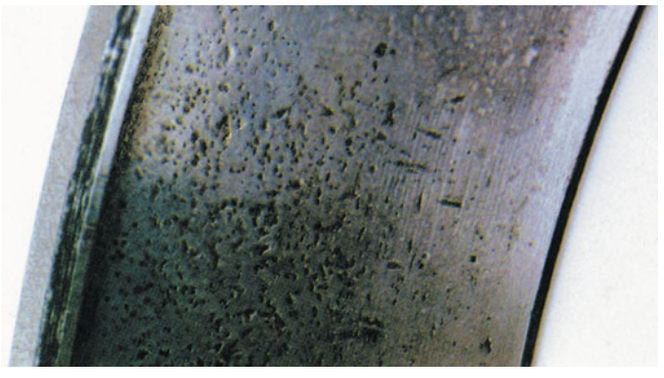


(a)



(b)

FIGURE 98–38 (a) Regular patterns of etching in the race are from corrosion. This bearing should be replaced. (b) Light pitting comes from contaminants being pressed into the race. Discard the bearing. (*Courtesy SKF USA Inc.*)



(a)



(b)

FIGURE 98–40 (a) In this more advanced case of pitting, you can see how the race has been damaged. (b) Discoloration is a result of overheating. Even a lightly burned bearing should be replaced. (*Courtesy SKF USA Inc.*)



(a)



(b)

FIGURE 98–41 (a) Pitting eventually leads to spalling, a condition where the metal falls away in large chunks. (b) In this spalled roller, the metal has actually begun to flake away from the surface. (*Courtesy SKF USA Inc.*)



FIGURE 98–42 These dents resulted from the rollers "hammering" against the race, a condition called brinelling. (*Courtesy SKF USA Inc.*)

ELECTRICAL ARCING Bearings can be damaged caused by poor ground wires or improper welding on the vehicle.

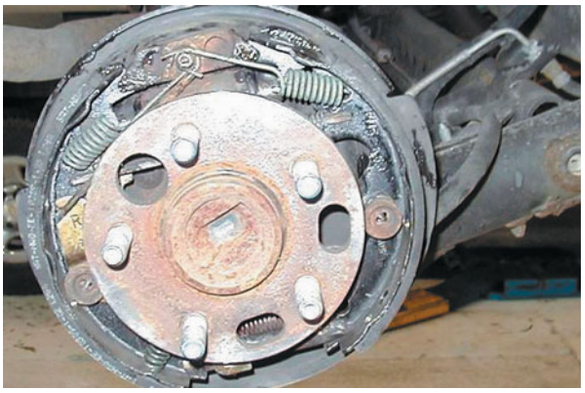
SHOCK LOADING Dents can be formed in the race of a bearing, which eventually leads to bearing failure. ● **SEE FIGURE 98–42.**

TECH TIP

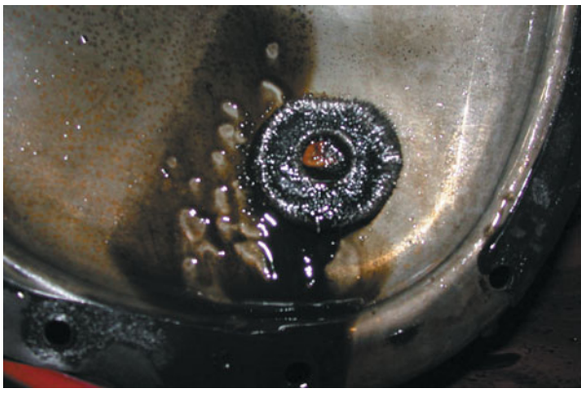
"Bearing Overload"

It is not uncommon for vehicles to be overloaded. This is particularly common with pickup trucks and vans. Whenever there is a heavy load, the axle bearings must support the entire weight of the vehicle, including its cargo. If a bump is hit while driving with a heavy load, the balls of a ball bearing or the rollers of a roller bearing can make an indent in the race of the bearing. This dent or imprint is called **brinelling,** named after Johann A. Brinell, a Swedish engineer who developed a process of testing for surface hardness by pressing a hard ball with a standard force into a sample material to be tested.

Once this imprint is made, the bearing will make noise whenever the roller or ball rolls over the indent. Continued use causes wear to occur on all of the balls or rollers and eventual failure. While this may take months to fail, the *cause* of the bearing failure is often overloading of the vehicle. Avoid shock loads and overloading for safety and for longer vehicle life.



1 After safely hoisting the vehicle, remove the rear wheels and brake drums.



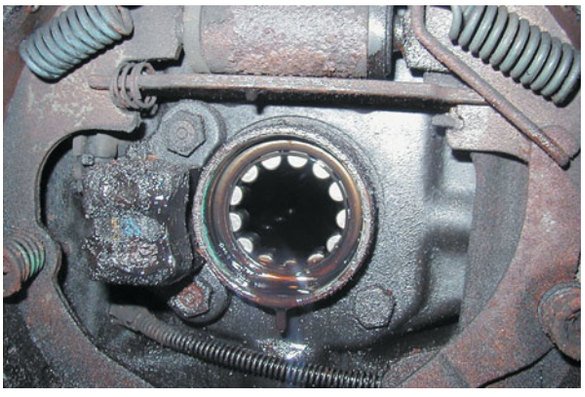
2 Remove the rear differential cover and inspect the magnet for metal particles that would indicate serious wear or damage.



3 Remove the retaining bolt and allow the pinion shaft to be removed.



4 Push the axle inward toward the center of the vehicle to free the axle clip.



5 After removing the clip, the axle can then be removed. Note that the backing plate is wet, indicating that the axle seal has been leaking.



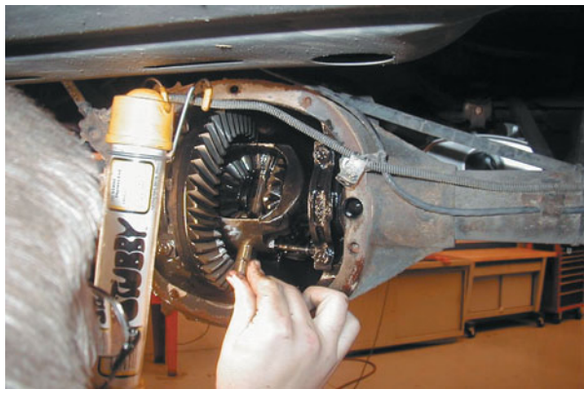
6 A seal removal tool being used to remove the axle seal.

CONTINUED ▶

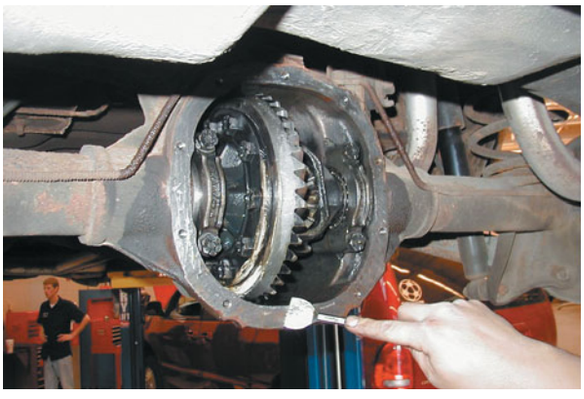
REAR AXLE BEARING (CONTINUED)



7 If a retainer-type axle is being serviced, the bearing and seal need to be pressed off of the axle.



8 After installing a new bearing and seal, insert the axle and install the clip, then the pinion shaft.



9 Clean the differential housing before installing the cover gasket and cover. Refill the differential with the specified fluid.

REVIEW QUESTIONS

1. List three common types of automotive antifriction bearings.
2. Explain the adjustment procedure for a typical tapered roller wheel bearing.
3. List four symptoms of a defective wheel bearing.
4. Describe how the rear axle is removed from a C-lock-type axle.

CHAPTER QUIZ

1. Which type of automotive bearing can withstand radial and thrust loads, yet must be adjusted for proper clearance?
   a. Roller bearing
   b. Tapered roller bearing
   c. Ball bearings
   d. Needle roller bearing
2. Most sealed bearings used on the front wheels of front-wheel-drive vehicles are usually which type?
   a. Roller bearing
   b. Single tapered roller bearing
   c. Double-row ball bearing
   d. Needle roller bearing

3. On a bearing that has been shock loaded, the race (cup) of the bearing can be dented. This type of bearing failure is called _____.
   a. Spalling **c.** Brinelling
   b. Arcing **d.** Fluting
4. The bearing grease most often specified is rated NLGI _____.
   a. #00 **c.** #1
   b. #0 **d.** #2
5. A non-drive-wheel bearing adjustment procedure includes a final spindle nut tightening torque of _____.
   a. Finger tight
   b. 5 lb-in.
   c. 12 to 30 lb-ft
   d. 12 to 15 lb-ft plus 1/16 in. turn
6. After a non-drive-wheel bearing has been properly adjusted, the wheel should have how much end play?
   a. Zero **c.** 0.10 to 0.30 in.
   b. 0.001 to 0.005 in. **d.** 1/16 to 3/32 in.
7. The differential cover must be removed before removing the rear axle on which type of axle?
   a. Retainer plate **c.** Press fit
   b. C-lock **d.** Welded tube
8. What part(s) should be replaced when servicing a wheel bearing on a non-drive wheel?
   a. The bearing cup
   b. The grease seal
   c. The cotter key
   d. Both the grease seal and the cotter key
9. Technician A says that a defective wheel or axle bearing often makes a growling or rumbling noise. Technician B says that a defective wheel or axle bearing often makes a noise similar to a tire with an aggressive mud or snow design. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
10. Two technicians are discussing differentials. Technician A says all differentials are vented. Technician B says that a clogged vent can cause the rear axle seal to leak. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

chapter 99 DRUM BRAKES

OBJECTIVES: After studying Chapter 99, the reader will be able to: • Prepare for the Brakes (A5) ASE certification test content area "B" (Drum Brake Diagnosis and Repair). • Identify drum brake component parts. • Describe the operation of non-servo brakes. • Explain the operation of dual-servo brakes. • Discuss drum brake adjusters.

KEY TERMS: Anchor eyes 1091 • Beehive holddown 1094 • Bonded linings 1092 • Brake fade 1089 • Brake shoe holddowns 1093 • Brake shoe return springs 1093 • Brake shoes 1091 • Core charge 1091 • Dual-servo brake 1095 • Duo-Servo 1095 • Edge codes 1092 • Gas fade 1089 • Labyrinth seal 1089 • Leading shoe 1094 • Leading-trailing brakes 1095 • Ledges 1089 • Lining fade 1089 • Lining table 1091 • Mechanical fade 1089 • Nibs 1091 • Non-servo brakes 1094 • Over-travel spring 1097 • Pawl 1097 • Piston stops 1090 • Platform 1091 • Primary shoe 1096 • Riveted linings 1092 • Secondary shoe 1096 • Self-energizing action 1094 • Shoe anchors 1090 • Shoe contact areas 1089 • Shoe rim 1091 • Shoe support pads 1089 • Shoe web 1091 • Trailing shoe 1095 • Water fade 1089

DRUM BRAKE ADVANTAGES

Drum brakes were the first type of brakes used on motor vehicles. Even today, over 100 years after the first "horseless carriages," drum brakes are still used on the rear of many vehicles, as shown in ● **FIGURE 99–1.** The drum brake has been more widely used than any other automotive brake design. ● **SEE FIGURE 99–2.**

Although the disc brake has proven its superiority in extreme braking conditions, and has replaced the drum brake on the front axle of vehicles, the drum brake continues to have a number of advantages that contribute to its widespread use on the rear axle of most automobiles.

SELF-ENERGIZING AND SERVO ACTION The primary advantage of drum brakes is that they can apply more stopping power for a given amount of force applied to the brake pedal than can disc brakes. This is possible because the drum brake design offers a self-energizing action that helps force the brake linings tightly against the drum. In addition, some drum brake designs use an effect called servo action that enables one brake shoe to help apply the other for

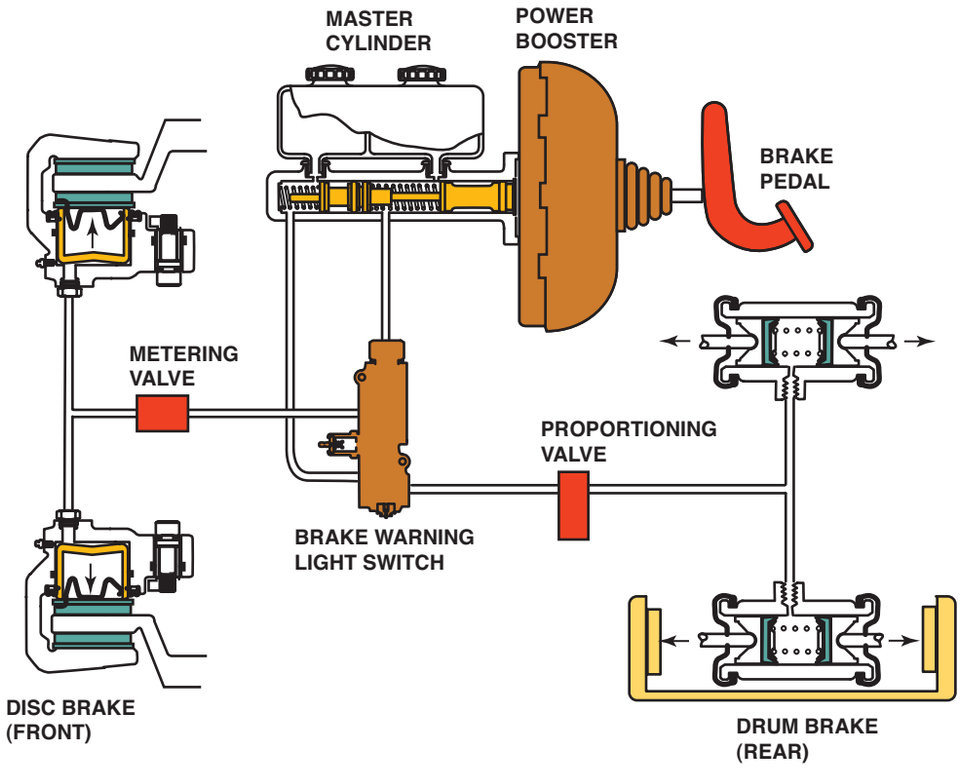


FIGURE 99–1 Typical brake system components showing disc brakes on the front and drum brakes on the rear.

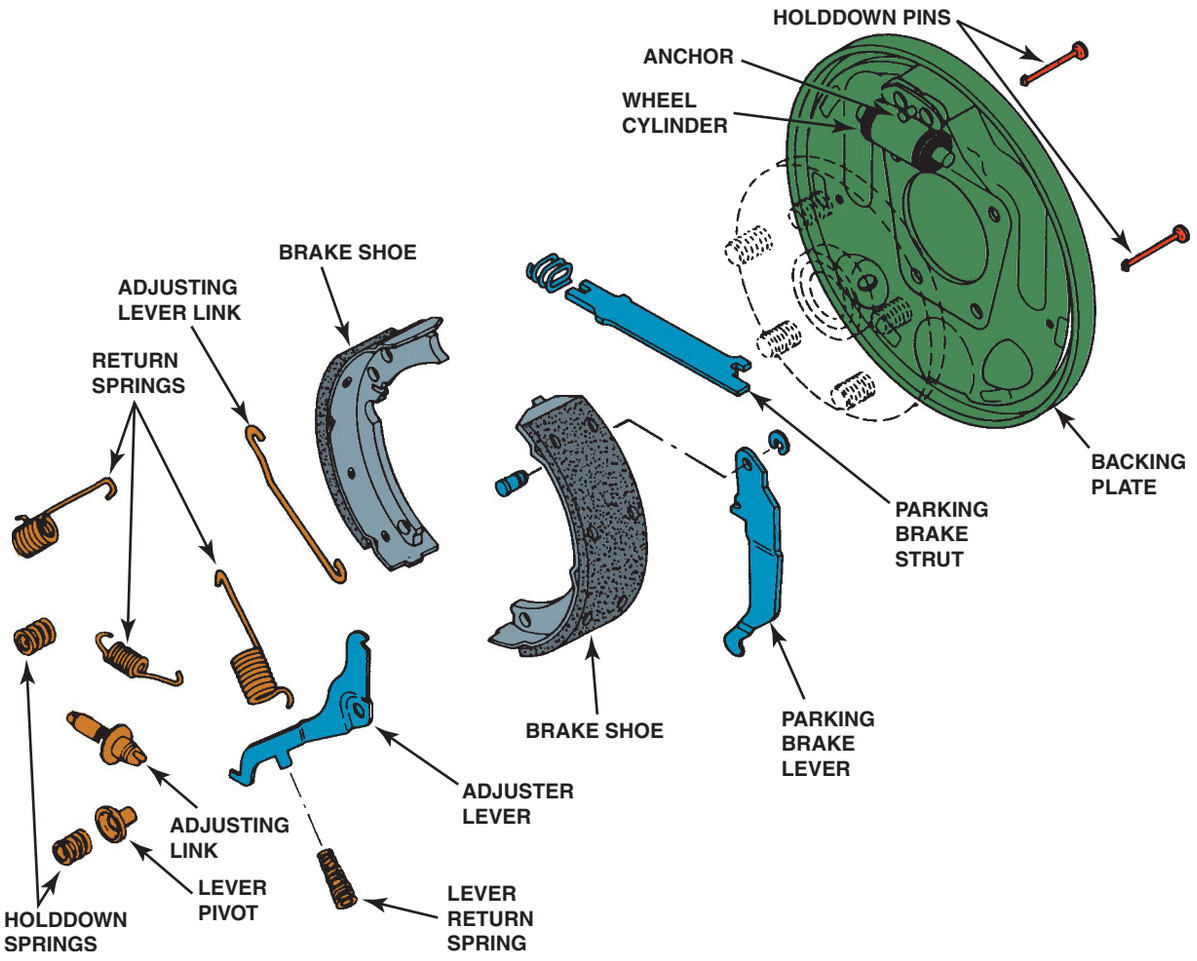


FIGURE 99–2 An exploded view of a typical drum brake assembly.

increased stopping power. Both self-energizing and servo action are explained in detail later in the chapter.

PARKING BRAKE One advantage of drum brakes is that they make excellent parking brakes. A simple linkage fitted to the brake assembly allows relatively low effort from the driver to hold a heavy vehicle in place when parked. Disc brakes, which do not benefit from self-energizing or servo action, require a complex set of extra parts to provide enough force to work well as parking brakes.

DRUM BRAKE DISADVANTAGES

BRAKE FADE Drum brakes are not very efficient at dissipating heat. The brake drum covers the linings, and most of the heat produced during braking must pass through the drum, from the inside out into the air.

The greatest drawback of drum brakes is that they are susceptible to fade. **Brake fade** is the loss of stopping power that occurs when excessive heat reduces the friction between the brake shoe linings and the drum. The four types of brake fade include:

1. **Mechanical Fade. Mechanical fade** occurs when the brake drum gets so hot it expands away from the brake linings. The brake shoes then move outward to maintain contact with the drum, causing the brake pedal to drop toward the floor as additional brake fluid moves into the hydraulic system.
2. **Lining Fade. Lining fade** occurs when the friction coefficient of the brake lining material drops off sharply because intense heat makes it "slippery." Unlike mechanical fade, brake pedal travel does not increase when lining fade occurs. Instead, the pedal becomes hard and there is a noticeable loss of braking power.
3. **Gas Fade. Gas fade** occurs under extended hard braking from high speeds, a thin layer of hot gases and dust particles can build up between the brake shoe linings and drum. The gas layer acts as a lubricant and reduces friction. As with the lining fade, the brake pedal becomes hard, and greater application force is required to maintain a constant level of stopping power.
4. **Water Fade. Water fade** occurs when moisture is trapped between the shoes and drum, where it acts as a lubricant. This lowers braking efficiency until friction creates enough heat to evaporate the water.

BRAKE ADJUSTMENT Another disadvantage of the drum brake design is its need for an adjusting mechanism. As the brake shoe lining material wears, the clearance between the linings and drum increases, resulting in longer brake pedal travel. To maintain a high brake pedal, a mechanism must be included in the brake assembly for adjustment of the clearance between the brake shoe and drum. Most vehicles have automatic adjusters that maintain the proper drum to linings clearance.

BRAKE PULL Brake pull occurs when the friction assemblies on opposite sides of the vehicle have different amounts of stopping power. These differences can be caused by many conditions, component failures, brake fade and mis-adjustment of the clearance between the brake linings and drum.

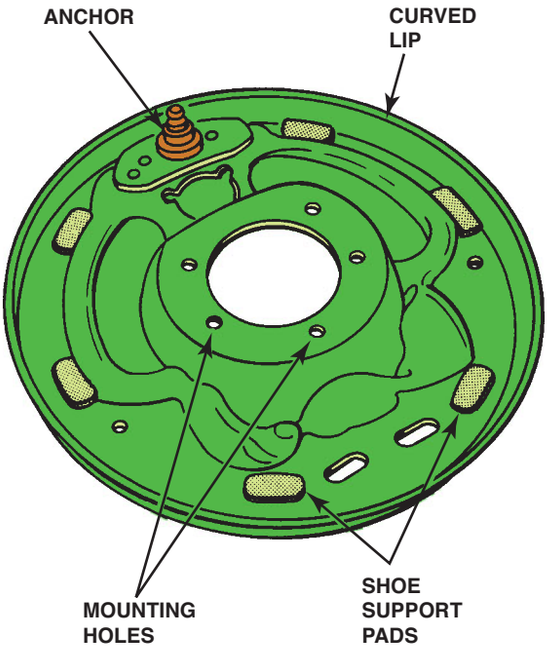


FIGURE 99–3 The backing plate is the foundation of every drum brake. There are normally six pads where the brake shoes contact the backing plate.

TECH TIP

Quick-and-Easy Drum Brake Adjustment Check

Tap the brake drum lightly with a hammer or wrench. If the brake shoes are not contacting the drum, the drum will ring like a bell. If the shoes are contacting the drum, the sound will be muffled.

DRUM BRAKE PARTS

BACKING PLATE The foundation of every drum brake is the backing plate that mounts to the suspension or axle housing on the rear brakes. The **shoe support pads** are stamped into the backing plate and contact the edges of the brake shoes to keep the linings properly aligned with the center of the friction surface inside the brake drum. These pads are also called **ledges** or **shoe contact areas.** The support pads are slightly coated with special high-temperature silicone brake grease to minimize wear, prevent rust, and eliminate squeaking that can occur when the shoes move slightly on the pads during a stop. ● **SEE FIGURE 99–3.**

The backing plate serves as the mounting surface for all the other friction assembly parts. The backing plate also functions as a dust and water shield to keep contaminants out of the brake assembly. The edge of the backing plate curves outward to form a lip that strengthens the backing plate and fits inside the brake drum to help prevent water entry. The lip fits into a machined groove in the open edge of the brake drum to provide an even better water barrier or seal. This type of seal is called a **labyrinth seal.** ● **SEE FIGURE 99–4.**

In addition to mounting holes for the various brake parts, the backing plate may also have openings that are used to inspect the wear of the brake linings, or adjust the lining-to-drum clearance. These openings are sometimes sealed with metal plugs that must

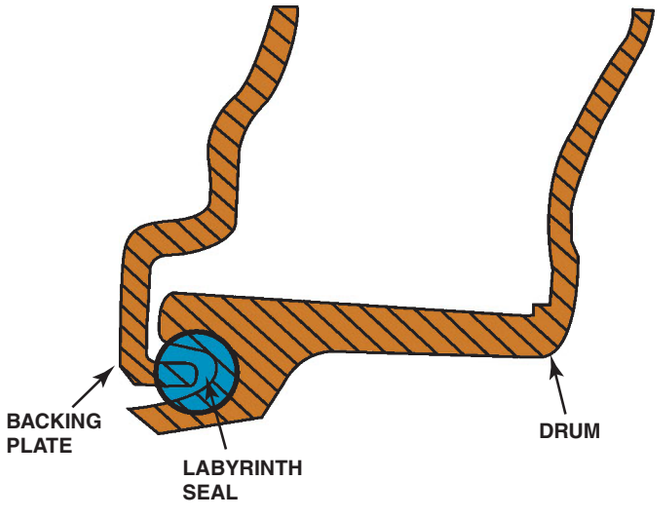


FIGURE 99–4 A labyrinth seal is created between the lip of the backing plate and the groove in the brake drum.

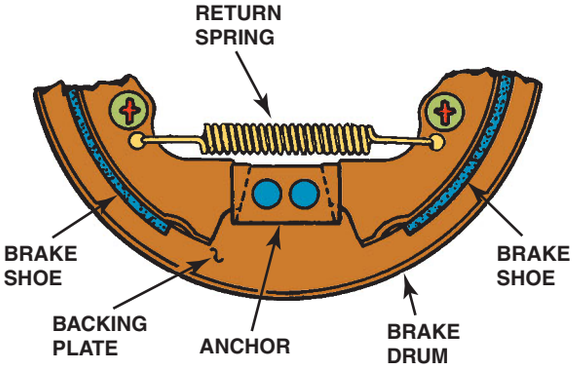


FIGURE 99–5 A keystone anchor allows the brake shoes to self-center in the drum.

be punched out the first time inspection or adjustment is needed. Rubber plugs are available to seal the holes and prevent water entry once the metal plugs have been removed.

SHOE ANCHORS

Shoe anchors prevent the brake shoes from rotating with the drum when the brakes are applied. The majority of drum brakes have a single anchor, but some drum brake designs use two or more.

Many anchors are a simple round post that is permanently mounted on the backing plate. The brake shoes have semicircular cutouts where they contact the anchor, and the anchor positively locates the shoe on the backing plate. Another type of anchor is the self-centering or keystone anchor. ● **SEE FIGURE 99–5.** It is called a keystone anchor because of the angled shape similar to a keystone used on the top center of a stone arch.

PISTON STOPS

Some backing plates incorporate **piston stops** that prevent the wheel cylinder pistons from coming out of their bores when the friction assembly is disassembled for servicing. The stops may be part of a reinforcing plate positioned under the anchor or they can be stamped directly into the shape of the backing plate itself. ● **SEE FIGURE 99–6.**

When piston stops are used, the wheel cylinder must be removed from the backing plate before it can be taken apart for servicing.

WHEEL CYLINDERS

Hydraulic pressure is transferred from the master cylinder to each wheel cylinder through brake fluid. The force exerted on the brake fluid by the driver forces the piston inside the wheel cylinder to move outward. ● **SEE FIGURE 99–7.** Through pushrods or links, this movement acts on the brake shoes, forcing them outward against the brake drum. ● **SEE FIGURE 99–8.**

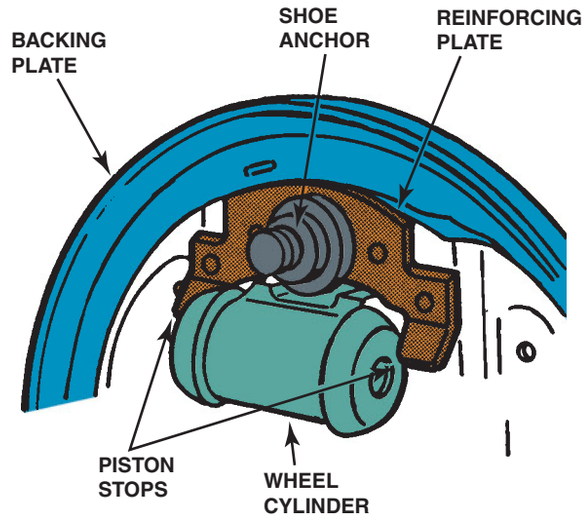


FIGURE 99–6 Piston stops prevent the wheel cylinder from coming apart.

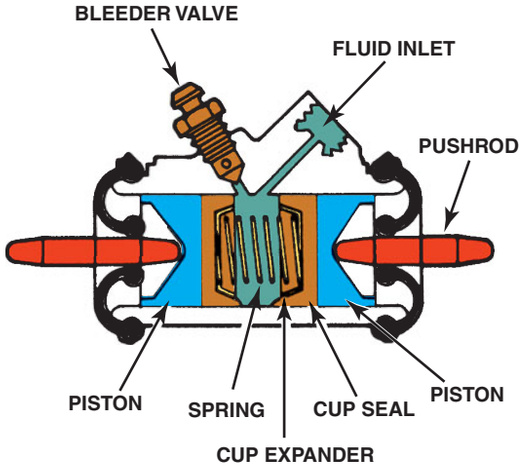


FIGURE 99–7 Cross-section of a wheel cylinder that shows all of its internal parts. The brake line attaches to the fluid inlet. The cup extender prevents the cup seal lip from collapsing when the brakes are released.

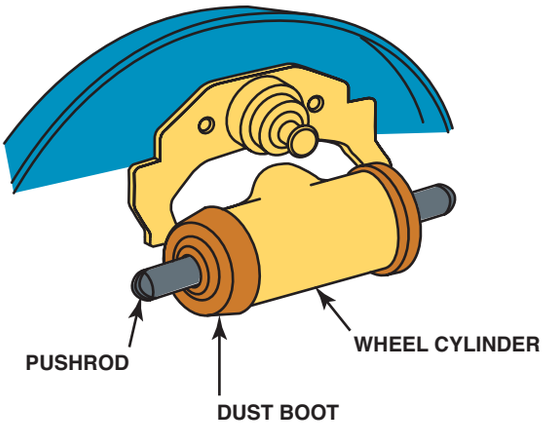


FIGURE 99–8 The pushrods are held in place by the rubber dust boots. As the wheel cylinder pistons move outward, the pushrods transfer the movement to the brake shoes.

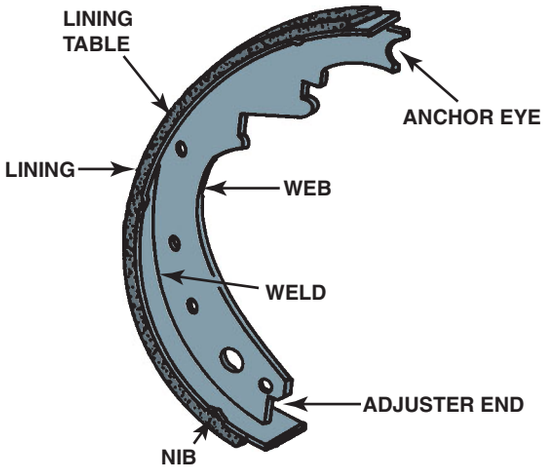


FIGURE 99–9 Steelbrake shoes are made from two stampings welded together—the web and the lining table.

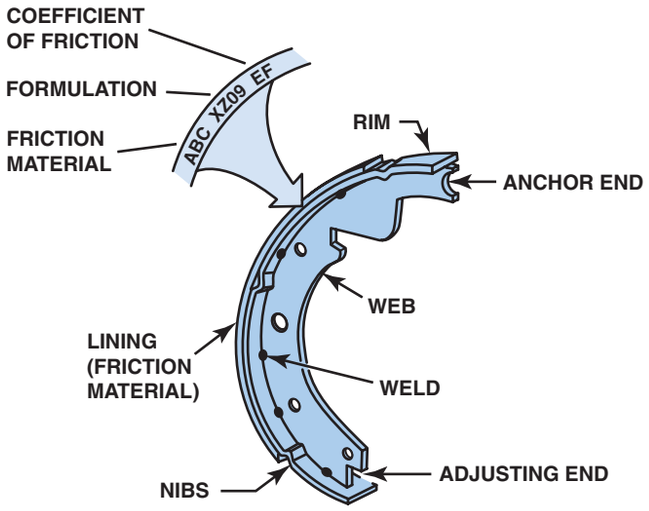


FIGURE 99–11 Typical drum brake shoe and the names of the parts.

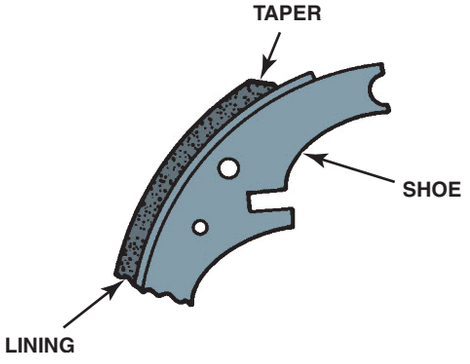


FIGURE 99–10 Tapered ends on the linings help to reduce brake noise.

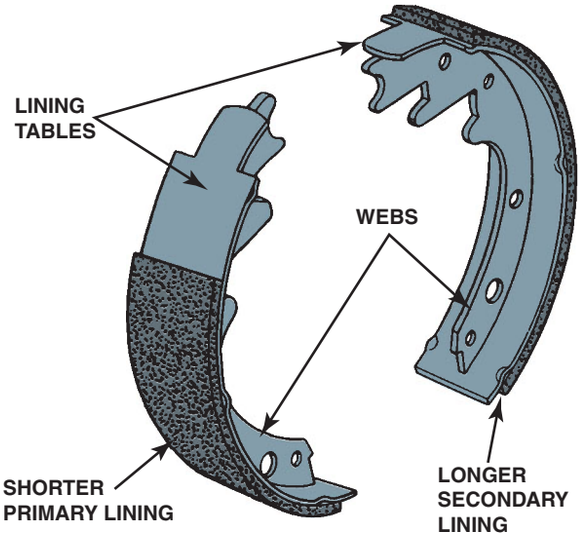


FIGURE 99–12 The primary (forward facing) brake shoe often has a shorter lining than the secondary shoe (rearward facing). The color of the primary and secondary lining can also be different due to differences in friction and wear requirements.

DRUM BRAKE SHOES

The linings of drum brakes are attached to curved metal assemblies called **brake shoes.** Most shoes are made of two pieces of sheet steel welded together in a T-shaped cross section. ● **SEE FIGURE 99–9.**

The outer edge is lined with a friction material that contacts the brake drum to generate the actual stopping power. The ends of the linings on most brake shoes are tapered to prevent vibration and brake noise as shown in ● **FIGURE 99–10.**

The curved metal piece on the outer portion of the shoe is called the **lining table,** the **shoe rim** or **platform.** The lining table supports the block of friction material that makes up the brake lining. On some shoes, the edge of the lining table contains small V- or U-shaped notches called **nibs.** The nibs rest against the shoe support pads on the backing plate when the shoe is installed.

The metal piece of the shoe positioned under the lining table and welded to it is called the **shoe web.** All of the application force that actuates the shoe is transferred through the web to the lining table. The web usually contains a number of holes in various shapes and sizes for the shoe return springs, hold-down hardware, parking brake linkage, and self-adjusting mechanism.

One end of the web usually has a notch where the wheel cylinder touches the shoe, while the other end commonly has a flat or curved surface where the shoe meets an anchor or adjusting link. The upper ends of the webs on dual-servo brake shoes have semicircular cutouts called **anchor eyes.** ● **SEE FIGURE 99–11.**

Brake shoes are parts that can be relined and reused many times if the web and lining table are not damaged. Brake shoes for any given application are usually available in both “new” and “relined” versions from suppliers. Relined brake shoes are usually sold on an exchange basis. At the time of purchase, a **core charge** is added to the cost of the relined parts. This charge is refunded when the old shoes are returned in rebuildable condition.

PRIMARY AND SECONDARY BRAKE SHOES

The primary shoe (forward facing shoe) is self-energized by drum rotation to create a servo action that forces the secondary shoe more firmly against the drum. Because of this, the two shoes have physical differences and cannot be interchanged.

To help deal with the added friction, heat, and wear it undergoes, the lining of the secondary shoe extends nearly the full length of the shoe lining table. ● **SEE FIGURE 99–12.** The secondary shoe lining material also has a high coefficient of friction to provide good stopping power. The primary shoe undergoes far less stress than the secondary shoe, and its lining is often shorter—sometimes less

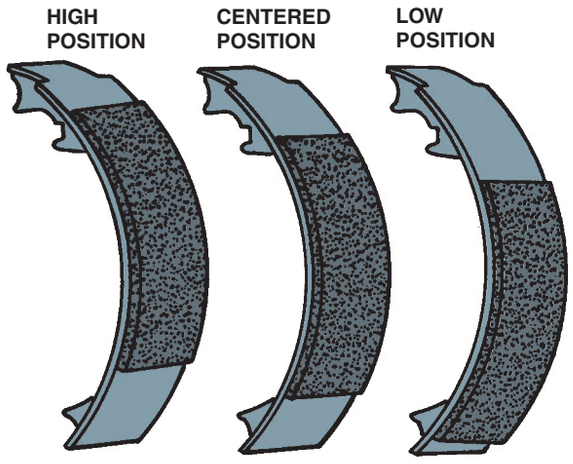


FIGURE 99–13 Primary shoe lining may vary depending on the application.

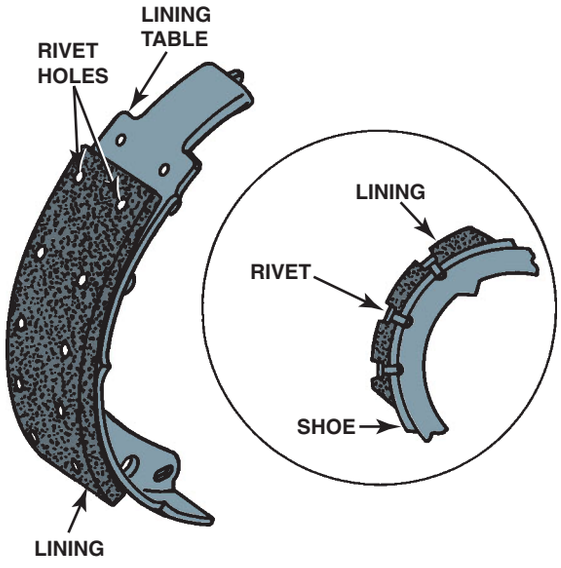


FIGURE 99–14 Riveted brake linings are quiet and reliable at high temperatures.

than half the length of the lining table. In addition, the lining material usually has a lower coefficient of friction. This prevents the shoe from engaging the drum too quickly or harshly, which could cause the brakes to grab or lock.

On most dual-servo brake primary shoes, the lining is positioned near the center of the lining table. However, in some cases, the lining may be positioned above or below the lining table centerline. Higher or lower lining positions provide better braking action, or prevent noise, in some vehicles. ● **SEE FIGURE 99–13.**

LINING ASSEMBLY METHODS

There are two main methods used to mount brake linings to the brake shoe.

RIVETING. The brake lining is attached to the lining table with copper or aluminum rivets. ● **SEE FIGURE 99–14.** Riveting has the following advantages:

- The major advantage of riveting is that it allows a small amount of flex between the brake lining and lining table. This play enables the assembly to absorb vibration, and the result is that **riveted linings** operate more quietly than bonded linings.
- Rivets are also very reliable and will not loosen at high temperatures.

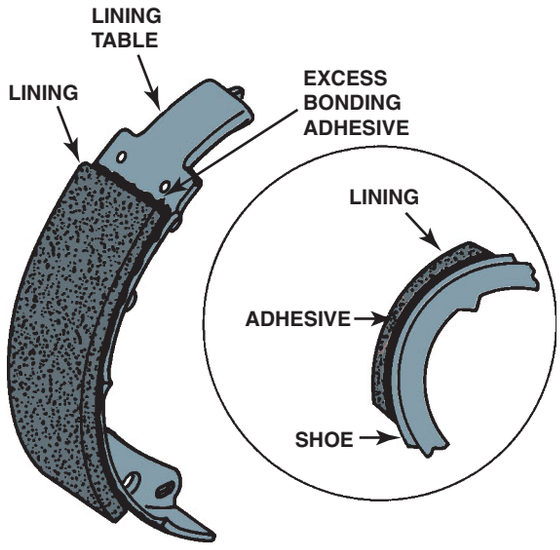


FIGURE 99–15 Many brake linings are bonded.

Riveting has the following disadvantages:

- Rivet holes however do create stress points in the lining where cracks are likely to occur.
- Riveted lining has a reduced service life because the linings must be replaced before the rivet head contacts the brake drum.
- The rivet can cause deep grooves to be cut into the drum often requiring replacement if the worn brakes are not detected early enough to prevent damage.

BONDING. **Bonded linings** use high-temperature adhesive to glue the brake block directly to the shoe lining table or pad backing plate as shown in ● **FIGURE 99–15.** Heat and pressure are then applied to cure the assembly. Bonding is a common form of shoe and pad assembly, and is most often used to mount organic friction materials.

Bonding has several advantages including:

- Without rivets, bonded linings can wear closer to the lining table and provide a longer service life. If the linings wear too far, bonding adhesive is not as destructive to drums or rotors as rivets.
- Bonded linings also have fewer problems with cracking because they have no rivet holes to weaken the brake block.

Bonded linings have the following disadvantages:

- If a bonded lining gets too hot, the bonding adhesive will fail and allow the brake block to separate from the lining table or backing plate.
- Bonded linings are also more prone to be noisy because they do not allow any vibration absorbing flex between the brake block and lining table or backing plate.

EDGE CODES

Starting in 1964, brake linings have been using a standardized way to identify the brake lining materials. The edge codes follow the Society of Automotive Engineers (SAE) Standard J866a. The **edge codes** contain three groups of letters and numbers:

- The first group is a series of letters that identify the manufacturer of the lining.
- The second group is a series of numbers, letters, or both that identify the lining compound or formula. This code is usually known to the manufacturer of the lining material and helps identify the lining after manufacture.
- The third group is two letters that identify the coefficient of friction.



FIGURE 99–16 Typical drum brake lining edge codes, showing the coefficient of friction codes for cold and hot circled.

Code C	0.00 to 0.15
Code D	0.15 to 0.25
Code E	0.25 to 0.35
Code F	0.35 to 0.45
Code G	0.45 to 0.55
Code H	0.55 and above
Code Z	ungraded

CHART 99–1

Edge code letters represent a range of coefficient of friction of the linings.

TECH TIP

Purchase Quality Brake Linings for Best Performance

While many brands of replacement brake lining provide acceptable stopping power and long life, purchasing factory brake lining from a dealer is usually the best opportunity to get lining material that meets all vehicle requirements. Aftermarket linings are not required by federal law to meet performance or wear standards that are required of original factory brake linings.

The coefficient of friction is a number that indicates the amount of friction between two surfaces. A coefficient of friction will always be less than 1; the higher the number, the greater the amount of friction between two surfaces. (For example, a material with 0.55 coefficient of friction has more friction than a material with a coefficient of friction of 0.39.)

These coefficient of friction codes include letters that represent a range of coefficient of friction. ● **SEE CHART 99–1.**

There are always two letters used side by side and the first letter indicates its coefficient of friction when brakes are cold (250°F/121°C), and the second letter indicates the coefficient of friction of the brake lining when the brakes are hot (600°F/316°C).

For example, FF indicates that the brake lining material has a coefficient of friction between 0.35 and 0.45 when both cold and hot. ● **SEE FIGURE 99–16.**

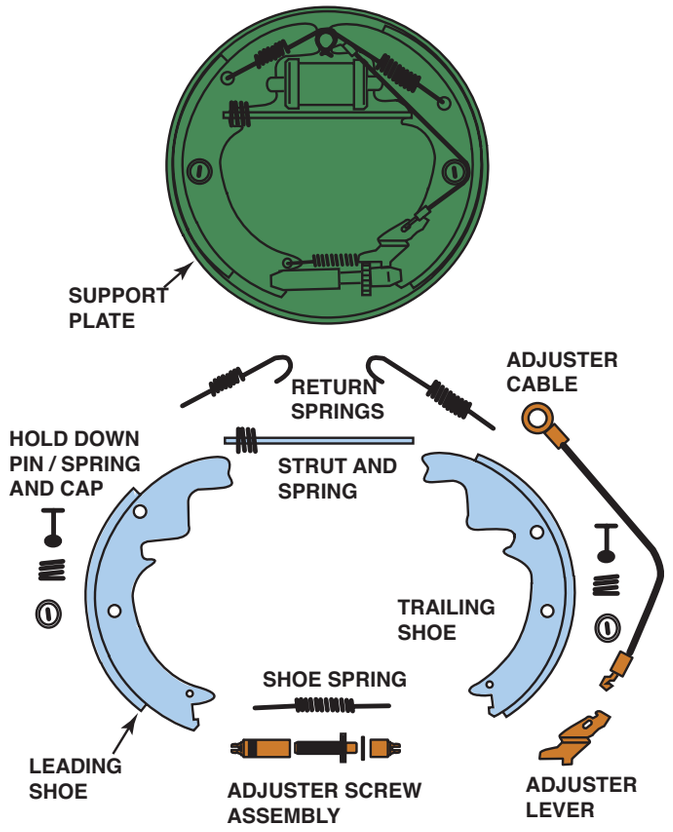


FIGURE 99–17 A typical drum brake assembly showing the support plate (backing plate), brake shoes, and springs.

These letters do not mean the relative quality of the lining material. Lining wear, fade resistance, tensile strength, heat recovery rate, wet friction, noise, and coefficient of friction must be considered when purchasing high-quality linings. Unfortunately, there are no standards that a purchaser can check regarding all of these other considerations. For best brake performance, always purchase the best-quality name-brand linings that you can afford.

DRUM BRAKE PARTS

RETURN SPRINGS

The **brake shoe return springs** retract the shoes to their unapplied positions when the brake pedal is released. This helps prevent brake drag, and aids the return of brake fluid to the master cylinder reservoir. Most brakes use closed-coil return springs to retract the brake shoes. ● **SEE FIGURE 99–17.**

The coils on these springs are very tightly wound and contact one another when the spring is relaxed. Some vehicles have a single, large, horseshoe-shaped return spring. ● **SEE FIGURE 99–18.**

The type, location, and number of return springs vary from one brake design to the next. All springs are installed in one of two ways. Some connect directly from shoe to shoe, while others connect from one shoe to the anchor post.

BRAKE SHOE HOLDDOWNS

While the return springs retract the brake shoes to their unapplied positions, the **brake shoe holddowns** keep the shoes securely against the support pads on the backing plate. The holddowns prevent noise, vibration, and wear, but still allow the shoes to move out and back as the brakes are applied and released. The holddowns also provide enough freedom of movement to allow adjustments of the shoes outward as

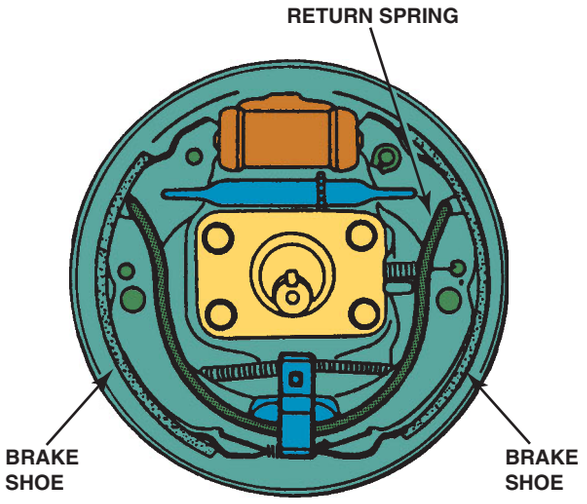


FIGURE 99–18 A single spring-steel spring is used on some drum brakes.

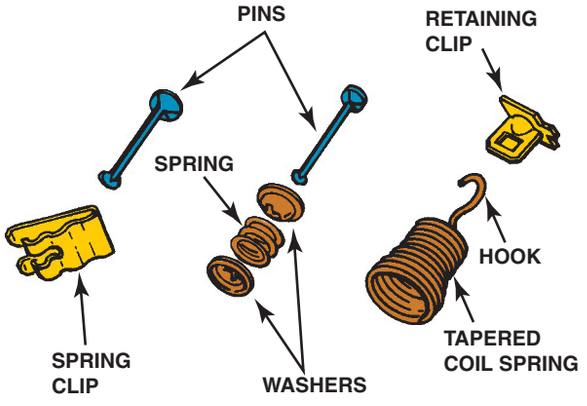


FIGURE 99–19 Various types and styles of hold-down springs. The hold down pins are commonly called *nails.*

the linings wear. Shoe holddowns take many forms, as shown in ● **FIGURE 99–19.**

The most common design is a steel pin installed through a hole in the backing plate and a corresponding hole in the brake shoe web. A spring fits over the end of the pin against the shoe web, and a special washer compresses the spring and locks onto the flattened end of the pin.

Another type of holddown is a taper-wound coil spring with a hook formed on its end. Because of its shape, this part is sometimes called a **beehive holddown.** The hook end of the spring is installed through a hole in the brake shoe web and attached into a retaining clip that fits into a corresponding hole in the backing plate.

PARKING BRAKE LINKAGE Most rear drum brake friction assemblies include a parking brake linkage. The linkage commonly consists of a cable, lever, and strut system that spread the brake shoes apart to apply the brake mechanically. The parking brake strut plays a large part in many of the automatic brake adjusters. ● **SEE FIGURE 99–20.**

BRAKE DRUMS The brake drum is not connected to the backing plate, but turns with the wheel. The drum mounts on the hub or axle, and covers the rest of the brake assembly. Brake drums are made of cast iron or cast aluminum with a cast-iron liner. Many of these drum types may have ribs or fins on their outer edge to help dissipate heat. ● **SEE FIGURE 99–21.**

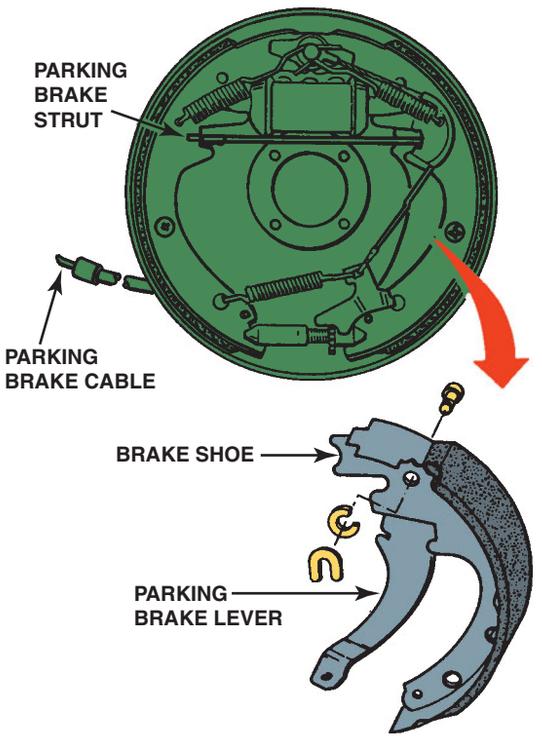


FIGURE 99–20 A mechanical brake linkage is part of most drum brake assemblies.



FIGURE 99–21 An aluminum brake drum with a cast iron friction surface. The cooling fins around the outside help dissipate the heat from the friction surface to the outside air.

NON-SERVO BRAKE DESIGN

PURPOSE AND FUNCTION A **non-servo brake** feature is that each brake shoe is applied individually. The action of one shoe has no effect on the action of the other. Many non-servo drum brakes use **self-energizing action** to improve their braking performance.

PARTS AND OPERATION Self-energizing action occurs when the forward or **leading shoe** contacts the drum and the drum attempts to rotate the shoe along with it. However, the shoe cannot rotate because its far end (relative to drum rotation) is fixed in place by an anchor. As a result, drum rotation *energizes* the shoe by forcing it outward and wedging it tightly against the brake drum.

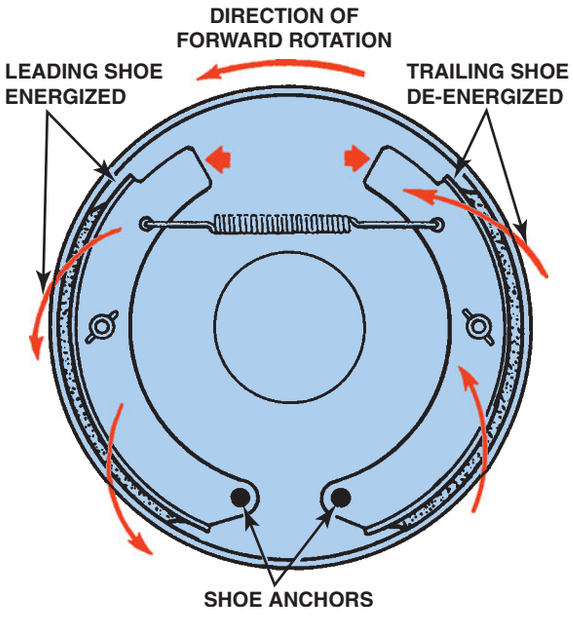


FIGURE 99–22 Self-energizing action can increase or decrease the stopping power of a brake shoe.

The drum also attempts to rotate the reverse or **trailing shoe** as it contacts the drum. However, in this case, the far end of the shoe (relative to drum rotation) is not solidly anchored. As a result, drum rotation *de-energizes* the shoe by forcing it inward away from the brake drum.

When this type of brake is applied with the vehicle backing up, the roles of the forward and reverse shoes are switched. The reverse shoe becomes the leading shoe, which is self-energized by drum rotation, while the forward shoe becomes the trailing shoe, which is de-energized. *A leading shoe is always energized by drum rotation. A trailing shoe is always de-energized by drum rotation.* The simple drum brake assembly shown in ● **FIGURE 99–22** shows how the self-energizing process works.

To identify the leading shoe on a non-servo brake with only one wheel cylinder, the first shoe from the wheel cylinder in the direction of drum rotation is the leading shoe. If the piston of a wheel cylinder moves in the same direction as drum rotation when the brakes are applied, the shoe it actuates is a leading shoe. If the piston moves opposite the direction of drum rotation, the shoe actuated is the trailing shoe.

Leading shoes generally wear at a faster rate than trailing shoes because they are applied with greater force. Where a brake uses one leading and one trailing shoe, the leading shoe will sometimes have a thicker lining or one with a larger surface area than that of the trailing shoe. The thicker or larger lining balances the wear between the two shoes so that they will both need replacement at about the same time.

LEADING-TRAILING BRAKE DESIGN

The non-servo **leading-trailing brake** has one leading shoe and one trailing shoe. ● **SEE FIGURE 99–23.** Typically, a single, two-piston wheel cylinder is mounted at the top of the backing plate and the two brake shoes are anchored at the bottom of the backing plate.

The brake design has one energized and one de-energized shoe regardless of whether it is applied while the vehicle is traveling forward or in reverse. This allows the leading-trailing brake to work equally well in either direction. The leading shoe usually wears more than the trailing shoe.

Leading-trailing brakes are popular on the rear wheels of many small and front-wheel-drive vehicles because, although they are not as powerful as a servo brake, they are less prone to lockup. They have the further benefit of making a good parking brake in both directions.

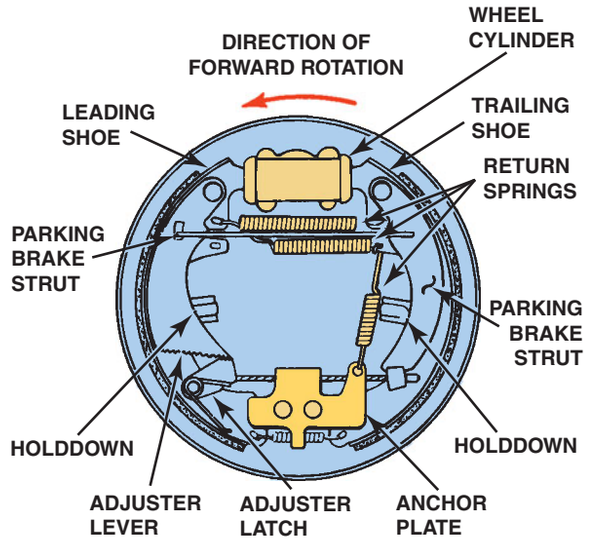


FIGURE 99–23 A leading-trailing non-servo brake.

DUAL-SERVO BRAKE DESIGN

PURPOSE AND FUNCTION

The **dual-servo brake** is the most common drum brake design. The name "servo" comes from the fact that one shoe "serves" the other to increase application force. All servo brakes used on automobiles are of the dual-servo design that works with equal force in both directions.

The primary advantage of the dual-servo brake is that it is more powerful than any of the non-servo designs. Another advantage of the dual-servo brake is that it makes a good parking brake. Dual-servo action not only makes the brake very powerful, it allows the brake to hold equally well in both directions.

Dual-servo brakes are more susceptible to pull than other brake designs, and their greater application force can lead to faster fade under extreme braking conditions.

NOTE: Dual-servo brakes are also called Duo-Servo, which is a brand name of the Bendix Corporation.

DUAL-SERVO BRAKE CONSTRUCTION

The basic dual-servo brake uses one anchor and a single two-piston wheel cylinder. ● **SEE FIGURE 99–24.** The anchor is usually mounted at the top of the backing plate with the wheel cylinder directly beneath it. The tops of the brake shoes are held against the anchor by individual return springs. The bottoms of the shoes are spaced apart by an adjusting link held in position by a third return spring that connects the two shoes.

ADJUSTING LINK (STARWHEEL ADJUSTER). The adjusting link consists of a starwheel that is part of an adjusting screw, a pivot nut that one end of the adjusting screw threads into, and a socket that rotates freely on the opposite end of the adjusting screw. ● **SEE FIGURE 99–25.** The outer ends of the pivot nut and socket are notched to fit over the brake shoe webs. Some adjusting links have a steel thrust washer and/or spring washer installed between the socket and the starwheel. These washers allow easier rotation of the starwheel and help reduce brake squeal.



FIGURE 99–24 A typical dual-servo drum brake.

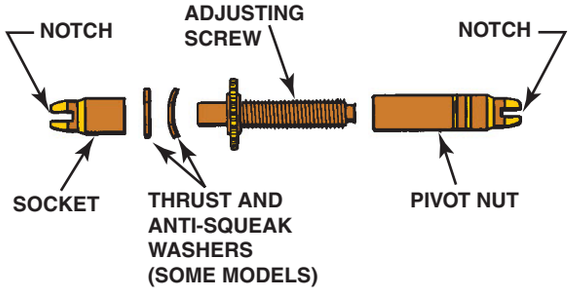


FIGURE 99–25 A typical dual-servo brake adjusting link assembly commonly called a *starwheel adjuster.*

NOTE: Adjusting links generally have specific left- or right-hand threads, and must be installed on the correct side of the vehicle.

PRIMARY AND SECONDARY BRAKE SHOES. Although dual-servo brakes make use of self-energizing action to help provide servo action, the two brake shoes are not called leading and trailing parts as in non-servo brakes. Instead, they are identified as the **primary shoe** and the **secondary shoe.** To identify the primary shoe on a dual-servo brake with a single two-piston wheel cylinder, point to the wheel cylinder, and then move your finger in the direction of drum rotation. The first shoe reached is the primary shoe (always facing to the front of the vehicle) and the other shoe is the secondary shoe (always facing toward the rear of the vehicle).

The secondary brake shoe provides approximately 70% of the total braking power in a dual-servo brake. For this reason, the lining is usually somewhat larger than that of the primary shoe. In addition, some manufacturers use different types of friction materials on the primary and secondary shoes to help equalize wear.

DUAL-SERVO BRAKE OPERATION

When a dual-servo brake is applied, the wheel cylinder attempts to force the tops of both brake shoes outward against the drum. ● **SEE FIGURE 99–26.** As the primary shoe makes contact it rotates with the drum because its far end (relative to the direction of drum rotation) is not directly anchored to the backing plate. As the primary shoe rotates, it forces the adjusting link and the secondary shoe to also rotate until the secondary shoe seats firmly against the anchor.

Although the wheel cylinder attempts to push the top of the secondary shoe outward, the rotational force developed by friction between the brake shoes and drum is much greater than the force developed by hydraulic pressure in the wheel cylinder. As a result, the secondary shoe is held against the anchor. In effect, only one-half of the wheel cylinder is used to apply the brakes.

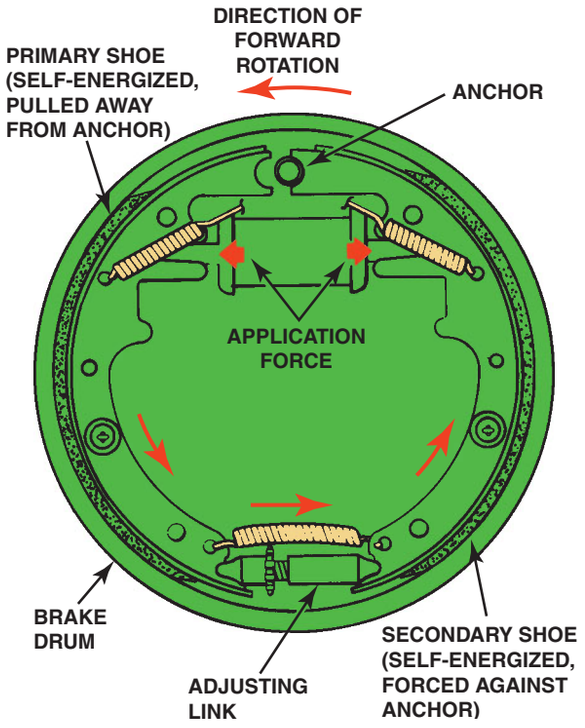


FIGURE 99–26 Dual-servo brake operation. The primary shoe on the left exerts a force on the secondary shoe on the right.

TECH TIP

Rear Wheel Lockup? Check the Adjustment

Servo action enables a drum brake to provide increased stopping power, but it can also cause the brakes to grab and lock if they get too far out of adjustment. As clearance between the shoes and drum increases, the primary brake shoe is allowed a greater range of movement. The farther the shoe moves, the more speed it picks up from the rotating brake drum. At the moment the slack is taken up between the brake shoes, adjusting link, and anchor, the speed of the primary shoe is converted into application force by servo action. If the primary shoe is moving too quickly, it will apply the secondary shoe very hard and fast, causing the brakes to grab and possibly lock the wheels.

SERVO ACTION

Once all clearance is taken up between the brake shoes, adjusting link, and anchor, both brake shoes become self-energized like the leading shoes in a non-servo brake. The anchor pin prevents the secondary shoe from rotating, and the adjusting link (held in position by the secondary shoe) serves as the anchor for the primary shoe. Servo action then occurs as a part of the braking force generated by the primary shoe is transferred through the adjusting link to help apply the secondary shoe. The secondary shoe is "wedged" between the anchor pin and brake drum and therefore provides more stopping force than the primary shoe which is applied only by hydraulic force. ● **SEE FIGURE 99–27.**

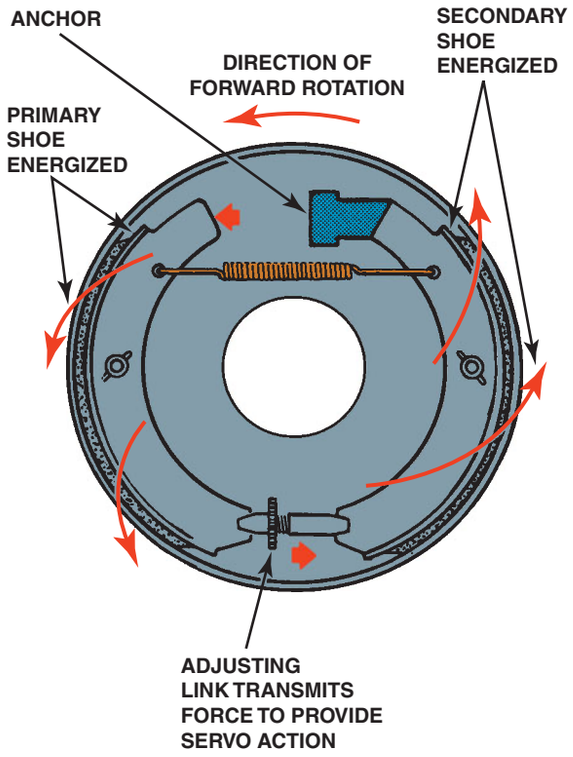


FIGURE 99–27 Dual servo action greatly increases the application force on the secondary shoe.

When a dual-servo brake is applied with the vehicle moving in reverse, the primary and secondary shoes switch roles. The primary shoe is forced against the anchor while the secondary shoe moves outward and rotates with the drum to apply the primary shoe with a greater force.

AUTOMATIC BRAKE ADJUSTERS

SERVO BRAKE STARWHEEL AUTOMATIC ADJUSTERS

Servo brakes use three styles of starwheel adjusters:

- **Cable.** ● **SEE FIGURE 99–28.**
- **Lever.** ● **SEE FIGURE 99–29.**
- **Link.** ● **SEE FIGURE 99–30.**

All three adjusters mount on the secondary brake shoe and adjust only when the brakes are applied while the vehicle is moving in reverse.

As the brakes are applied on a vehicle with a cable or link automatic adjuster, the wheel cylinder and drum rotation combine to move the secondary shoe away from the anchor. Movement of the shoe causes the cable or linkage to pull up on the adjuster **pawl.** ● **SEE FIGURE 99–31.** If the brake lining has worn far enough, the pawl engages the next tooth on the starwheel. When the brakes are released, the pawl return spring pulls the pawl down, rotating the starwheel and moving the brake shoes apart to reduce the lining-to-drum clearance.

Some servo brakes with cable-actuated starwheel automatic adjusters have an **over-travel spring** assembly on the end of the cable. ● **SEE FIGURE 99–32.** In this design, the adjuster pawl is mounted *under* the starwheel, and adjustment is made as the brakes are applied rather than released. The over-travel spring dampens the movements of the adjuster mechanism, and prevents

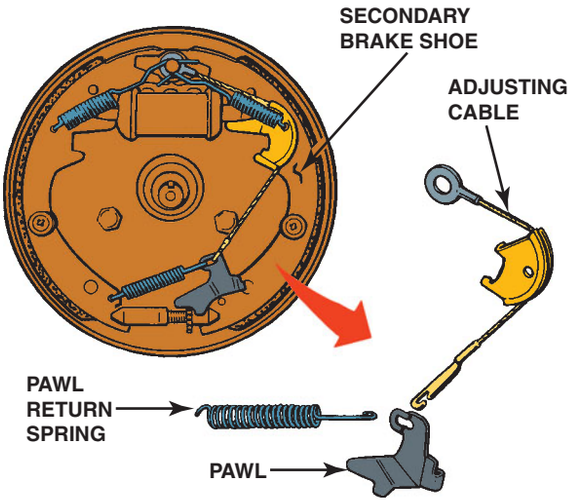


FIGURE 99–28 A cable-actuated starwheel adjuster. This type of adjuster makes the adjustment when the vehicle is being driven in reverse and the brakes are released.

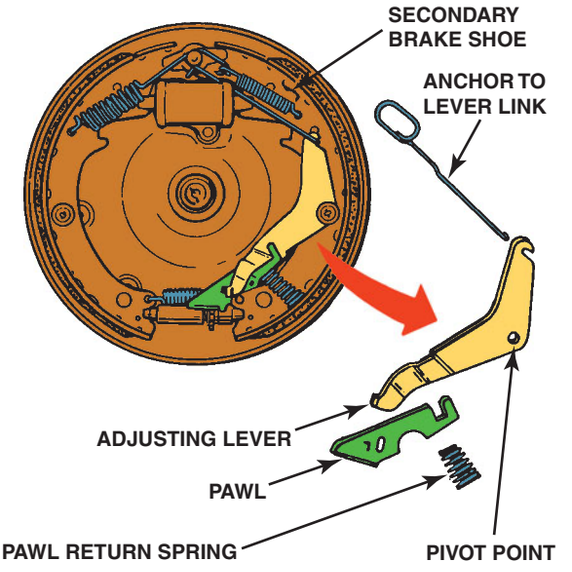


FIGURE 99–29 A lever-actuated starwheel automatic adjuster. This type of adjuster makes the adjustment when the vehicle is being driven in reverse and the brakes are applied.

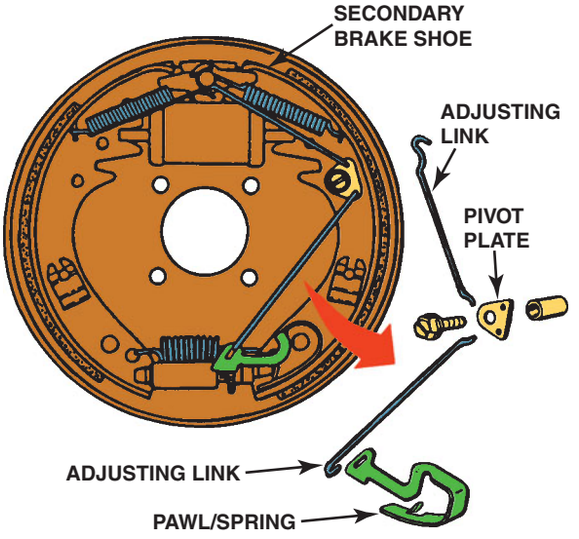


FIGURE 99–30 A link-actuated starwheel adjuster. This type of adjuster makes the adjustment when the brakes are released.

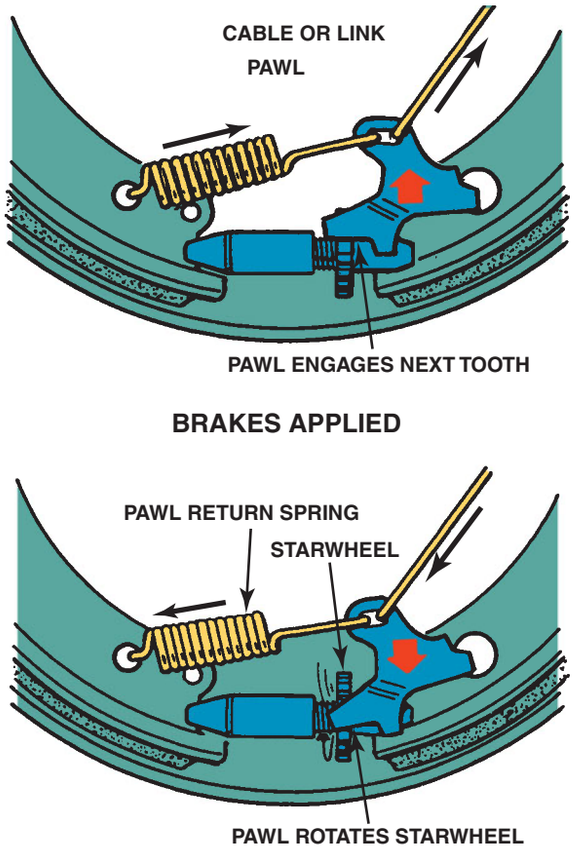


FIGURE 99–31 The operation of a typical self-adjuster. Notice that the adjuster actually moves the starwheel.

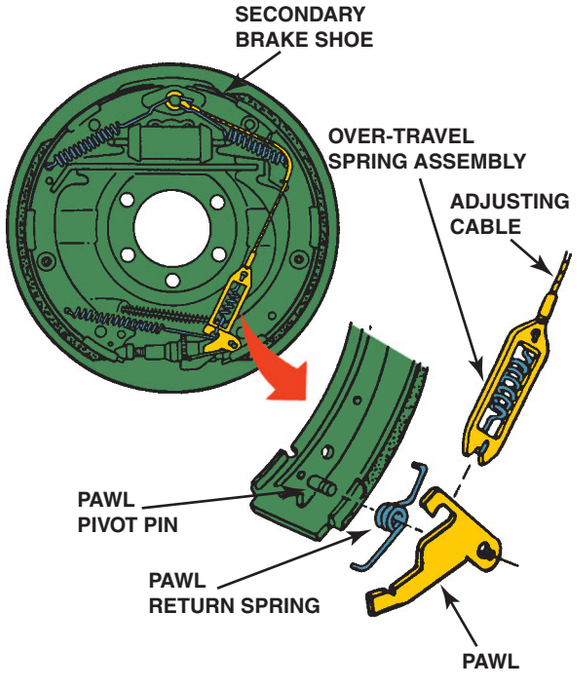


FIGURE 99–32 A cable-actuated starwheel adjuster with an over-travel spring.

overadjustment if the brakes are applied very hard and fast. It also prevents damage to the adjusting mechanism if the starwheel seizes or is otherwise unable to rotate.

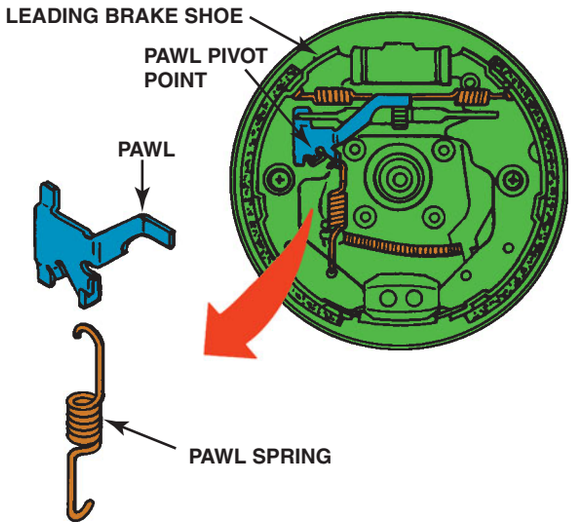


FIGURE 99–33 A non-servo brake with a lever-actuated starwheel automatic adjuster on a leading shoe. This type of adjuster makes an adjustment as the brakes are applied.

The lever starwheel adjuster makes the adjustment as the brakes are applied rather than released. The operation includes the following actions:

- As the secondary shoe moves away from the anchor, the solid link between the anchor and the top of the adjuster lever forces the lever to rotate around the pivot point where it attaches to the brake shoe.
- This moves the bottom half of the lever downward, which causes the pawl to rotate the starwheel and make the adjustment.
- The separate pawl piece is free to pivot on the lever to prevent damage if the starwheel will not rotate.
- When the brakes are released, the return springs lift the lever. If the brakes have worn enough, the end of the lever engages the next tooth on the starwheel and additional adjustment will be made the next time the brakes are applied.

NON-SERVO STARWHEEL AUTOMATIC ADJUSTERS

OPERATION. The starwheel automatic adjusters used on non-servo brakes may be mounted on either the leading or trailing shoe. These types of adjusters work whenever the brakes are applied—in either the forward or reverse direction. A leading-shoe design is shown in ● **FIGURE 99–33.**

When the brakes are not applied, the adjuster pawl is held in position by the parking brake strut. When the brakes are applied and the primary shoe moves out toward the brake drum (away from the parking brake strut), the pawl spring pivots the pawl downward where it mounts on the brake shoe and rotates the starwheel to adjust the brake. When the brakes are released, the return springs retract the shoes and the pawl is levered back into its resting position by the parking brake strut. If the linings have worn far enough, the lever engages the next tooth on the starwheel and further adjustment will occur the next time the brakes are applied.

The trailing-shoe non-servo starwheel adjuster shown in ● **FIGURE 99–34** works somewhat like the leading-shoe design, but it makes the adjustment as the brakes are released rather than applied. The upper shoe return spring in this design returns the brake shoes and operates the automatic adjuster, as follows:

- When the brakes are not applied, spring tension holds the trailing shoe and the adjuster pawl tightly against the parking brake strut.

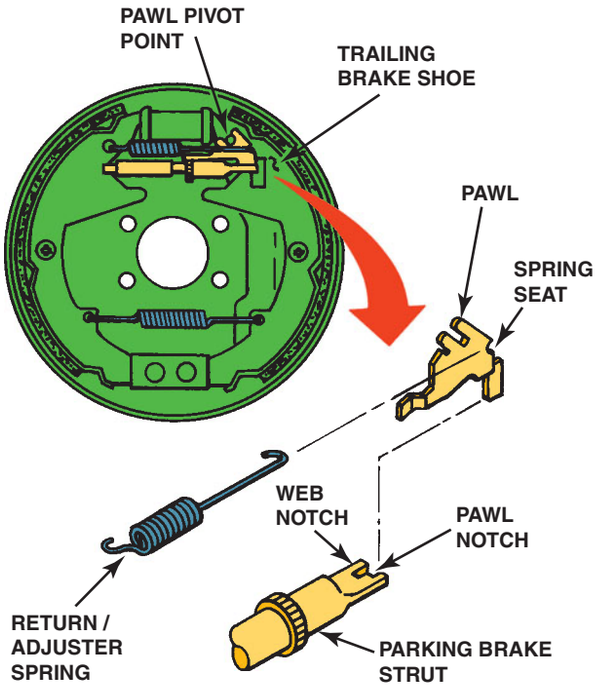


FIGURE 99–34 A non-servo brake with a lever-actuated star-wheel automatic adjuster on the trailing shoe. This type of adjuster makes the adjustment as the brakes are released.

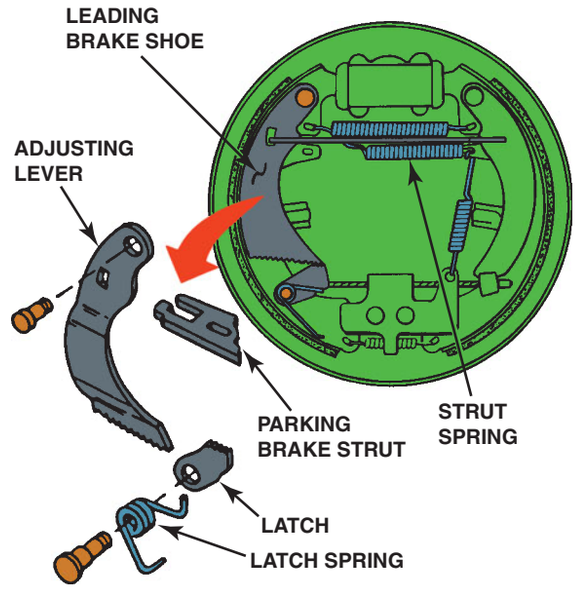


FIGURE 99–35 A lever-latch ratchet automatic adjuster.

- When the brakes are applied, the trailing shoe moves out toward the drum and away from the parking brake strut. This allows the adjuster pawl, which is restrained by the return spring, to pivot where it attaches to the brake shoe, causing the adjuster arm to move upward.
- If the brakes have worn far enough, the arm will engage the next tooth of the starwheel.
- When the brakes are released, the return spring pulls the brake shoes back together and the parking brake strut levers the adjuster pawl downward to rotate the starwheel and adjust the brakes.

RATCHET-TYPE AUTOMATIC ADJUSTERS

Most ratchet automatic adjusters use movement of the brake shoes to adjust the lining-to-drum clearance. The adjustment of a ratchet adjuster is carried out by two parts that have small interlocking teeth. As the adjustment is made, the two toothed elements ratchet across one another. Once adjustment is complete, the teeth lock together to hold the brake shoes in their new positions.

LEVER-LATCH RATCHET AUTOMATIC ADJUSTER. The lever-latch automatic adjuster installs on the leading shoe of a non-servo brake and operates whenever the brakes are applied. ● **SEE FIGURE 99–35.** This design consists of a large lever and a smaller latch with interlocking teeth. A spring on the latch piece keeps it in contact with the lever to maintain the adjustment. One end of the parking brake strut hooks into an opening in the lever and the other end is held against the trailing brake shoe by a strong spring. As the brakes are applied and the shoes move outward toward the drum, the parking brake strut pulls on the adjuster lever and forces it to pivot inward from where it attaches to the top of the leading shoe. If the brakes are sufficiently worn, the bottom of the lever will ratchet one or more teeth on the latch. When the brakes are released, the parking brake strut, which bottoms against the lever, will hold the shoes farther apart to reduce the lining-to-drum clearance.

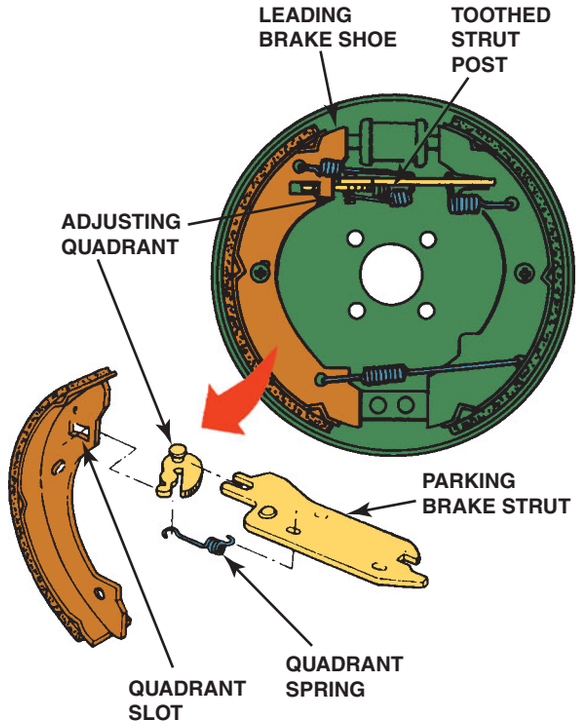


FIGURE 99–36 A strut-quadrant ratchet automatic adjuster.

STRUT-QUADRANT RATCHET AUTOMATIC ADJUSTER. The strut-quadrant automatic adjuster is used on some non-servo brakes. ● **SEE FIGURE 99–36.** The strut-quadrant adjuster consists of three basic parts:

1. The parking brake strut
2. Adjusting quadrant
3. A quadrant spring

The strut has a toothed post solidly mounted on its underside. The adjuster quadrant pivots on a pin that slips into a notch in the end of the strut, and the backside of the quadrant has a toothed, cam-shaped surface that interlocks with the toothed post on the strut. The quadrant also has an arm that extends through an opening in the web of the leading brake shoe. The outer side of this arm serves as the brake shoe stop when the brakes are released. The quadrant

TECH TIP

Cool the Brakes before Backing

Self-adjusters can overadjust the rear drum brakes if the brake drums are hot and have increased in diameter due to the heat. For example, if a pickup truck towing a boat had to brake while backing down a long, steep grade to the boat ramp, the rear brake drums could become larger in diameter due to the heat created during braking. The brakes could overadjust if the driver repeatedly depresses and releases the brake pedal while backing the trailer down the boat ramp. Then, after the boat has been removed from the trailer and the rear brakes have cooled, the drums will shrink and keep the rear brakes from releasing, preventing the truck from moving up the ramp.

NOTE: Some drum brakes are equipped with a bimetallic heat sensor that prevents the self-adjusters from working if the brakes are hot.

spring holds the quadrant in contact with the post to maintain the adjustment.

STEP 1 When the brakes are applied, the leading shoe moves out toward the brake drum.

STEP 2 If there is sufficient wear of the brake lining, the edge of the slot in the shoe web contacts the inner side of the adjuster quadrant arm and pulls it outward.

STEP 3 When this happens, the toothed section of the quadrant is lifted away from the post on the parking brake strut.

STEP 4 The quadrant spring then rotates the quadrant until its pivot pin is bottomed in the slot in the parking brake strut.

STEP 5 When the brakes are released, the quadrant returns inward with the leading shoe.

STEP 6 The toothed section of the quadrant then engages the teeth on the strut post, causing the quadrant arm to remain in its new extended position that holds the shoes farther apart and reduces the lining-to-drum clearance.

REVIEW QUESTIONS

1. Describe the difference between a dual-servo and a leading–trailing drum brake system.
2. List all the parts of a typical drum brake.
3. Explain how a self-adjusting brake mechanism works.
4. What do the last two letters of the lining or pad edge code identify?

CHAPTER QUIZ

1. Two technicians are discussing drum brake shoes. Technician A says that forward and rearward facing shoes are the same and can be installed in either position on any drum brake system. Technician B says that the darker color lining should always be placed toward the front of the vehicle. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
2. Two technicians are discussing brake lining edge codes. Technician A says that the code can identify the manufacturer. Technician B says that all friction material from the same manufacturer will have the same edge codes. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
3. Technician A says that starwheel adjusters use different threads (left- and right-handed) for the left and right sides of the vehicle. Technician B says that a pawl moves the teeth of the starwheel adjuster. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
4. Technician A says that drum brakes can fail to slow the vehicle if driven through deep water. Technician B says that when drum brakes get hot, the brake pedal will drop because the drum expands away from the shoes. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
5. Technician A says that the anchor pin (shoe anchor) is used to hold one end of the primary and secondary shoe return springs. Technician B says that shoe anchor prevents the brake shoes from rotating with the drum when the brakes are applied. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. Drum brake shoes _____.
   a. Can have riveted linings
   b. Can have bonded linings
   c. Can have one shoe that is longer than the other on the same wheel brake
   d. All of the above are possible
7. Which lining does most of the braking on a dual-servo brake?
   a. Front (forward facing)
   b. Rear (rearward facing)
   c. Both contribute equally
   d. Depends on the speed of the vehicle
8. Which lining does most of the braking on a leading-trailing brake?
   a. Leading (forward facing)
   b. Trailing (rearward facing)
   c. Both contribute equally
   d. Depends on the speed of the vehicle

9. Two technicians are discussing drum brake self-adjusters. Technician A says that some brakes self-adjust when the brakes are released when the vehicle is driven in reverse. Technician B says that some brakes self-adjust when the brakes are applied rather than when released. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

10. A typical drum brake backing plate has how many shoe support pads (also called ledges)?
   a. 3
   b. 4
   c. 6
   d. 8

chapter 100 DRUM BRAKE DIAGNOSIS AND SERVICE

OBJECTIVES: **After studying Chapter 100, the reader will be able to:** • Prepare for the Brakes (A5) ASE certification test content area "B" (Drum Brake Diagnosis and Repair). • Discuss symptom diagnosis of drum brakes • Describe how to inspect drum brake components such as wheel cylinders, brake shoes and springs. • Explain why wheel cylinders should be replaced or serviced. • Discuss the procedure recommended for brake drum removal. • Discuss the inspection and lubrication points of the backing plate. • Explain the importance of the proper drum brake hardware. • Disassemble and reassemble a drum brake assembly.

KEY TERMS: Bearingized 1105 • Brake hardware kits 1107 • Speed nuts 1102 • Tinnerman nuts 1102

DRUM BRAKE FAULTS

Drum brakes are very reliable and usually work well for many years and miles. However, like anything mechanical, drum brakes wear and faults can occur. Faults that can occur include:

- Brake lining wear and braking force is reduced.
- Brake springs get weaker due to being exposed to hot brake temperatures and the outside elements such as water and salt in northern areas.
- Brake drum wear as a result of the friction material on the brake shoes rubbing on the friction surface.
- Parking brake mechanisms can wear, rust or corrode. That often allows the brake shoe to fail to retract leading to premature brake shoe and drum wear.
- Faults such as contaminated brake shoes that can cause the drum brakes to grab or lockup.

DRUM BRAKE DIAGNOSIS

Diagnosing brake concerns includes the following steps:

STEP 1 Verify the customer complaint (concern). For example, common drum brake concerns include:
- Low brake pedal
- Parking brake does not hold the vehicle on a hill
- Noise while braking
- Noise when the vehicle is moving, but the brakes are not applied

STEP 2 Perform a visual inspection of the brakes and related parts, such as the wheels, tires, and suspension system.

STEP 3 Determine the root cause. For example, this could include determining that the parking brake linkage is corroded causing the brake shoes to wear. Replacing just the brake shoes will not correct the root cause.

STEP 4 Restore the brake system to like-new operation, which is the purpose of any repair.

STEP 5 Test-drive the vehicle to verify that the service has corrected the customer's complaint.

Drum brake service usually involves the following steps:

STEP 1 Remove the brake drums.

STEP 2 Inspect the brake drums for damage and measure the inside diameter and compare to specifications.

STEP 3 Inspect brake linings and hardware for wear or damage.

STEP 4 Inspect the wheel cylinder and brake lines for leakage.

STEP 5 Check the backing plate for excessive rust or wear.

BRAKE DRUM REMOVAL

The drum has to be removed before inspection or repair of a drum brake can begin. There are two basic types of drums, and the removal procedure depends on which type is being serviced. With either type it is usually recommended that the drums be marked with an "L" for left or an "R" for right so that they can be replaced in the same location.

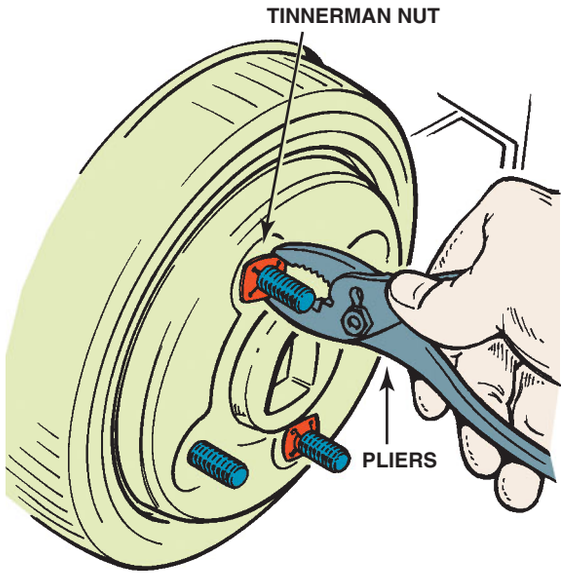


FIGURE 100–1 Tinnerman nuts are used at the assembly plant to prevent the brake drum from falling off until the wheels are installed.



FIGURE 100–2 Turning the bolts that are threaded into the brake drum forces the drum off of the hub.

HUB OR FIXED DRUMS

A fixed or hub-mounted drum is often used on the rear of front-wheel-drive vehicles. The drum has a hub for inner and outer bearings and is retained by a spindle nut. To remove the brake drum, remove the dust cap and cotter key that is used to retain the spindle nut. Remove the spindle nut and washer and then the brake drum can be carefully pulled off the spindle.

HUBLESS OR FLOATING DRUMS

Floating or hubless drums are usually used on the rear of a rear-wheel-drive vehicle. The drums are secured to the axle flange by the wheel and lug nuts. New vehicles have **tinnerman nuts** (clips), also called **speed nuts,** on the stud when the vehicle is being assembled. These thin sheet-metal nuts keep the brake drum from falling off during shipping and handling prior to installation of the rear wheels. ● **SEE FIGURE 100–1.**

The tinnerman nuts can be discarded because they are not needed after the vehicle leaves the assembly plant. After removing the wheels, the drum *should* move freely on the hub and slip off over the brake shoes. Some drum brakes have two threaded holes in the drum that allow bolts to be installed. ● **SEE FIGURE 100–2.**

By tightening the bolts, the drum is forced off of the hub. Two situations that can prevent the drum from being removed include the following:

1. **The Drum Is Rusted to the Hub.** The fit between the drum and the hub is very close because it is this center pilot hole in the drum that centers the drum on the axle. Rust and corrosion often causes the drum to seize to the hub. Use penetrating oil on the hub surface to help free the drum. Striking the area inside the wheel studs will usually break the drum loose from the hub. Sometimes a torch has to be used to expand the pilot hole.

   NOTE: Use of an air hammer with a flat-headed driver against the hub also works well to break the drum loose from the hub.

   CAUTION: Overheating or not allowing the drum to cool slowly can cause the brake drum to distort. Using a puller can also damage a drum.

2. **The Brake Shoes Are Worn into the Drum.** Even if the center hole is loose, many brake drums cannot be removed because the inner edge of the brake drum catches on the lining. Pulling outward on the drum often bends the backing plate or breaks some of the mounting hardware. To prevent damage, remove the adjuster plug from the backing plate or drum and back off the adjuster. ● **SEE FIGURE 100–3.**

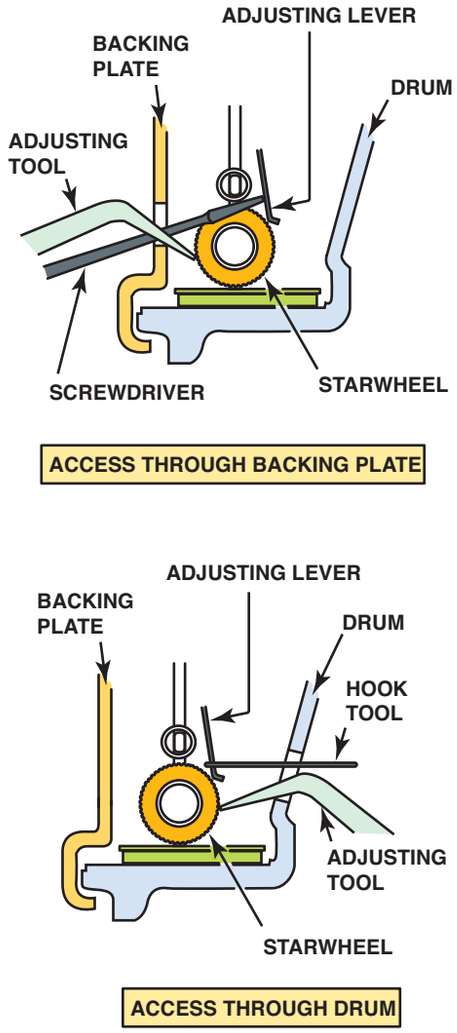


FIGURE 100–3 If the brake shoes have worn into the drum, the adjuster can be backed in after removing the access plug. After removing the plug, use a wire or a screwdriver to move the adjusting lever away from the starwheel, then turn the starwheel with a brake adjusting tool, often called a "brake spoon."

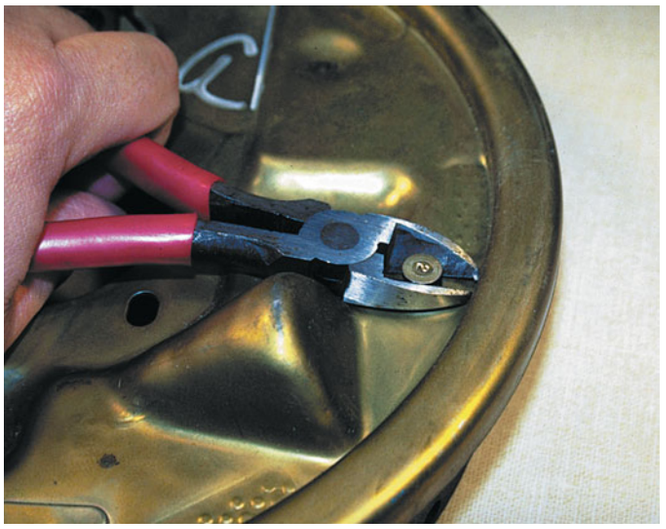


FIGURE 100–4 Using side-cut pliers to cut the heads off of the hold-down pins (nails) from the backing plate to release the drum from the shoes.

TECH TIP

Cutting the Nails Trick

Many times a brake drum cannot be removed because the linings have worn a groove into the drum. Attempting to adjust the brakes inward is often a frustrating and time-consuming operation. The easy solution is to use a pair of diagonal side-cut pliers and cut the heads off the hold-down pins (nails) at the backing plate. This releases the brake shoes from the backing plate and allows enough movement of the shoes to permit removal of the brake drum without bending the backing plate.

The hold-down pins (nails) must obviously be replaced, but they are included in most drum brake hardware kits. Since most brake experts recommend replacing all drum brake hardware anyway, this solution does not cost any more than normal, may save the backing plate from damage, and saves the service technician lots of time. ● **SEE FIGURE 100–4.**

NOTE: Be sure to reinstall the adjuster opening plugs. These plugs help keep water and debris out of the brakes.

After removing the brake drums, they should be cleaned, inspected, measured, and possibly machined before being returned to service.

DRUM BRAKE DISASSEMBLY

After removal of the brake drum, the brake shoes and other brake hardware should be wetted down with a solvent or enclosed in an approved evacuation system to prevent possible asbestos release into the air. Precautions should be taken to prevent any asbestos that may be present in the brake system from becoming airborne. Removal of the brake drum should occur inside a sealed vacuum enclosure equipped with a HEPA filter or washed with water or solvent. ● **SEE FIGURE 100–5.**

Usually, the first step in the disassembly of a drum brake system is removal of the return (retracting) springs. ● **SEE FIGURE 100–6.**



FIGURE 100–5 A liquid soaking solvent, such as brake cleaner, should be used to wet the linings. The purpose of wetting the lining material to prevent the possibility of asbestos from the lining becoming airborne. Asbestos is only hazardous when asbestos dust is airborne and is breathed in during brake system service.

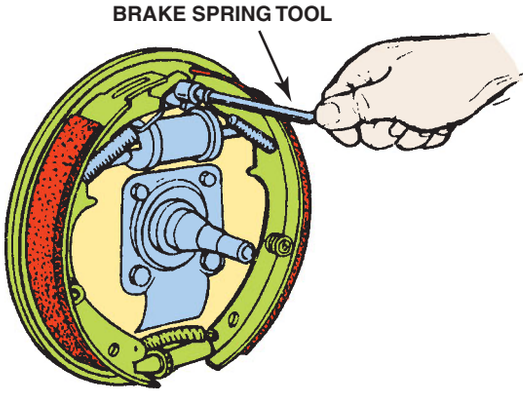


FIGURE 100–6 Using a brake spring tool to release a return (retracting) spring from the anchor pin.

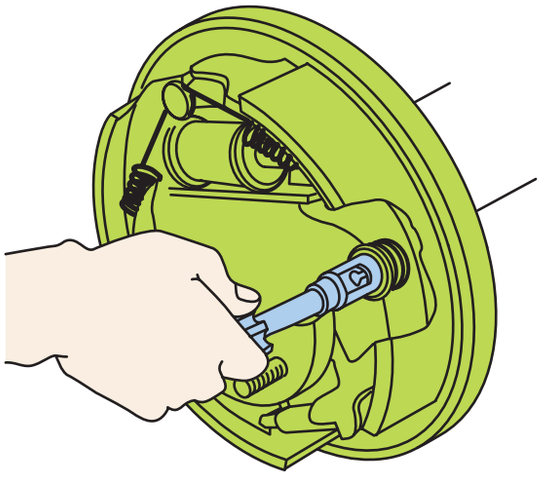


FIGURE 100–7 A special tool, called a hold-down spring tool, being used to depress and rotate the retainer.

After the return springs have been removed, the hold-down springs and other brake hardware can be removed. ● **SEE FIGURE 100–7.**

NOTE: There are generally no "exact" disassembly or reassembly procedures specified by the manufacturer. The order in which the parts are disassembled or reinstalled is based on experience and the personal preference of the technician.



FIGURE 100–8 A typical rusty backing plate shoe pad. This can cause the brakes to squeak when the shoes move outward during a brake application and again when the brake pedal is released.

INSPECTING THE BACKING PLATE

Once all drum brake components have been removed, inspect and service the backing plate. The backing plate supports the parts of the drum brake and helps to keep water from getting onto the brake shoes. The backing plate bolts to the rear axle or spindle and is made from stamped steel. Backing plates are plated (usually with cadmium) or painted to prevent rusting. To inspect the backing plate, follow these steps:

STEP 1 When brakes are serviced, the six raised contact surfaces, called pads, ledges, or shoe contact areas, of the backing plate should be inspected because they rub against the sides of the shoes. If the pads are worn more than 1/16 in. (1.5 mm), the backing plate should be replaced. ● **SEE FIGURE 100–8.**

STEP 2 The backing plate must be inspected for looseness or bending.

STEP 3 Backing plates should also be inspected to ensure that they are parallel with the axle flange.

STEP 4 The raised pads should be cleaned and lubricated. Lithium high-temperature brake grease, synthetic brake grease, silicone grease, or antiseize should be used to lubricate drum brake parts. ● **SEE FIGURE 100–9.**

DRUM BRAKE LINING INSPECTION

Both primary (front facing) and secondary (rear facing) lining material must be thicker than 0.060 in. (1.5 mm). To inspect the drum brake lining, follow these steps:

STEP 1 Some vehicles are equipped with holes in the backing plate that allow for a visual inspection of the thickness of the lining. Most vehicle and brake lining manufacturers recommend replacing worn brake lining when the thickness of the riveted lining reaches 0.060 in. or less. An American nickel is about 0.060 in. thick, so simply remember that you must always have at least "a nickel's worth of lining." ● **SEE FIGURE 100–10.**



FIGURE 100–9 Applying lithium grease to the raised pads on the backing plate.



FIGURE 100–10 A rule of thumb is that the lining should be at least the thickness of a nickel. This applies to both drum brake shoes and disc brake pads.

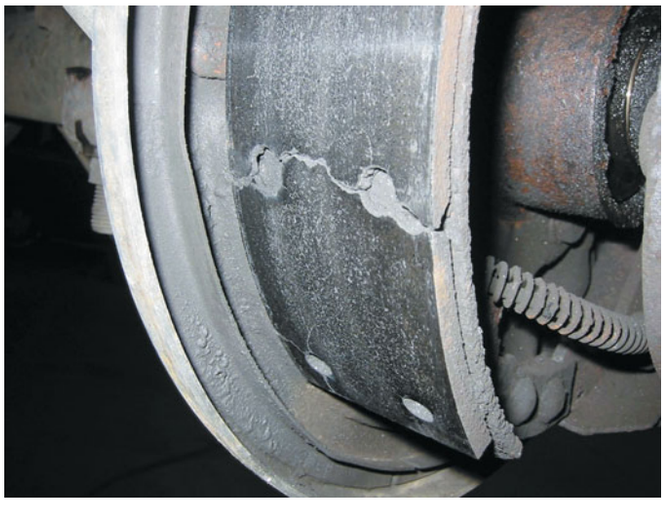


FIGURE 100–11 Cracked brake lining must be replaced.

STEP 2 Most experts agree that the best possible inspection involves removing the brake drum and making a thorough visual inspection of the entire brake instead of just looking at the thickness of the remaining lining. If a riveted brake lining is cracked between rivets, the lining should be replaced. ● **SEE FIGURE 100–11.**



FIGURE 100–12 The top spring is a good-looking spring because all coils of the spring are touching each other. The bottom spring is stretched and should be discarded. The arrow points to the back side of the spring, which goes into a hole in the brake shoe. The open loop of the spring is not strong enough to keep from straightening out during use. Using the back side of the hook provides a strong, long-lasting hold in the brake shoe.

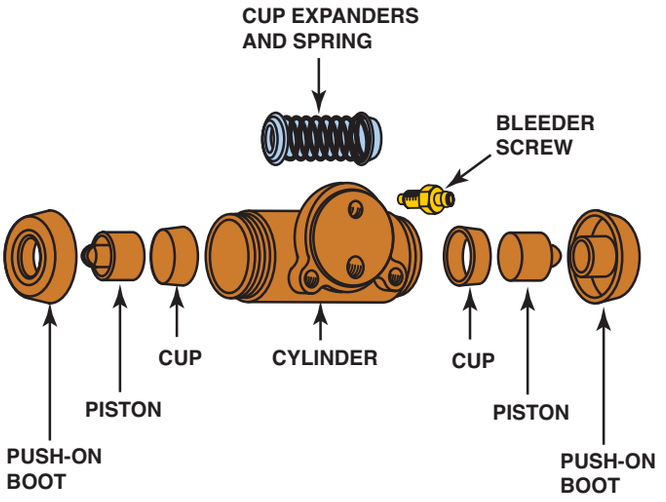


FIGURE 100–13 Exploded view of a typical wheel cylinder. Note how the flat part of the cups touches the flat part of the piston. The cup expander and spring go between the cups.

TECH TIP

The Drop Test

Brake return (retracting) springs can be tested by dropping them to the floor. A good spring should "thud" when the spring hits the ground. This noise indicates that the spring has not stretched and that all coils of the springs are touching each other. If the spring "rings" when dropped, the spring should be replaced because the coils are not touching each other. ● **SEE FIGURE 100–12.**

Although this drop test is often used, many experts recommend replacing all brake springs every time the brake linings are replaced. Heat generated by the brake system often weakens springs enough to affect their ability to retract brake shoes, especially when hot, yet not "ring" when dropped.

BRAKE SPRING INSPECTION

RETURN SPRINGS Each lining has a return spring (retracting spring) that returns the brake shoes back from the drums whenever the brakes are released. The springs are called primary and secondary return springs. The primary return spring attaches to the primary brake shoe and the secondary return spring attaches to the secondary brake shoe. These springs should be tested prior to a brake overhaul, especially when uneven lining wear is discovered.

Some drum brakes use a spring that connects the primary and secondary shoes and is commonly called a shoe-to-shoe spring. Return springs can get weak due to heat and time and can cause the linings to stay in contact with the drum when the brakes are released.

HOLD-DOWN SPRINGS Hold-down springs (one on each shoe) are springs used with a retainer and a hold-down spring pin (or nail) to keep the linings on the backing plate. Other types of hold-down springs include U-shape, flat spring steel type, and the combination return-and-hold spring. These springs still allow the freedom of movement necessary for proper braking operation.

CONNECTING SPRING (ADJUSTING SCREW SPRING) The connecting spring attaches to the lower portion and connects the two shoes together. Check or replace at every brake lining change for best results.

WHEEL CYLINDER INSPECTION

Drum brake wheel cylinders are cast iron that are bored and finished to provide a smooth finish for the wheel cylinder seals and pistons. This special finish is called **bearingized.** The final step in manufacture of the wheel cylinder is to force a hardened steel ball through the bore to bend over the "grain" of the metal and to smooth the inner surface. This process provides a smooth porous-free surface for the sealing caps to travel over. It is this bearingized surface finish on the inside of the wheel cylinder that is often destroyed when a wheel cylinder is honed.

CAUTION: It is because of this bearingized surface finish that most vehicle manufacturers do not recommend that wheel cylinders be honed. Be sure to follow the vehicle manufacturer's recommended procedures. Some manufacturers state that the wheel cylinders can be overhauled using new (replacement) sealing cups and dust shields after cleaning the cylinder bore only.

Outside each wheel cylinder piston are dust boots installed to keep dirt out of the cylinder bore. Between both piston sealing cups there is a spring with piston seal expanders to keep the seals from collapsing toward each other and to keep pressure exerted on the lips of both sealing cups to ensure proper sealing. ● **SEE FIGURE 100–13.**

On the back of each wheel cylinder there is a threaded hole for the brake line and a bleeder valve that can be loosened to remove (bleed) air from the hydraulic system. The wheel cylinder is bolted or clipped to the backing plate. ● **SEE FIGURES 100–14 AND 100–15.**

WHEEL CYLINDER SERVICE Most repair procedures involve replacement of the wheel cylinder assembly. However, overhauling the wheel cylinder can be done if recommended by the vehicle

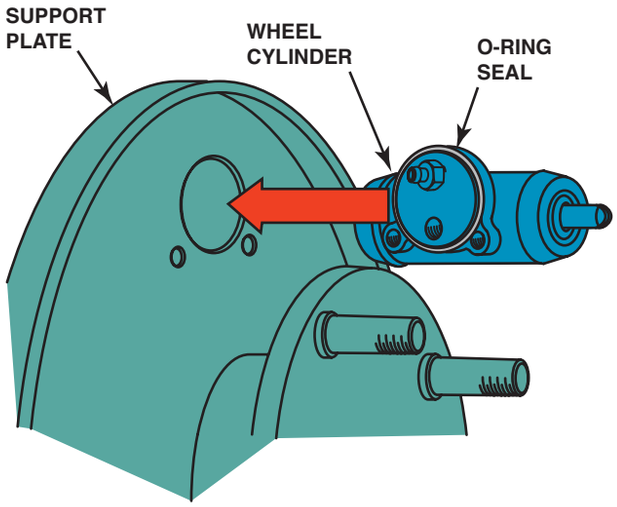


FIGURE 100–14 Many wheel cylinders are bolted to the support plate (backing plate). The O-ring seal helps keep water and dirt out of the drum brake.

TECH TIP

Wet Is OK—Dripping Is Not OK

When inspecting a wheel cylinder, use a blunt nose tool and pry up the dust boot. If the inside of the seal is wet, this means that some seepage has occurred, which is normal. If, however, brake fluid drips from the dust seal, this indicates that the wheel cylinder sealing cups have failed and the wheel cylinder should be replaced. Also check to see if the internal pistons can move easily by pushing on the pushrods. Replace the wheel cylinder if a piston does not move.

manufacturer and is often the only option on antique or restored muscle cars if the parts are available. The following steps and procedures should be followed:

STEP 1 Loosen the bleeder valve. If unable to loosen the bleeder valve without having it break off, a new replacement wheel cylinder is required. To help prevent broken bleeder valves, attempt to tighten the bleeder valve while tapping on the valve to loosen the rust before loosening the valve.

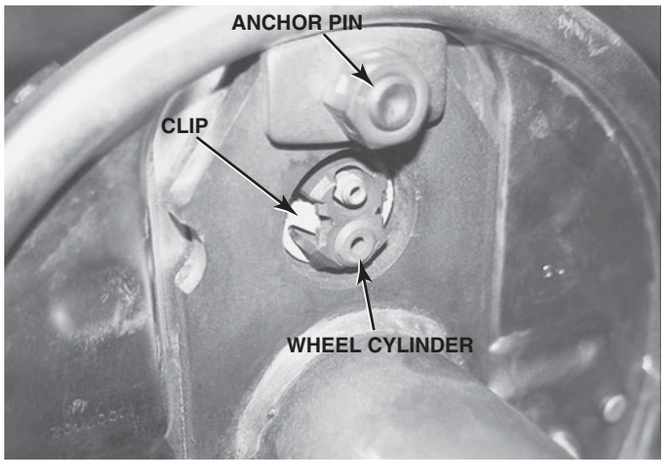
STEP 2 To remove the wheel cylinder, the brake line must first be removed from the wheel cylinder. Unbolt or remove the wheel cylinder retainer clip. Be sure to check that the brake line nut is turning on the brake line to avoid breaking the brake line.

STEP 3 If the bleeder valve can be removed, remove all internal parts of the wheel cylinder.

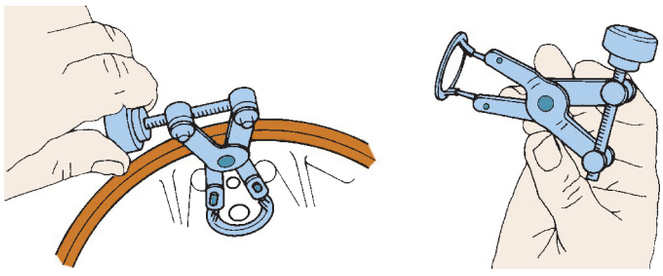
NOTE: With some vehicles equipped with piston stops, the wheel cylinder must be unbolted from the backing plate to enable removal of the seals and piston.

STEP 4 Clean and/or hone a wheel cylinder as specified by the manufacturer to remove any rust and corrosion. ● **SEE FIGURE 100–16.**

STEP 5 Install the pistons (usually not included in a wheel cylinder overhaul kit), seals, spring, and dust boots. Install on the vehicle and bleed the system.



(a)



(b)

FIGURE 100–15 (a) Some wheel cylinders are simply clipped to the backing plate. (b) This special tool makes it a lot easier to remove the wheel cylinder clip. A socket (1 1/8 in., 12 point) can be used to push the clip back onto the wheel cylinder.

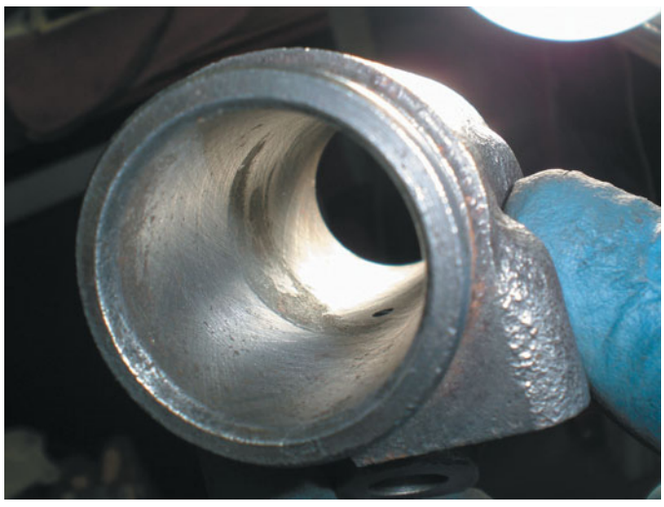


FIGURE 100–16 The rust inside this wheel cylinder will not affect the operation as it is located inside the working area of the sealing cups.

NOTE: Even though the wheel cylinder is not leaking, some brake experts recommend replacing or rebuilding the wheel cylinder every time new replacement linings are installed. Any sludge buildup in the wheel cylinder can cause the wheel cylinder to start to leak shortly after a brake job. When the new, thicker replacement linings are installed, the wheel cylinder piston may be pushed inward enough to cause the cup seals to ride on a pitted or corroded section of the wheel cylinder. As the cup seal moves over this rough area, the seal can lose its ability to maintain brake fluid pressure and an external brake fluid leak can occur. ● **SEE FIGURE 100–17.**

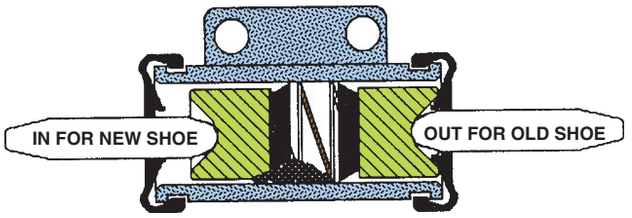


FIGURE 100–17 When new, thicker brake linings are installed, the pistons and cups are forced back into the wheel cylinder and pushed through the sludge that is present in every cylinder.

TECH TIP

Time—Not Mileage—Is Important

Many brake experts recommend rebuilding or replacing wheel cylinders at every other brake job. Some experts recommend that the wheel cylinders be overhauled or replaced every time the brake linings are replaced. If the wheel cylinders are found to be leaking, they must be replaced or overhauled. The most important factor is time, not mileage, when determining when to repair or replace hydraulic components.

The longer the time, the more moisture is absorbed by the brake fluid. The greater the amount of moisture absorbed by the brake fluid, the greater the corrosion to metal hydraulic components. For example, the brakes will probably wear out much sooner on a vehicle that is used all day every day than on a vehicle driven only a short distance every week. In this example, the high-mileage vehicle may need replacement brake linings every year, whereas the short-distance vehicle will require several years before replacement brakes are needed. The service technician should try to determine the amount of time the brake fluid has been in the vehicle. The longer the brake fluid has been in the system, the greater the chances that the wheel cylinders need to be replaced or overhauled.

DRUM BRAKE HARDWARE KIT

If any spring is found to be defective, it is possible to purchase most parts individually or in pairs. However, for best results, many brake suppliers sell drum **brake hardware kits.** These kits usually include the items listed below for two drum brakes (axle set):

1. Primary and secondary return springs
2. Connecting spring
3. Hold-down springs
4. Hold-down spring retainers
5. Hold-down spring pins (nails)

Self-adjuster kits are available if needed. Other brake parts such as adjusters are available separately or as part of a self-adjuster kit. **SEE FIGURE 100–18.**



FIGURE 100–18 This starwheel adjuster is damaged and must be replaced. A lack of proper lubrication can cause the starwheel to become frozen in one place and not adjust properly.

INSPECTING THE DRUM BRAKE SHOES

Carefully inspect the replacement brake shoes. Check all of the following:

1. Check that the replacements are exactly the same size (width and diameter) as the original. Hold the replacement shoes up against the old shoes to make the comparison.
2. Check for sound rivets (if rivet type). The friction material should also be snug against the metal brake shoe backing.

After checking that the replacement brake lining is correct, place the old shoes into the new linings' box. This helps ensure proper credit for the old shoes (called the core) as well as protection against asbestos contamination exposure.

BRAKE PARTS CLEANING

Whenever cleaning brake parts or components always use the following guidelines:

- Denatured alcohol or "brake clean" should only be used to clean brake parts that are disassembled. When individual parts are cleaned, they should be allowed to dry before being assembled.
- Never clean or flush assembled brake components with denatured alcohol or brake clean. Often, the alcohol cannot evaporate entirely from an assembled component. The trapped alcohol will evaporate inside the brake system, causing contamination. The trapped alcohol vapors also act like trapped air in the braking system and can cause a spongy brake pedal.

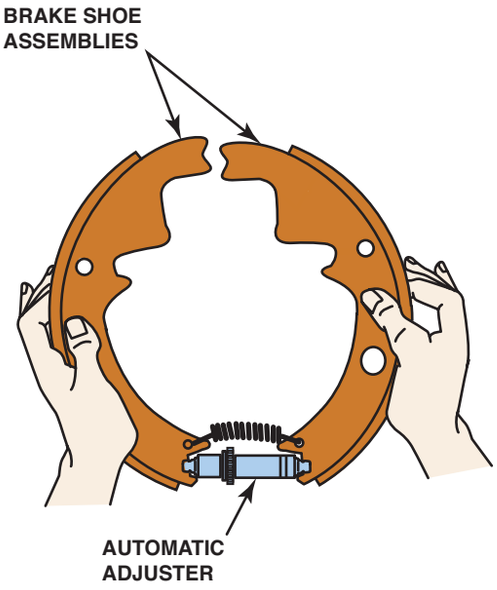


FIGURE 100–19 Pre-assembly of the starwheel adjuster with its connecting spring often helps when reassembling a drum brake.

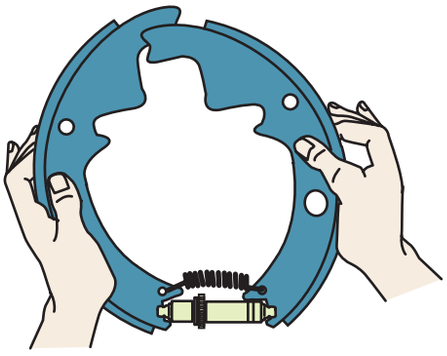


FIGURE 100–20 Sometimes it is necessary to cross the shoes when pre-assembling the starwheel adjuster and connecting spring.

REASSEMBLING THE DRUM BRAKE

Reassembling the drum brake includes the following steps:

STEP 1 Carefully clean the backing plate.

STEP 2 Check the anchor pin for looseness.

STEP 3 Lubricate the shoe contact surfaces (shoe pads) with anti-seize, brake grease, or synthetic grease.

STEP 4 Reassemble the primary and secondary shoes and brake strut, along with all springs.

STEP 5 Finish assembling the drum brake, being careful to note the correct location of all springs and parts.

NOTE: Many technicians preassemble the primary and secondary shoes with the connecting (lower retracting) spring as a unit before installing them onto the backing plate. ● **SEE FIGURES 100–19 AND 100–20.**

Most self-adjusters operate off the rear (secondary) shoe and should therefore be assembled toward the rear of the vehicle. Be sure that the star wheel adjuster is used on the correct side of the vehicle as the threads are different. The self adjuster for one side of the vehicle has right hand threads and the adjuster for the other side has left hand threads. This means that the self adjusters should be marked, if they are not already marked, and kept separated until they are placed on the correct side and then the connecting spring can be installed. ● **SEE FIGURE 100–21.**

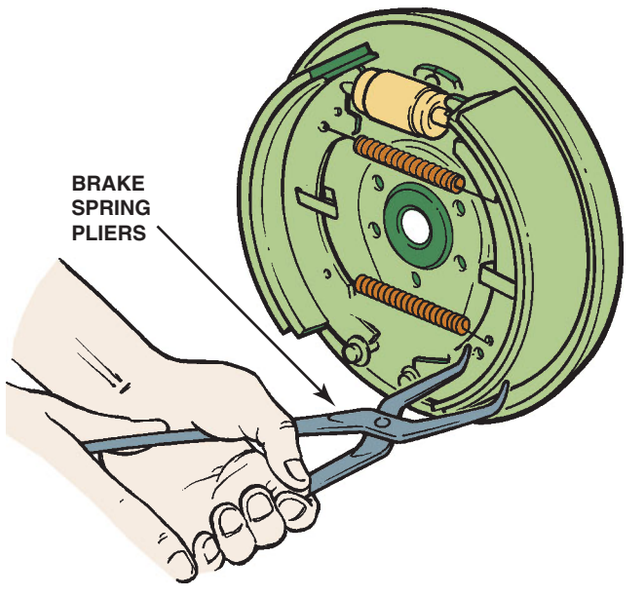


FIGURE 100–21 Brake spring pliers being used to install the connecting spring.

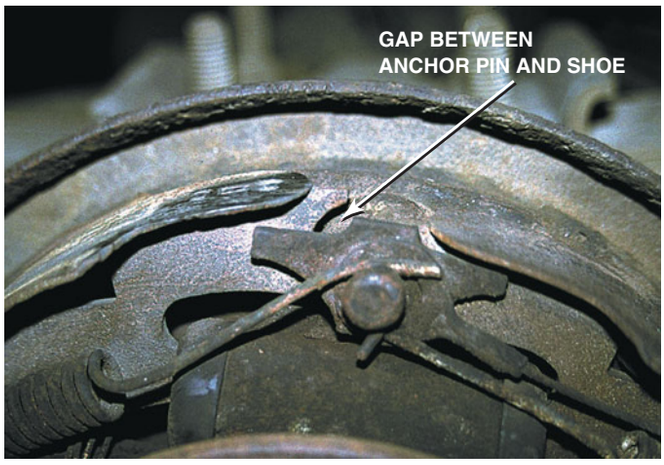


FIGURE 100–22 Notice that the brake shoe is not contacting the anchor pin. This often occurs when the parking brake cable is stuck or not adjusted properly.

ADJUSTING DRUM BRAKES

Most drum brakes are adjusted by rotating a starwheel or rotary adjuster. As the adjuster is moved, the brake shoes move toward the drum. If the brakes have been assembled correctly and with the parking brake fully released, both brake shoes should make contact with the anchor pin at the top. ● **SEE FIGURE 100–22** for an example where one shoe does not make contact with the anchor pin.

If the clearance between the brake shoes and the brake drum is excessive, a low brake pedal results. The wheel cylinder travel may not be adequate to cause the lining to contact the drums. Often, the driver has to pump the brakes to force enough brake fluid into the wheel cylinder to move it enough for braking action to occur.

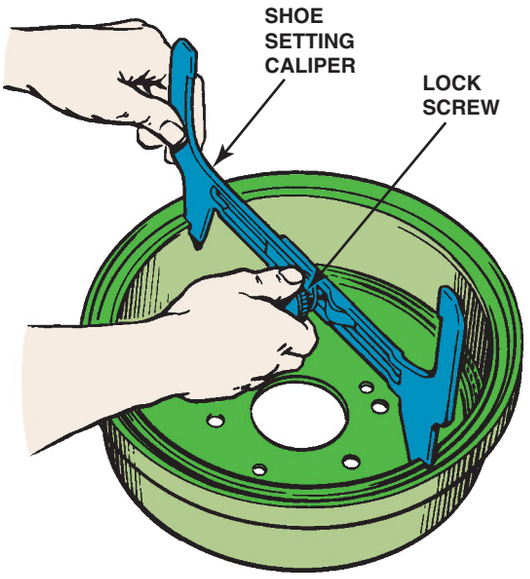


FIGURE 100–23 The first step in using a brake shoe clearance gauge is to adjust it to the drum inside diameter and tighten the lock screw.

Many technicians use a brake shoe setting gauge to adjust the brake shoes before installing the drum. ● **SEE FIGURES 100–23 AND 100–24.**

CAUTION: Before installing the brake drum, be sure to clean any grease off the brake lining. Some experts warn not to use sandpaper on the lining to remove grease. The sandpaper may release asbestos fiber into the air. Grease on the linings can cause the brakes to grab.

LUBRICATION CHECKLIST

For proper operation, the following points should be lubricated with approved brake lubricant:

1. The starwheel adjuster threads and under end caps
2. The backing plate contact areas (pads or ledges)
3. Anchor pins

CAUTION: Do not use wheel bearing or chassis grease on a braking system. Use only approved brake lubricant such as molybdenum disulfide (moly) grease, synthetic grease, lithium-based brake grease, or antiseize compound.

Also, be sure to check and lubricate the parking brake cable, if necessary.

DRUM BRAKE SYMPTOM-BASED GUIDE

LOW PEDAL OR THE PEDAL GOES TO THE FLOOR Possible causes for low pedal include the following:

1. Excessive clearance between the linings and drum
2. Automatic adjusters not working

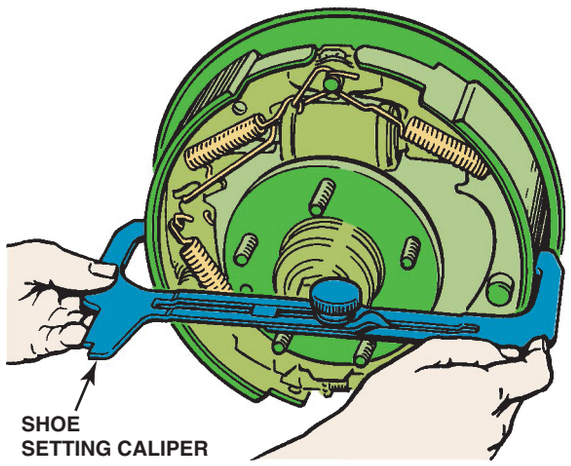


FIGURE 100–24 Place the gauge over the shoes and adjust the brakes until they contact the inside of the gauge.



FIGURE 100–25 To prevent getting grease on the lining, the wise service technician covers the friction material with masking tape. The tape is removed after the brake shoes have been installed.

TECH TIP

The Masking Tape Trick

Some technicians cover the friction material with masking tape to prevent contaminating the linings with dirt or grease during installation. After everything has been installed and double-checked, the masking tape is removed and the brake drums are installed. ● **SEE FIGURE 100–25.**

3. Leaking wheel cylinder
4. Air in the system

SPRINGY, SPONGY PEDAL Possible causes for springy, spongy pedal include the following:

1. Drums worn below specifications
2. Air in the system

EXCESSIVE PEDAL EFFORT REQUIRED TO STOP THE VEHICLE Possible causes for excessive pedal pressure include the following:

1. Grease or fluid-soaked linings
2. Frozen wheel cylinder pistons
3. Linings installed on wrong shoes

LIGHT PEDAL EFFORT—BRAKES TOO SENSITIVE Possible causes for light pedal pressure include the following:

1. Brake adjustment not correct
2. Loose backing plate
3. Lining loose on the shoe
4. Excessive dust and dirt in the drums
5. Scored, bell-mouthed, or barrel-shaped drum
6. Improper lining contact pattern

BRAKE PEDAL TRAVEL DECREASING Possible causes for brake pedal travel decreasing include the following:

1. Weak shoe retracting springs
2. Wheel cylinder pistons sticking

PULSATING BRAKE PEDAL (PARKING BRAKE APPLY PULSATES ALSO) Possible cause for pulsating brake pedal include the following:

1. Drums out-of-round

BRAKES FADE (TEMPORARY LOSS OF BRAKE EFFECTIVENESS WHEN HOT) Possible causes for brake fade include the following:

1. Poor lining contact
2. Drums worn below the discard dimension
3. Charred or glazed linings

SHOE CLICK NOISE Possible causes for shoe click noise include the following:

1. Shoes lift off the backing plate and snap back
2. Hold-down springs weak
3. Shoe bent
4. Grooves in the backing plate pads

THUMPING NOISE WHEN BRAKES ARE APPLIED Possible causes for thumping noise include the following:

1. Cracked drum; hard spots in the drum
2. Retractor springs unequal—weak

GRINDING NOISE Possible causes for grinding noise include the following:

1. Excessively worn braking lining
2. Bent shoe web
3. Brake improperly assembled

ONE WHEEL DRAGS Possible causes for one wheel dragging include the following:

1. Weak or broken shoe retracting springs
2. Brake-shoe-to-drum clearance too tight—brake shoes not adjusted properly
3. Brake assembled improperly
4. Wheel cylinder piston cups swollen and distorted
5. Pistons sticking in the wheel cylinder
6. Drum out-of-round
7. Loose anchor pin/plate
8. Parking brake cable not free
9. Parking brake not adjusted properly

VEHICLE PULLS TO ONE SIDE Possible causes for vehicle pulling to one side include the following:

1. Brake adjustment not correct
2. Loose backing plate
3. Linings not of specified kind; primary and secondary shoes reversed or not replaced in pairs
4. Water, mud, or other material in brakes
5. Wheel cylinder sticking
6. Weak or broken shoe retracting springs
7. Drums out-of-round
8. Wheel cylinder size different on opposite sides
9. Scored drum

WET WEATHER: BRAKES GRAB OR WILL NOT HOLD Possible causes for brakes grabbing or not holding include the following:

1. Bent backing plate flange
2. Incorrect or abused shoe and linings

BRAKES SQUEAK Possible causes for brakes squeaking include the following:

1. Backing plate is bent or shoes twisted
2. Shoes scraping on backing plate pads
3. Weak or broken hold-down springs
4. Loose backing plate, anchor, or wheel cylinder
5. Glazed linings
6. Dry shoe pads and hold-down pin surfaces

BRAKES CHATTER Possible causes for brake chattering include the following:

1. Incorrect lining-to-drum clearance
2. Loose backing plate
3. Weak or broken retractor spring
4. Drums out-of-round
5. Tapered or barrel-shaped drums
6. Improper lining contact pattern



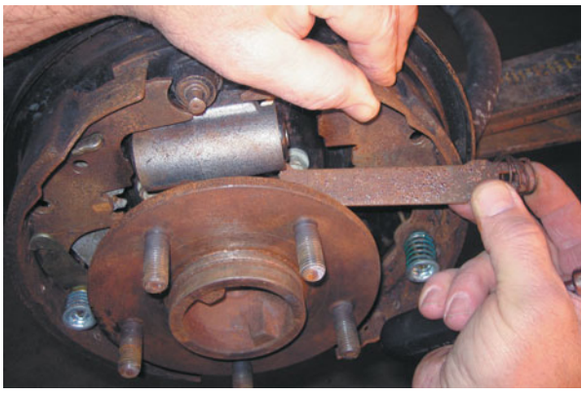
1 Tools needed to service a drum brake assembly include brake tools, silicone grease, wheel lug nut sockets, and torque limiting adapters or a torque wrench.



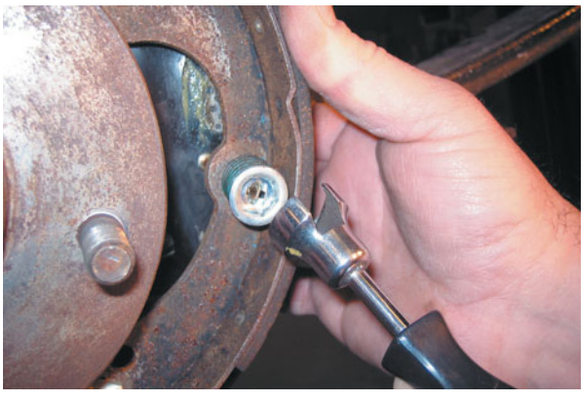
2 After safely hoisting the vehicle to chest height, remove the brake drum.



3 Remove the primary (forward facing) shoe return spring, using a brake tool. Then, remove the secondary return spring.



4 Remove the parking brake strut along with the antirattle spring.

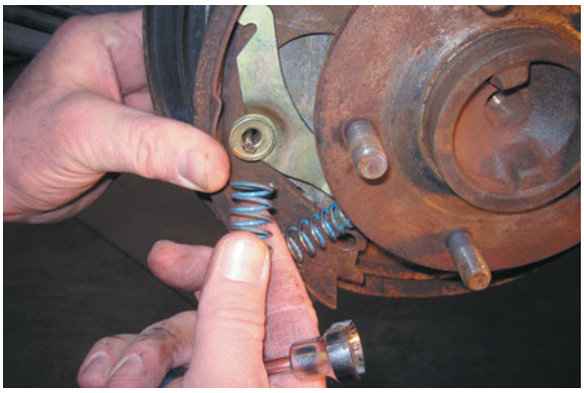


5 Use a brake tool to depress the hold-down spring, and then rotate it until the slot in the retainer lines up with the flattened part of the hold-down pin.



6 Removing the primary brake shoe plus the starwheel adjuster and connecting spring.

CONTINUED ▶



7 When the secondary lining hold-down spring is removed, the adjusting lever and pawl return spring can be removed.



8 The parking brake lever can now be disconnected from the secondary brake shoe.



9 Check the wheel cylinder for leakage. Check the pistons to see that they can move too during the inspection. This wheel cylinder is relatively new and not leaking.



10 Clean all six brake shoe ledges. Lubricate the ledges with silicone brake grease.



11 Many technicians prefer to assemble the connecting spring and starwheel adjuster to both shoes to help in the reinstallation.



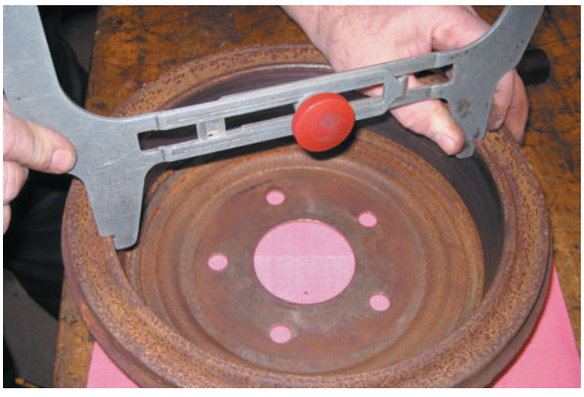
12 Attaching the parking brake lines to the secondary shoe. The assembled parts at the bottom help keep everything together.



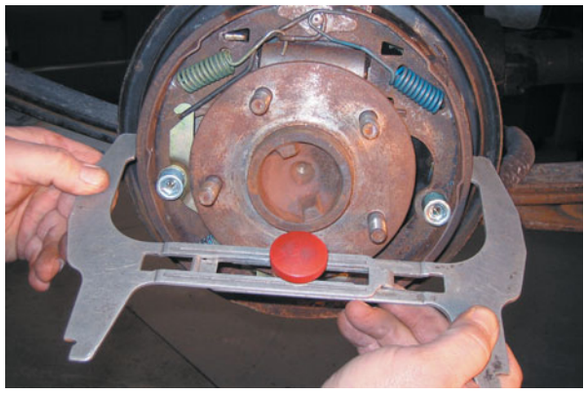
13 Installing the secondary shoe hold-down spring.



14 Installing the secondary shoe return spring. Note that the primary return spring has already been installed.



15 After installing the brake shoes and springs, use a drum/shoe clearance gauge and set it to the inside diameter of the drum.



16 Adjust the starwheel adjuster until the linings contact the drum brake shoe clearance gauge.



17 After installing the drum, it may be necessary to make the final adjustment using a brake adjusting tool (spoon).



18 After completing the brake service, be sure to cover the brake adjustment opening to prevent water from getting into the brake.

REVIEW QUESTIONS

1. Explain how to remove a brake drum.
2. List all items that should be lubricated on a drum brake.
3. List the steps necessary to follow when replacing drum brake linings.
4. Explain why many vehicle manufacturers do not recommend the wheel cylinder be honed.

CHAPTER QUIZ

1. Technician A says that the tinnerman nuts are used to hold the brake drum on and should be reinstalled when the drum is replaced. Technician B says that a drum should be removed inside a sealed vacuum enclosure or washed with water or solvent to prevent possible asbestos dust from being released into the air. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
2. The backing plate should be replaced if the shoe contact areas (pads or ledges) are worn more than _____.
   a. 1/2 in. (13 mm) **c.** 1/8 in. (4 mm)
   b. 1/4 in. (7 mm) **d.** 1/16 in. (1.5 mm)
3. Technician A says that silicone brake grease can be used to lubricate the shoe contact ledges. Technician B says that synthetic brake grease, lithium brake grease, or antiseize compound can be used as a brake lubricant. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
4. Most brake experts and vehicle manufacturers recommend replacing brake lining when the lining thickness is _____.
   a. 0.030 in. (0.8 mm) **c.** 0.050 in. (1.3 mm)
   b. 0.040 in. (1.0 mm) **d.** 0.060 in. (1.5 mm)
5. Technician A says that starwheel adjusters use different threads (left- and right-handed) for the left and right sides of the vehicle. Technician B says that the threads and end caps of the adjusters should be lubricated with brake grease before being installed. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
6. Technician A says that many vehicle manufacturers recommend that wheel cylinders not be honed because of the special surface finish inside the bore. Technician B says that some experts recommend that the wheel cylinders be replaced every time the brake linings are replaced. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
7. Most manufacturers recommend that brake parts should be cleaned with _____.
   a. Clean water only **c.** Stoddard solvent
   b. Denatured alcohol **d.** Detergent and water
8. Old brake shoes are often returned to the manufacturer when new friction material is installed. These old shoes are usually called the _____.
   a. Core **c.** Rim
   b. Web **d.** Nib
9. After assembling a drum brake, it is discovered that the brake drum will not fit over the new brake shoes. Technician A says that the parking brake cable may not have been fully released. Technician B says to check to see if both shoes are contacting the anchor pin. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
10. Technician A says to use masking tape temporarily over the lining material to help prevent getting grease on the lining. Technician B says that grease on the brake lining can cause the brakes to grab. Which technician is correct?
    a. Technician A only **c.** Both Technicians A and B
    b. Technician B only **d.** Neither Technician A nor B

chapter 101

DISC BRAKES

OBJECTIVES: **After studying Chapter 101, the reader will be able to:** • Prepare for the Brakes (A5) ASE certification test content area "C" (Disc Brake Diagnosis and Repair). • Describe how disc brakes function. • Name the parts of a typical disc brake system. • Describe the construction of disc brake pads. • Describe the difference between fixed caliper and floating or sliding caliper. • Explain the difference between a standard caliper and a low-drag caliper.

KEY TERMS: Anchor plate 1122 • Antirattle clips 1117 • Aramid fiber 1121 • Bonded linings 1120 • Brake block 1121 • Brake pad 1118 • CFRC 1121 • Fixed brake caliper 1122 • Floating caliper 1124 • Gas fade 1116 • Integrally molded 1120 • Kevlar 1121 • Lining fade 1115 • Low-drag caliper 1125 • Mechanical fade 1115 • Mold-bonded lining 1120 • NAO 1121 • NAS 1121 • Natural frequency 1117 • Nonasbestos 1121 • Pad wear indicators 1119 • Pin-slider caliper 1124 • Riveted linings 1120 • Semimets 1121 • Sintered metal 1121 • Sintering 1121 • Sliding caliper 1126 • Swept area 1115 • Water fade 1116 • Ways 1126

DISC BRAKES

PARTS AND OPERATION

Disc brakes use a piston(s) to squeeze friction material (pads) on both sides of a rotating disc (rotor). Disc may be spelled *disk* by some manufacturers, but *disc* is the SAE (Society of Automotive Engineers) term and the most commonly used spelling in the industry. The rotor is attached to and stops the wheel.

Disc brakes are used on the front wheels of late-model vehicles, and on the rear wheels of an increasing number of automobiles. Disc brakes were adopted primarily because they can supply greater stopping power than drum brakes with less likelihood of fade. This makes disc brakes especially well suited for use as front brakes, which must provide 60% to 80% of the vehicle's total stopping power.

DISC BRAKE ADVANTAGES

Although increased federal brake performance standards hastened the switch to disc brakes, the front drum brakes would eventually have been eliminated anyway because disc brakes are superior in almost every respect. The disc brake friction assembly has several significant strong points, and only a few relatively minor weak points. ● **SEE FIGURE 101–1.**

The main advantages of the disc brake include the following.

FADE RESISTANCE. The main design features that help disc brakes avoid heat-induced fade is their cooling ability because all of the major parts of a disc brake are exposed to the air flowing over the friction assembly. Many brake rotors also have cooling passages cast into them to further reduce operating temperatures and have greater fade resistance than drum brakes because they have greater swept area. **Swept area** is the amount of brake drum or rotor friction surface that moves past the brake linings every time the drum or rotor completes a rotation. Disc brakes are resistant to all kinds of fade, including the following:

- **Mechanical fade** is not a problem with disc brakes because, unlike a brake drum, the disc brake rotor expands *toward* the brake linings as it heats up rather than *away* from them. This fundamental design difference makes it physically impossible for heat to cause the rotor to expand out of contact with the brake linings. Because of this, there is never the need to move the brake linings out to keep them in contact with the rotor, so brake pedal travel does not increase. If the brake pedal on a vehicle with disc brakes drops toward the floor, it is almost always a sign of vapor lock, a fluid leak, fluid bypassing the seals in the master cylinder, or mechanical fade of the rear *drum* brakes.
- **Lining fade** can and does occur if the brakes become overheated. A little bit of heat brings the brake pads to their operating temperature and actually increases the friction coefficient of the lining material. A warm brake performs better than a cold brake. However, when too much heat is generated by braking, the lining material overheats. Its friction coefficient drops, and lining fade occurs.

  The primary symptom of lining fade is a hard brake pedal that requires the driver to apply greater force to maintain

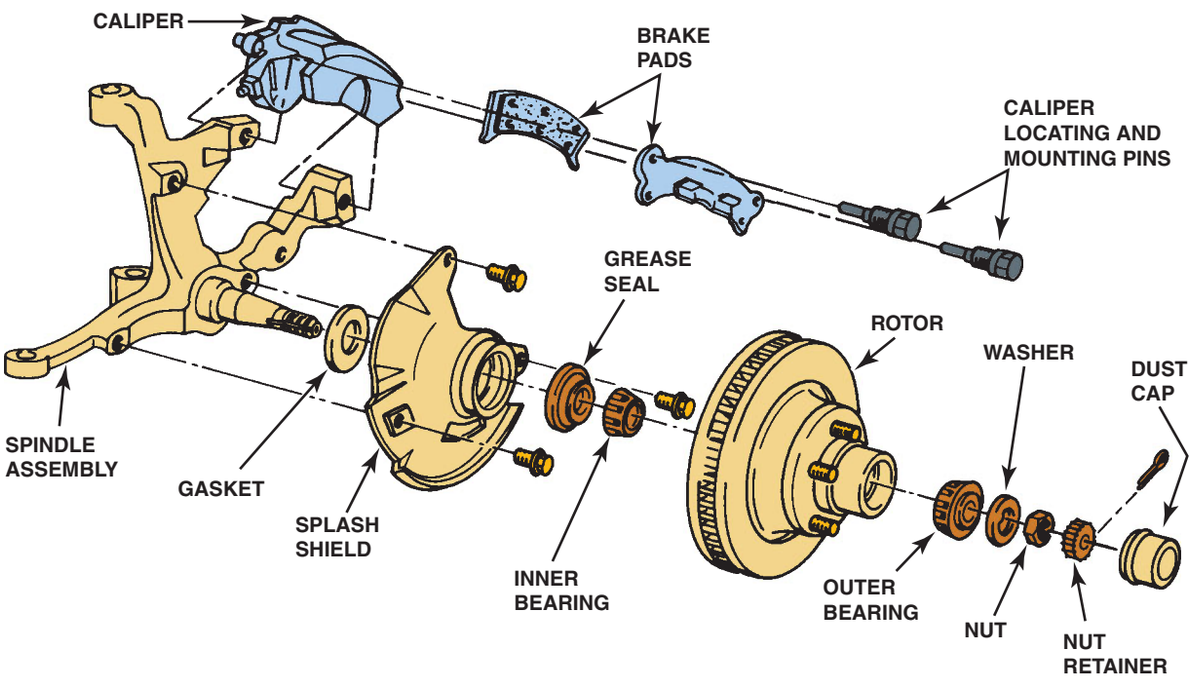


FIGURE 101–1 An exploded view of a typical disc brake assembly.

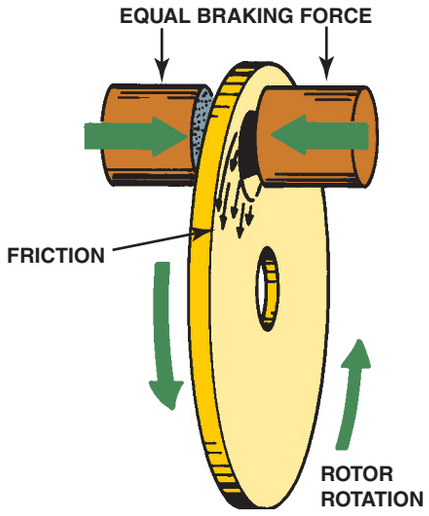


FIGURE 101–2 Braking force is applied equally to both sides of the brake rotor.



FIGURE 101–3 Disc brakes can absorb and dissipate a great deal of heat. During this demonstration, the brakes were gently applied as the engine drove the front wheels until the rotor became cherry red. During normal braking, the rotor temperature can exceed 350°F (180°C), and about 1,500°F (800°C) on a race vehicle.

stopping power. Unlike the similar situation in a drum brake, however, increased application force will not distort the brake rotor because the caliper applies equal force to both sides. ● **SEE FIGURE 101–2.**

Increased pressure will, however, create even more heat, and if brake lining temperatures continue to increase, gas fade and vapor lock of the hydraulic system can occur. If the pads are overheated to the point where the lining material is physically damaged, the brakes will not recover their full stopping power until the pads are replaced. ● **SEE FIGURE 101–3.**

- **Gas fade** is a problem only under severe braking conditions when hot gases and dust particles from the linings are trapped between the brake linings and rotor, where they act as lubricants. The symptoms of gas fade are the same as those for lining fade. The pedal becomes hard and increased force is required to maintain stopping power.

  Even though disc brakes operate at higher temperatures than drum brakes, they have fewer problems with gas fade for a number of reasons.

  1. Disc brakes do not have a drum to contain gases and particles in the area around the brake linings.

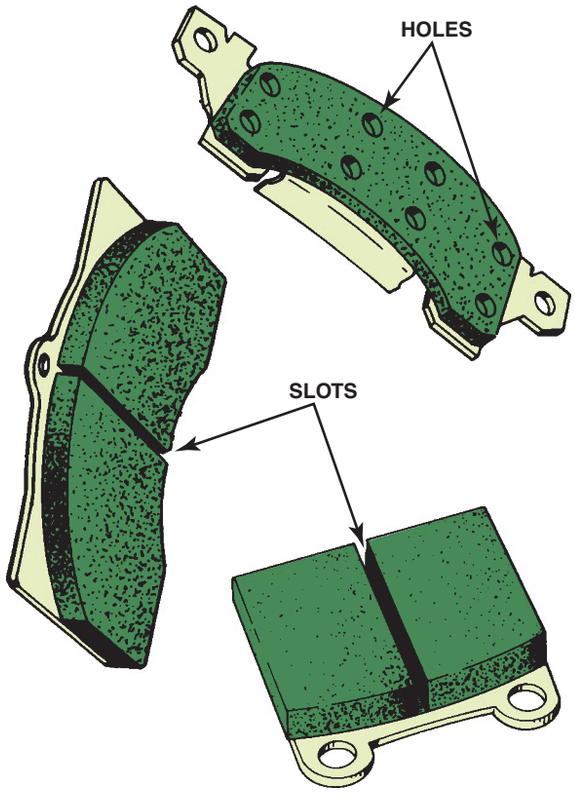


FIGURE 101–4 Slots and holes in the brake linings help prevent gas and water fade.

  2. The constant flow of air over the brake carries away contaminants that might otherwise build up.
  3. The surface area of the brake lining material in a disc brake is smaller than that of a comparable drum brake and this allows gases and particles to escape more easily.

  To help prevent gas fade, many brake pads have slots cut in the lining material. These slots allow gases and dust particles to escape. ● **SEE FIGURE 101–4.** The holes required in riveted linings also perform this function. For even greater protection against gas fade, high-performance vehicles and motorcycles sometimes have holes or slots cut into the rotor. These openings allow gases and water to escape, and their sharp edges continually wipe loose particles off the linings.

- **Water fade** is not a big problem with disc brakes because centrifugal force created by the spinning rotor throws off most moisture, and the brake pads positioned only a few thousandths of an inch away from the rotor continuously wipe it clean. When the brakes are applied, the leading edge of the brake pad lining material wipes the last bit of water from the disc. Once good lining-to-rotor contact is established, water is unable to enter the space between the linings and rotor until the brakes are released.

  Although far more resistant to water fade than drum brakes, disc brakes are not entirely free from its effects. Splash shields and the vehicle's wheels help keep water off of the rotor, and the brake lining materials specified for most vehicles minimize the effects of water fade.

SELF-ADJUSTING ABILITY. Disc brakes are self-adjusting because any wear of the linings is automatically compensated for by the action of the brake caliper.

When the brakes are applied, the caliper pistons move out as far as needed to force the brake pads into contact with the rotor. When

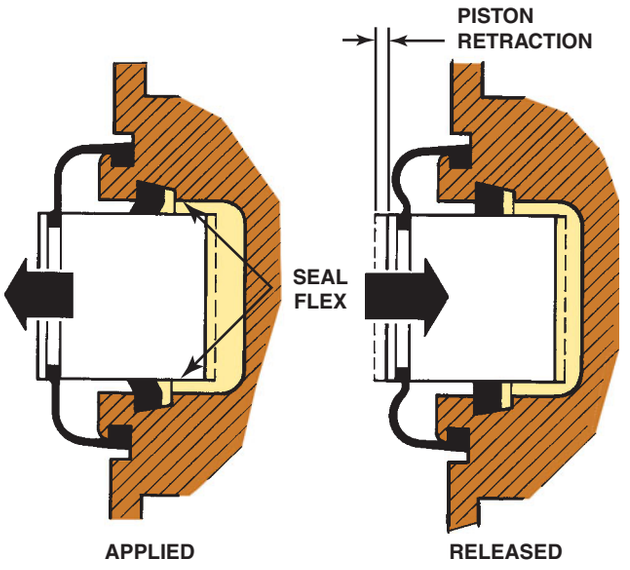


FIGURE 101–5 The square-cut O-ring not only seals hydraulic brake fluid, but also retracts the caliper piston when the brake pedal is released.

the brakes are released, the piston retracts only the small distance dictated by rotor runout and piston seal flex. ● **SEE FIGURE 101–5.** The surface finish on the piston must be clean to allow the piston to slide past this seal. Excessive friction between the caliper piston and the caliper bore can prevent the piston from retracting. If the force of the caliper seal is not strong enough, the piston stays in the applied position. Because the brake pads are still in contact with the rotor, one or both pads will show excessive wear.

FREEDOM FROM PULL. A disc brake will stop straighter under a wider range of conditions than will a drum brake. A disc brake is self-cleaning, will throw off most water, and is less likely to pull.

Disc brakes do not have self-energizing or servo action. Because disc brakes are not self-energizing to increase their braking power, the effects of a loss of friction on one side of the vehicle are far less pronounced than with drum brakes.

DISC BRAKE DISADVANTAGES

The most notable fact about the disadvantages of disc brakes is that there are so few. The weaknesses of disc brakes include the following.

- **No Self-Energizing or Servo Action**—The disc brake's lack of self-energizing or servo action is a disadvantage for two reasons.
  1. It contributes to poor parking brake performance and requires the driver to push harder on the brake pedal for a given stop. However, the problem of high pedal pressures has been eliminated through the use of brake power boosters.
  2. It is easier to control the brakes for the exact amount of stopping power desired.
- **Brake Noise**—Probably the biggest complaint about disc brakes is that they sometimes make various squeaks and squeals during a brake application. As long as the brake linings are not worn down to the backing plate, these noises are usually caused by high-frequency rattling or vibration of the brake pads. Several methods are used to quiet noisy disc brakes. Manufacturers use specific lining materials that dampen vibrations, and most calipers have **antirattle clips** or springs that hold the pads in the caliper under tension to help prevent vibration. ● **SEE FIGURE 101–6.**

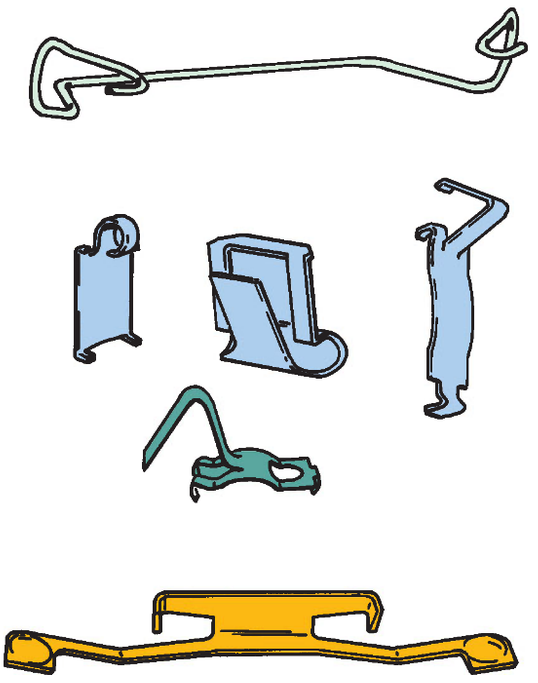


FIGURE 101–6 Antirattle clips reduce brake pad movement and vibration.

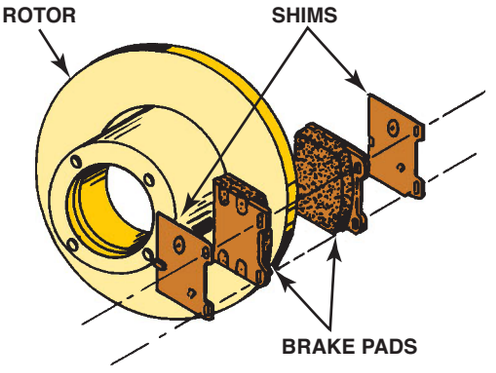


FIGURE 101–7 Antivibration shims are used behind the pads on many disc brake caliper designs.

TECH TIP

Check the Tire Size for a Pulling Problem

If an unequal braking problem is being diagnosed, check that the front tires match and that the rear tires match. Brakes slow and stop wheels. Unequal diameter tires create an unequal braking force. The result may be a pulling toward one side while braking. Tire diameter can vary from one tire manufacturer to another even though the size designation is the same. Even slight differences in the wear or inflation pressure of tires can cause a different tire diameter and, therefore, a different braking force.

Some calipers use special shims between the brake pad and the caliper piston to damp vibrations. ● **SEE FIGURE 101–7.** These shims may be made of metal or fiber. Antinoise sprays and brush-on liquids are available and provide a cushion layer between the pad and the caliper piston. The bond lowers the **natural frequency** of the pad, and the cushion layer dampens any vibration that may still occur.

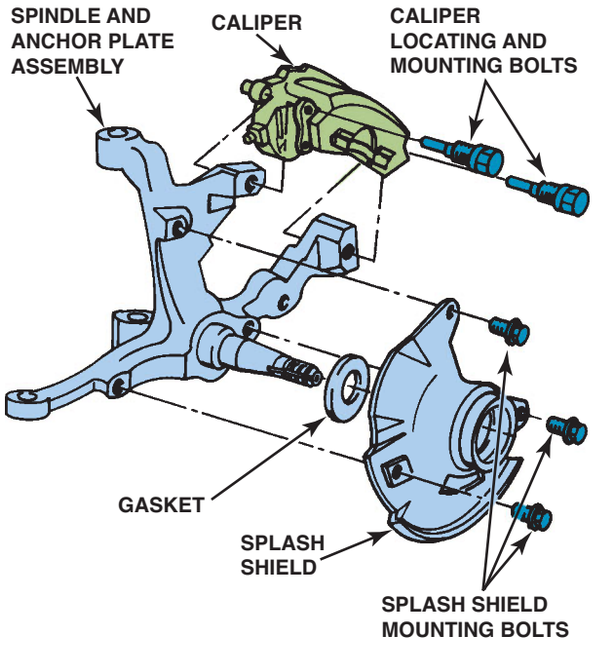


FIGURE 101–8 This brake caliper attaches to the front spindle.

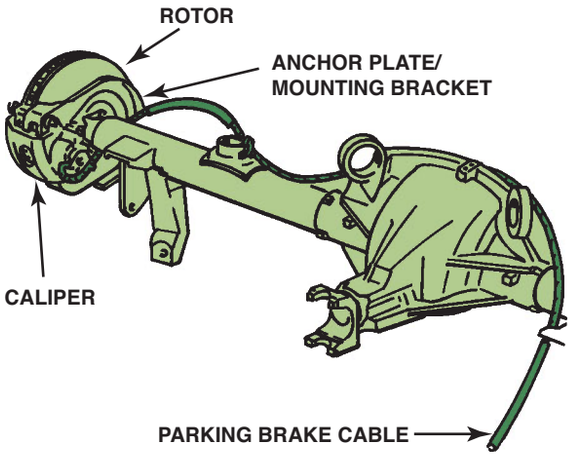


FIGURE 101–9 A rear disc brake caliper often attaches to a mounting bracket on the rear axle housing on this rear-wheel-drive vehicle.

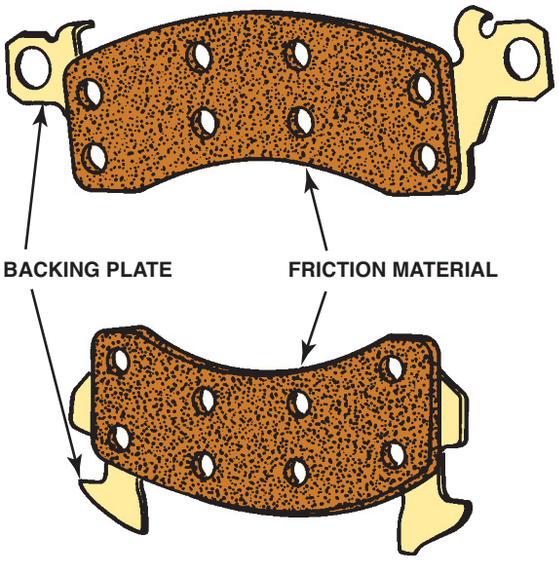


FIGURE 101–10 A typical disc brake pad.

TECH TIP

Wax the Wheels

Brake dust from semimetallic brake pads often discolors the front wheels. Customers often complain to service technicians about this problem, but it is normal for the front wheels to become dirty because the iron and other metallic and nonmetallic components wear off the front disc brake pads and adhere to the wheel covers. A coat of wax on the wheels or wheel covers helps prevent damage and makes it easier to wash off the brake dust.

BRAKE DUST. Because the lining is exposed on a disc brake, rather than being enclosed as on a drum brake, some brake dust can accumulate on the wheels. This brake dust is often dark brown or black and can stain wheels if not cleaned often or protected from the dust.

POOR PARKING BRAKE PERFORMANCE. The lack of self-energizing and servo action plays a large part in poor disc brake parking brake performance. The lining-to-rotor contact area of a disc brake is somewhat smaller than the lining-to-drum contact area of a drum brake. This causes the disc brake to have a lower static coefficient of friction, and therefore less holding power when the vehicle is stopped.

DISC BRAKE CONSTRUCTION

A disc brake is relatively simple compared with a drum brake. The major disc brake friction assembly components include the following.

CALIPER With the exception of the rotor, the caliper is the largest part of a disc brake friction assembly. The brake caliper uses hydraulic pressure to create the mechanical force required to move the brake pads into contact with the brake rotor. At the front axle, the caliper mounts to the spindle, caliper support bracket or steering knuckle. ● **SEE FIGURE 101–8.** Rear disc brake calipers mount to a support bracket on the axle flange or suspension. ● **SEE FIGURE 101–9.**

SPLASH SHIELD The splash shield bolts to the front spindle or steering knuckle, or in rear disc brake applications, to the axle flange or a suspension adapter plate. The job of the splash shield is to protect the inner side of the brake rotor from water and other contaminants, whereas the outer side of the rotor is protected by the wheel. Most splash shields are made of stamped steel or plastic.

DISC BRAKE PADS

BRAKE PAD ASSEMBLY The lining of a disc brake is part of an assembly called the **brake pad.** ● **SEE FIGURE 101–10.** Compared to a brake shoe, a brake pad is a relatively simple part that consists of a block of friction material attached to a stamped steel backing plate. Some pad backing plates have tabs that bend

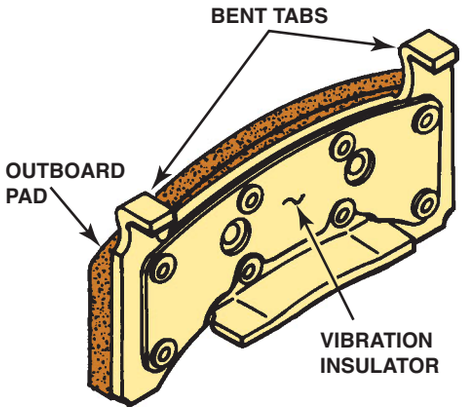


FIGURE 101–11 To prevent noise, bent tabs on the backing plate hold some brake pads to the caliper housing.

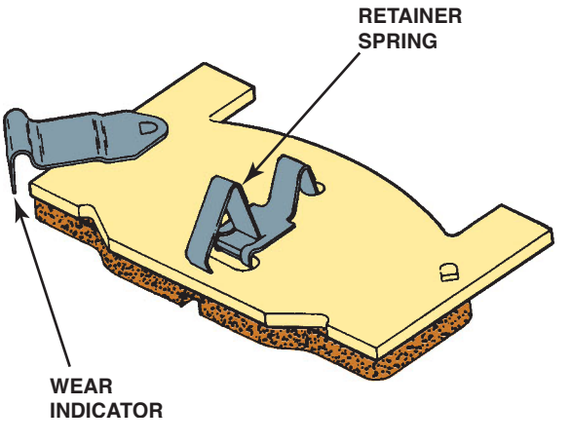


FIGURE 101–13 Retainer springs lock the pad to the caliper piston to prevent brake noise.

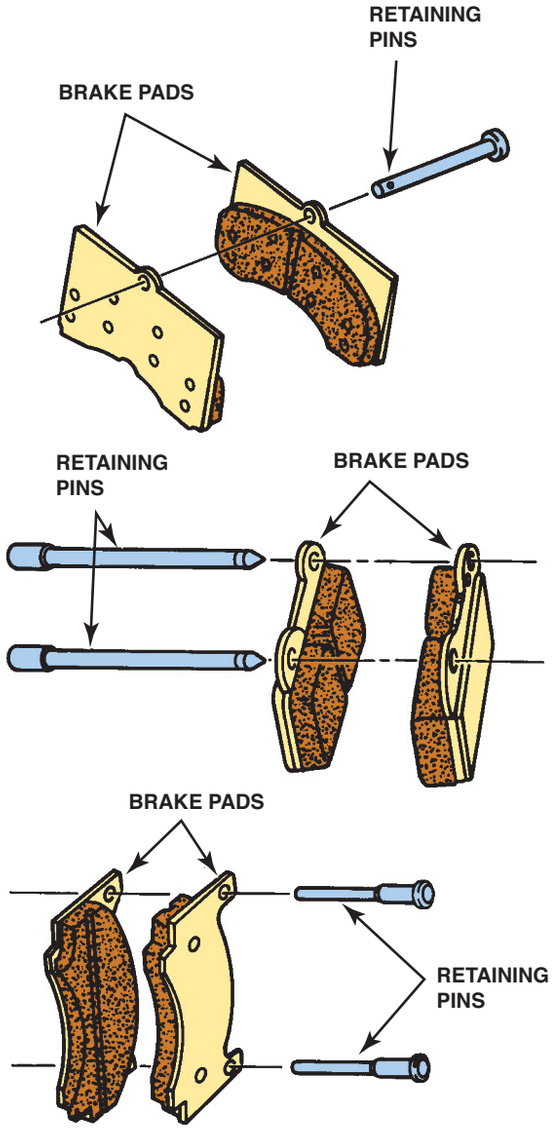


FIGURE 101–12 Holes in the backing plate are a common method of locating a pad in the caliper.

over the caliper to hold the pad tightly in place and help prevent brake noise. ● **SEE FIGURE 101–11.**

Other pad backing plates have tabs with holes in them as shown in ● **FIGURE 101–12.** A pin slips through the holes and fastens to the caliper body to hold the pads in position. Still other pad backing plates have a retainer spring attached that locates the pad in the caliper by locking it to the caliper piston. ● **SEE FIGURE 101–13.**

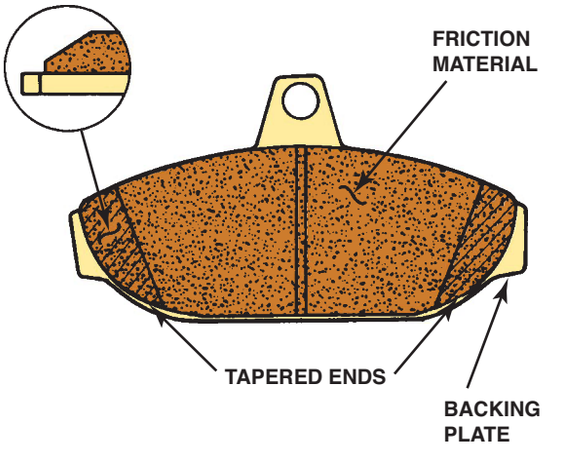


FIGURE 101–14 The lining edges of some brake pads are tapered to help prevent vibration.

As with brake shoes, the lining material of a disc pad can be any one of a number of products that can be fastened to the backing plate in several ways. The edges of the lining material on a brake pad are usually perpendicular to the rotor surface, although a few larger pads do have tapered edges to help combat vibration and noise. ● **SEE FIGURE 101–14.**

PAD WEAR INDICATORS

Although not required by law, a growing number of vehicle manufacturers are fitting **pad wear indicators** to their brakes for safety reasons. Pad wear indicators are either mechanical or electrical, and signal the driver when the lining material has worn to the point where pad replacement is necessary.

A mechanical wear indicator is a small spring-steel tab riveted to the pad backing plate. When the friction material wears to a predetermined thickness, the tab contacts the rotor and makes a squealing or chirping noise (when the brakes are not applied) that alerts the driver to the need for service. ● **SEE FIGURE 101–15.**

Electrical wear indicators, such as those shown in ● **FIGURE 101–16,** use a coated electrode embedded in the lining material to generate the warning signal. The electrode is wired to a warning light in the instrument panel and when the lining wears sufficiently, the electrode grounds against the rotor to complete the circuit and turn on the warning light.

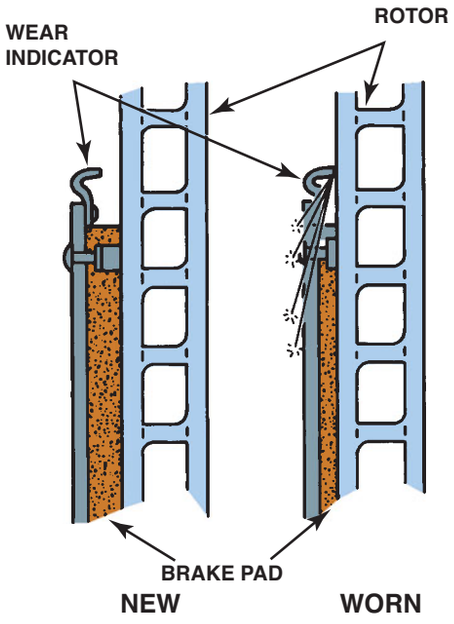


FIGURE 101–15 Typical pad wear sensor operation. It is very important that the disc brake pads are installed on the correct side of the vehicle to be assured that the wear sensor will make a noise when the pads are worn. If the pads with a sensor are installed on the opposite side of the vehicle, the sensor tab is turned so that the rotor touches it going the opposite direction. Usually the correct direction is where the rotor contacts the sensor before contacting the pads when the wheels are being rotated in the forward direction.

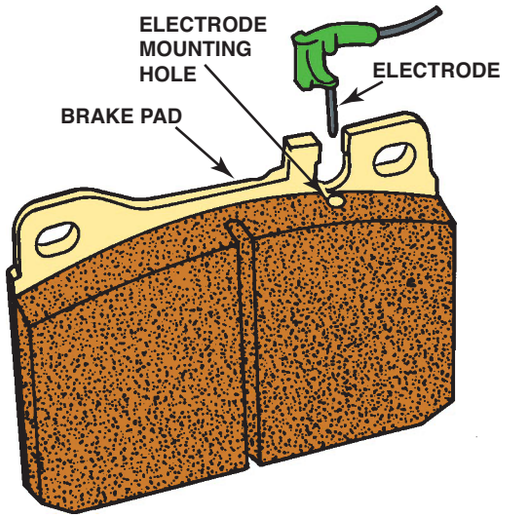


FIGURE 101–16 Electrical wear indicators ground a warning light circuit when the pads need replacement.

PAD ASSEMBLY METHODS

As mentioned previously, there are several methods that are used to mount brake linings, including:

- **Riveted linings** take advantage of the oldest method of lining attachment still in use. In this system, the brake block is attached to the backing plate with copper or aluminum rivets.

  The major advantage of riveting is that it allows a small amount of flex between the brake block backing plate. This play enables the assembly to absorb vibration, and the result is that riveted linings operate more quietly than bonded linings. However the rivet holes create stress points in the lining where cracks are likely to develop.

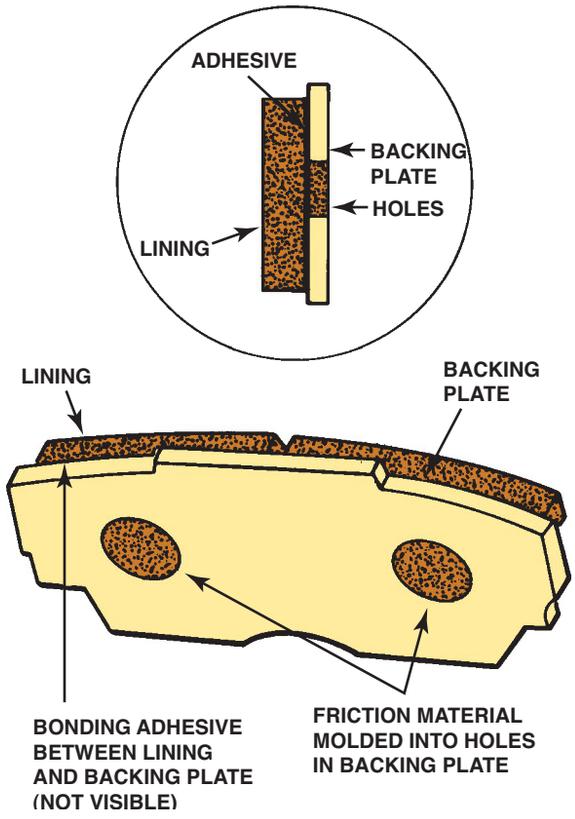


FIGURE 101–17 Mold-bonded linings are commonly used in many applications.

- **Bonded linings** use high-temperature adhesive to glue the brake block directly to the shoe pad backing plate. Heat and pressure are then applied to cure the assembly. Bonding is a common form of shoe and pad assembly, and is most often used to mount organic friction materials.

  Bonding offers several advantages. Without rivets, bonded linings can wear closer to the backing plate and provide a longer service life. If the linings wear too far, bonding adhesive is not as destructive to rotors as rivets. Bonded linings also have fewer problems with cracking because they have no rivet holes to weaken the brake block. The primary disadvantage of bonded linings is a limited ability to withstand high temperatures. If a bonded lining gets too hot, the bonding adhesive will fail and allow the brake block to separate from the backing plate. Bonded linings are also more prone to be noisy because they do not allow any vibration absorbing flex between the brake block and backing plate.

- **Mold-bonded linings** are found on some disc brake pads. Mold bonding is a manufacturing process that combines the advantages of bonding with some of the mechanical strength of riveting. Instead of riveting and/or bonding a cured brake block to a separate backing plate, the friction material in a mold-bonded pad is cured on the backing plate during manufacture. This process is also called **integrally molded.** Most high-performance disc brake pads are made in this way.

  To make a mold-bonded pad, one or more holes are punched in the pad backing plate, and a high-temperature adhesive is applied to it. The backing plate is then installed in a molding machine where uncured friction material is formed onto the plate and forced into the holes. ● **SEE FIGURE 101–17.** Once the pad is cured under heat and pressure, the bonding adhesive combines with the portions of the lining that extend into the backing plate holes to solidly lock the brake block in place.

INGREDIENT	TYPICAL FORMULA RANGE
Phenolic resin (binder)	9–15%
Asbestos fiber	30–50%
Organic friction modifiers (rubber scrap)	8–19%
Inorganic friction modifiers (barites, talc, whiting)	12–26%
Abrasive particles (alumina)	4–20%
Carbon	4–20%

CHART 101–1

Typical compositions for asbestos (organic) lining used on older vehicles.

INGREDIENT	FORMULA RANGE
Phenolic resin	15–40%
Graphite or carbon particles	15–40%
Steel fibers	10–30%
Ceramic powders	2–10%
Steel, copper, brass metal powders	15–40%
Other modifiers (rubber scrap)	0–20%

CHART 101–2

Typical compositions for semimetallic disc brake pads

BRAKE LINING COMPOSITION

Shoes and pads operate under the most extreme conditions in the entire brake system and are subject to a great deal of wear. The replacement of worn brake shoes and pads is a common part of brake service.

Friction materials such as disc brake pads or drum brake shoes contain a mixture of ingredients. These materials include a binder such as a thermosetting resin, fibers for reinforcement, and friction modifiers to obtain a desired coefficient of friction (abbreviated μ—Greek letter mu).

The various ingredients in brake lining are mixed and molded into the shape of the finished product. The fibers in the material are the only thing holding this mixture together. A large press is used to force the ingredients together to form a **brake block,** which eventually becomes the brake lining. ● **SEE CHART 101–1.**

SEMIMETALLIC FRICTION MATERIAL. The term *semimetallic* refers to brake lining material that uses metal rather than asbestos in its formulation. It still uses resins and binders and is, therefore, not 100% metal, but rather, semimetallic. Semimetallics are commonly called **semimets.** The metal in most metallic linings is made from metal particles that have been fused together without melting. This process is called **sintering** and the result is called **sintered metal** linings. ● **SEE CHART 101–2.**

Most semimetallic linings do not contain asbestos. Semimetallic linings require a very smooth finish on the rotor because the metal in the lining does not conform to the surface of the rotor, as does asbestos lining.

NOTE: If a magnet sticks the lining material, it is semimetallic.

TECH TIP

Competitively Priced Brakes

The term *competitively priced* means lower cost. Most brake manufacturers offer "premium" as well as lower-price linings, to remain competitive with other manufacturers or with importers of brake lining material produced overseas by U.S. or foreign companies. In fact, according to warehouse distributors and importers, the box often costs more than the brake lining inside.

Professional brake service technicians should only install brake linings and pads that will give braking performance equal to that of the original factory brakes. For best results, always purchase high-quality brake parts from a known brand-name manufacturer.

FREQUENTLY ASKED QUESTION

What Does "D³EA" Mean?

Original equipment brake pads and shoes are required to comply with the Federal Motor Vehicle Safety Standard (FMVSS) 135, which specifies maximum stopping distances. There is also a requirement for fade resistance, but no standard for noise or wear. Aftermarket (replacement) brake pads and shoes are not required to meet the FMVSS standard. However, several manufacturers of replacement brake pads and shoes are using a standardized test that closely matches the FMVSS standard and is called the "Dual Dynamometer Differential Effectiveness Analysis" or D³EA. This test is currently voluntary and linings that pass the test can have a "D³EA certified" seal placed on the product package.

NONASBESTOS FRICTION MATERIAL. Brake pads and linings that use synthetic material such as aramid fibers instead of steel are usually referred to as **nonasbestos, nonasbestos organic (NAO),** or **nonasbestos synthetic (NAS).** Linings are called *synthetic* because synthetic (man-made) fibers are used. These linings use **aramid fiber** instead of metal as the base material. Aramid is the generic name for aromatic polyamide fibers. **Kevlar** is the Dupont brand name of aramid and a registered trademark of E.I. Dupont de Nemours and Company. Nonasbestos linings are often quieter than semimetallics and do not cause as much wear to brake rotors as do semimetallic pads.

CARBON FIBER FRICTION MATERIAL. Carbon fiber brake lining is the newest and most expensive of the lining materials. Carbon fiber material is often called **CFRC (carbon fiber-reinforced carbon).** It is composed of a carbon mix into which reinforcing carbon fibers are embedded. CFRC is commonly used in the brakes of jet aircraft and racing cars. CFRC brakes provide constant friction coefficient whether cold or hot, low wear rates, and low noise development.

CERAMIC FRICTION MATERIAL. Some vehicle manufacturers use friction materials that contain ceramic fibers. These ceramic fibers are usually potassium titanite. Most pads today are ceramic and use little, if any steel. One way to check to see which type of pad is used is to use a magnet. If a magnet sticks to the pad, it has a high steel content but a magnet will not stick to a ceramic pad.

Code C	0.00 to 0.15
Code D	0.15 to 0.25
Code E	0.25 to 0.35
Code F	0.35 to 0.45
Code G	0.45 to 0.55
Code H	0.55 and above
Code Z	ungraded

CHART 101–3

The SAE brake pad edge codes are used to indicate the coefficient of friction of the pad material.

EDGE CODES As explained previously, the lining edge codes help identify the coefficient of friction. These codes were established by the SAE (Society of Automotive Engineers) and published as Standard J886a. ● **SEE CHART 101–3.**

The first letter, which is printed on the side of most linings, indicates its coefficient of friction when brakes are cold, and the second letter indicates the coefficient of friction of the brake lining when the brakes are hot. For example, FF indicates that the brake lining material has a coefficient of friction between 0.35 and 0.45 when both cold and hot.

BRAKE ROTORS

The brake rotor provides the friction surfaces for the brake pads to rub against. The rotor, the largest and heaviest part of a disc brake, is usually made of cast iron because that metal has excellent friction and wear properties. There are two basic types of rotors:

- **Solid**—Solid rotors are most often used on the rear of vehicles equipped with four-wheel disc brakes.
- **Vented**—Vented rotors have radial cooling passages cast between the friction surfaces. ● **SEE FIGURE 101–18.**

CALIPER DESIGNS

There are basically three types of calipers: fixed, floating, and sliding designs.

FIXED CALIPER DESIGN The **fixed brake caliper** is the earliest design. ● **SEE FIGURE 101–19.** The fixed caliper has a body manufactured in two halves, and uses two, four, or six pistons to apply the brake pads. The fixed caliper gets its name from the fact that the caliper is rigidly mounted to the suspension. When the brakes are applied, the pistons extend from the caliper bores and apply the brake pads with equal force from both sides of the rotor. No part of the caliper body moves when the brakes are applied.

FIXED CALIPER ADVANTAGES Fixed calipers are relatively large and heavy, which enables them to absorb and dissipate great amounts of heat. This allows the brake rotor and pads to run cooler, and reduce the amount of heat transferred to the brake fluid. Compared with other caliper designs, a fixed caliper is able to withstand a greater number of repeated hard stops without heat-induced fade or vapor lock of the hydraulic system.

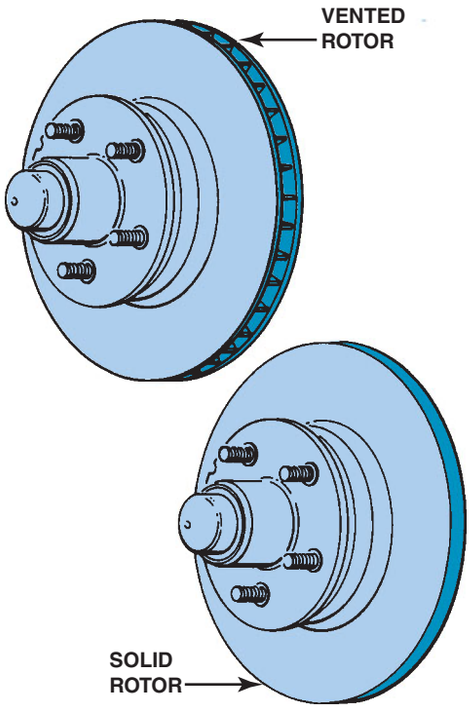


FIGURE 101–18 Disc brake rotors can be either solid or vented.

The size and rigid mounting of a fixed caliper also means it does not flex as much as other designs. A caliper that is flexing is usually felt by the driver as a spongy brake pedal. Fixed calipers are very strong and provide a firm and linear brake pedal feel.

The strength and heat-dissipating abilities of fixed calipers make them best suited for heavy-duty use such as in most race vehicles.

FIXED CALIPER DISADVANTAGES The size and weight of fixed calipers are advantages in heavy-duty use, but they add weight to the vehicle.

Another disadvantage of fixed calipers is that, with multiple pistons and split bodies, service is more difficult and allows greater opportunity for leaks. The drilled passages that route fluid through the inside of the caliper body also contribute to cracking as miles accumulate and the caliper goes through hundreds of thousands of heating and cooling cycles.

FLOATING AND SLIDING CALIPER DESIGN The front brakes of most vehicles are fitted with either floating or sliding calipers, which are *not* rigidly mounted. The caliper is free to move within a limited range on an **anchor plate** that *is* solidly mounted to the vehicle suspension. The anchor plate may be cast into a suspension member (often the front spindle) or it can be a separate piece that bolts to the suspension. ● **SEE FIGURE 101–20.**

When the brakes are applied, the caliper piston moves out of its bore and applies the inner brake pad. At the same time, the caliper body moves in the opposite direction on the anchor plate and applies the outer brake pad. With a floating or sliding caliper, the caliper body moves every time the brakes are applied. ● **SEE FIGURE 101–21.**

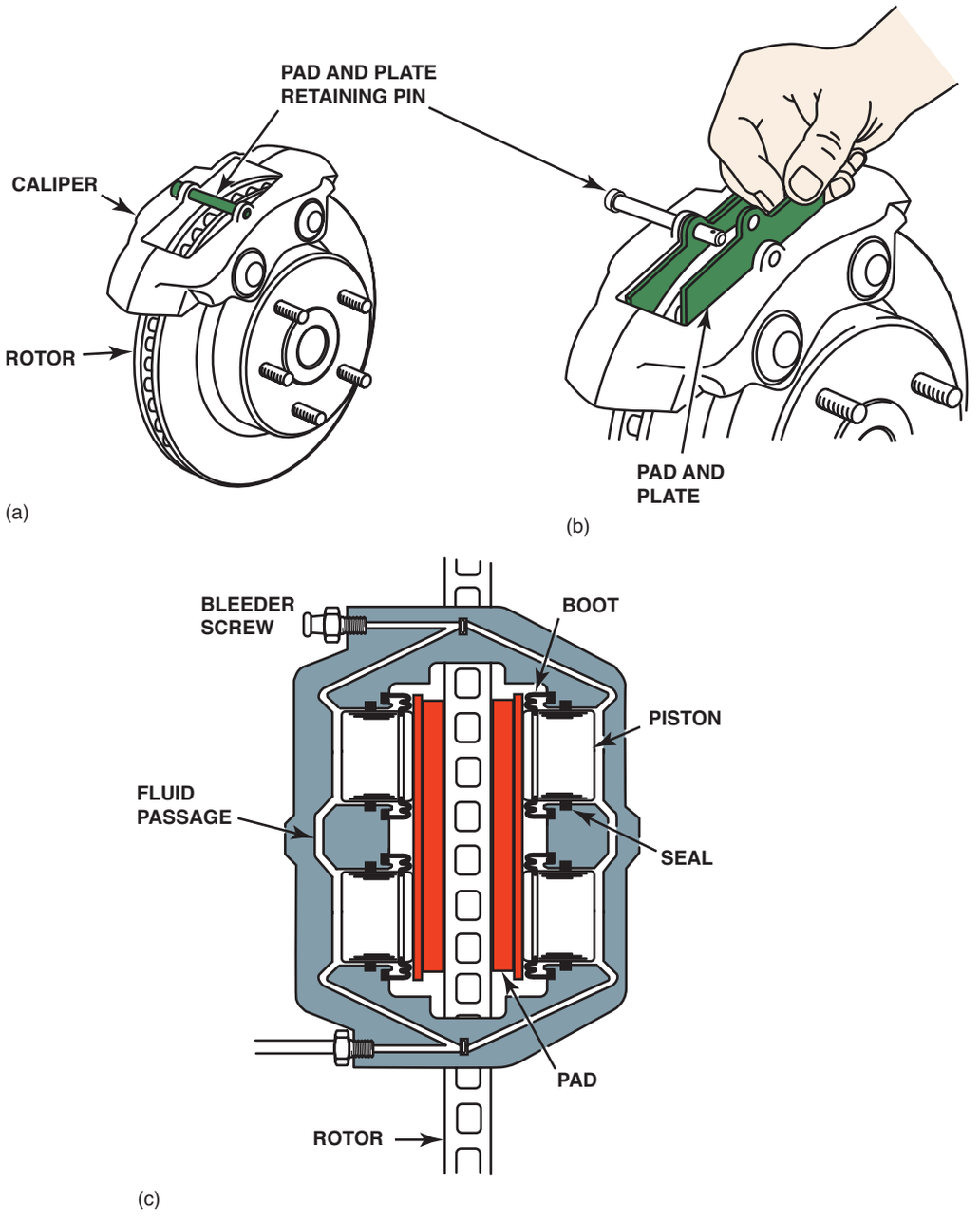


FIGURE 101–19 (a) Many fixed caliper disc brakes use a simple retaining pin to hold the disc brake pads. (b) Removing the retainer pin allows the brake pads to be removed. (c) Notice the cross-over hydraulic passage that connects both sides of the caliper.

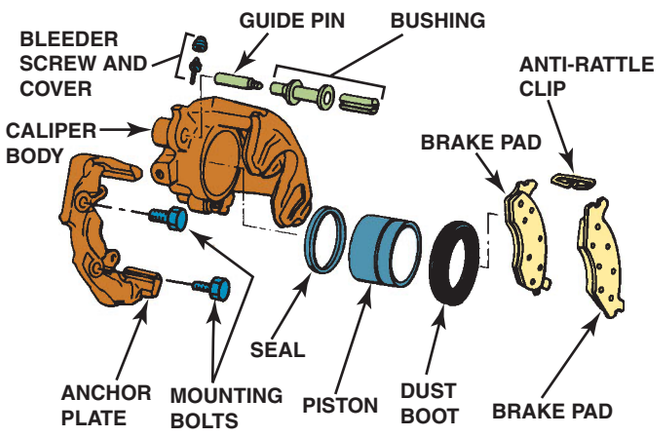


FIGURE 101–20 This floating caliper mounts on a separate anchor plate that bolts to the vehicle suspension.

NORMAL CALIPER OPERATION

The piston moves just enough to distort the caliper seal and returns to the original position when the brake pedal is released.

WEAR COMPENSATION. The piston moves more than the caliper seal can distort. The piston moves through the seal until the pad contacts the rotor. The caliper piston returns to the released position by the seal distortion, the same as during normal operation, except now in a different, more applied position.

As the wear occurs and the piston moves, additional brake fluid is needed behind the piston. This additional brake fluid comes from the master cylinder and the brake fluid level drops as the disc brake pads wear.

FLOATING AND SLIDING CALIPER ADVANTAGES

The biggest advantages of floating and sliding calipers are lower cost, simple construction, and compact size. Most floating and sliding

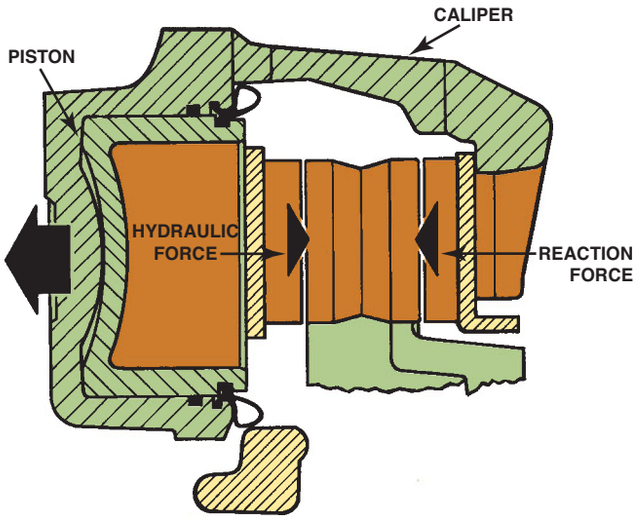


FIGURE 101–21 Hydraulic force on the piston (left) is applied to the inboard pad and the caliper housing itself. The reaction of the piston pushing against the rotor causes the entire caliper to move toward the inside of the vehicle (large arrow). Since the outboard pad is retained by the caliper, the reaction of the moving caliper applies the force of the outboard pad against the outboard surface of the rotor.

calipers are single-piston designs. Because they have fewer pieces, floating and sliding calipers are cheaper to build and service, and have fewer places where leaks can develop.

The smaller size of floating and sliding calipers also allows better packaging of the caliper on the vehicle. A single-piston caliper with the piston located on the inboard side of the brake rotor fits easily within the diameter of a small wheel. The inboard position of the caliper piston also contributes to better cooling because the bulk of the caliper body is exposed to the passing airflow.

Like any disc brake, floating and sliding calipers have poor parking brake performance. Unlike a fixed caliper, a floating or sliding caliper can be mechanically actuated by applying the single piston with a cable and lever mechanism.

FLOATING AND SLIDING CALIPER DISADVANTAGES

The movable caliper body allows a certain degree of flex, which can contribute to a spongy brake pedal. Caliper flex also allows the caliper body to twist slightly when the brakes are applied, causing tapered wear of the brake pad lining material. ● **SEE FIGURE 101–22.**

Although the inboard piston location of floating and sliding calipers provides good cooling, these designs can never absorb as much heat (and therefore have the fade resistance) as a fixed caliper with similar stopping power. Floating and sliding calipers simply do not have the mass of fixed calipers, and their flexible mounting systems slow the transfer of heat from the caliper body to the anchor plate and other suspension components that aid in the cooling process.

FLOATING CALIPER OPERATION

The body of a **floating caliper** does not make direct metal-to-metal contact with the anchor plate. ● **SEE FIGURE 101–23.** Instead, the caliper body is supported by bushings and/or O-rings that allow it to "float" or slide on metal guide pins or locating sleeves attached to the anchor plate. For this reason, some automakers call the floating caliper a **pin-slider caliper.**

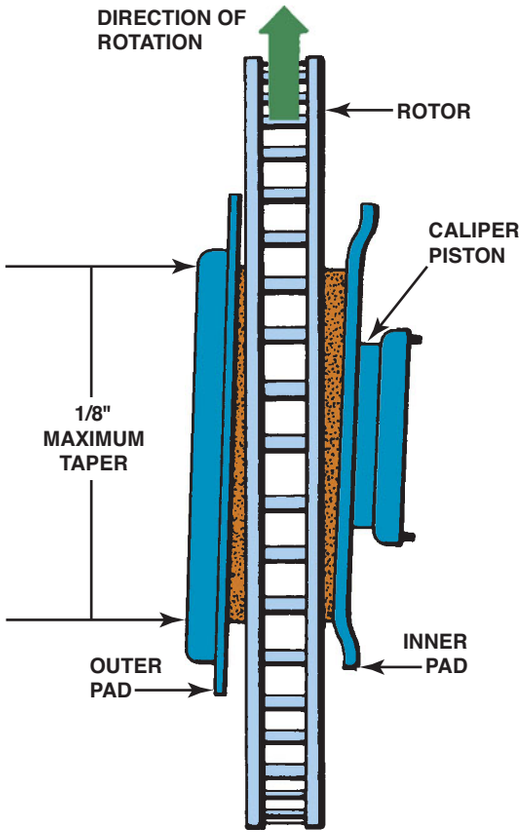


FIGURE 101–22 Caliper flex can cause tapered wear of the brake lining.

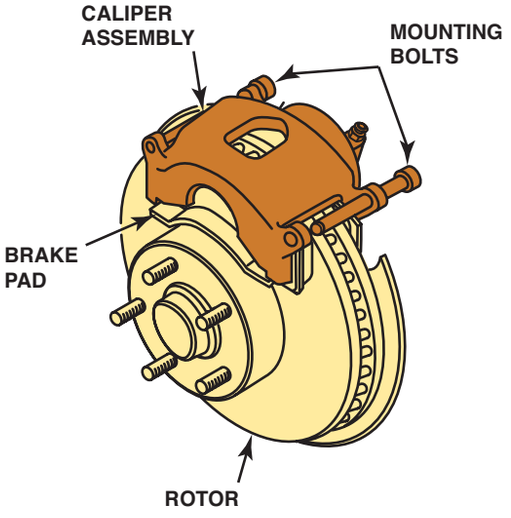


FIGURE 101–23 A typical single-piston floating caliper. In this type of design, the entire caliper moves when the single piston is pushed out of the caliper during a brake application. When the caliper moves, the outboard pad is applied against the rotor.

The bushings that support floating calipers are made from a number of materials including rubber, Teflon, and nylon. The O-rings are generally made from high-temperature synthetic rubber. ● **SEE FIGURE 101–24.** The guide pins and sleeves are made of steel and come in a variety of shapes and sizes for different caliper designs. ● **SEE FIGURE 101–25.**

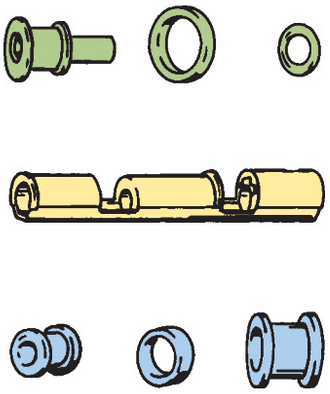


FIGURE 101–24 Floating calipers are supported by rubber O-rings or plastic bushings.

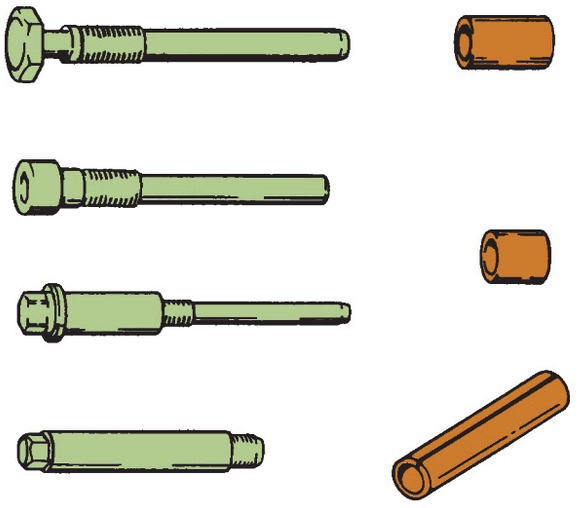


FIGURE 101–25 Metal guide pins and sleeves are used to retain and locate floating calipers.

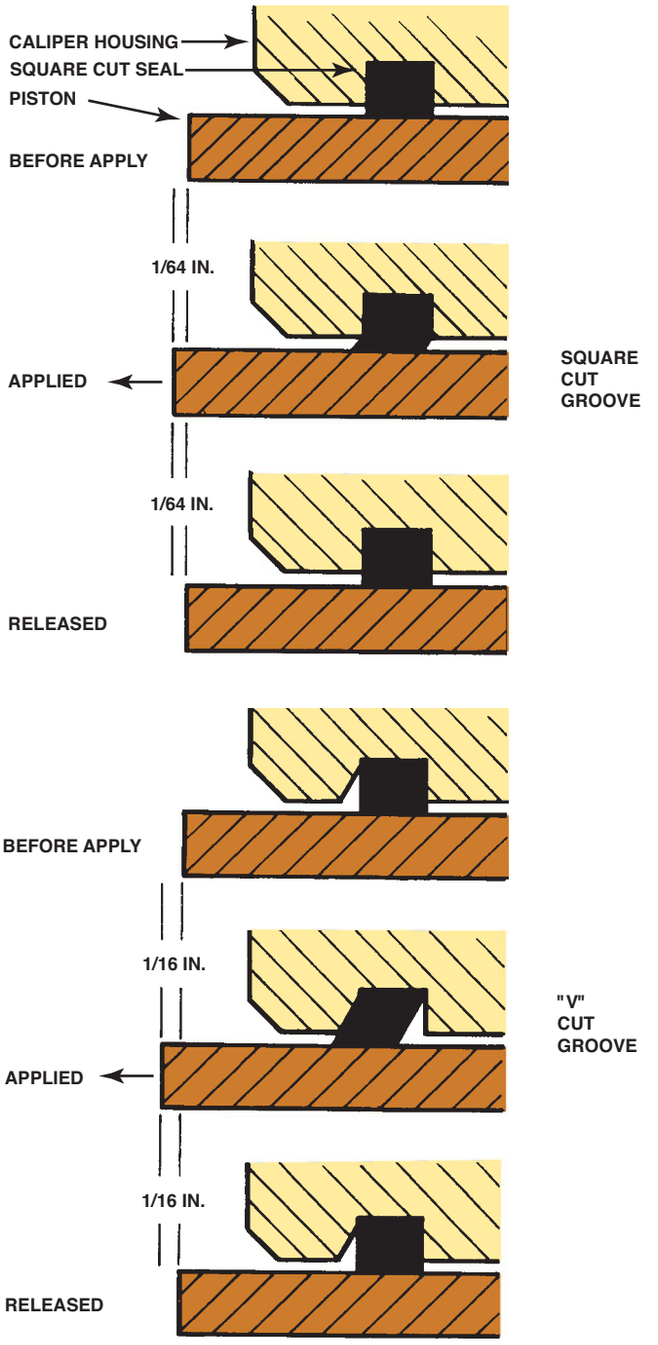


FIGURE 101–26 In a standard disc brake caliper, the square-cut O-ring deforms when the brakes are applied and returns the piston to its original (released) position due to the elastic properties of the rubber seal. In a low-drag caliper design, the groove for the square-cut O-ring is V-shaped, allowing for more retraction. When the brake pedal is released, the piston is moved away from the rotor farther, resulting in less friction between the disc brake pads and the rotor when the brakes are released.

? FREQUENTLY ASKED QUESTION

What Is a Low-Drag Caliper?

A **low-drag caliper** differs from a standard caliper in the area of the square-cut O-ring. A V-shaped cutout allows the O-ring to deflect more and, as a result, is able to pull the caliper piston back into the bore when the brakes are released. Because of this further movement, the brake pads are pulled farther from the rotor and are less likely to drag. The negative aspect of this design is that greater volume of brake fluid is needed to achieve a brake application. To compensate for this need for greater brake fluid volume, a quick-take-up master cylinder was designed and is used whenever low-drag calipers are used.

● **SEE FIGURE 101–26.**

Floating calipers depend on proper lubrication of their pins, sleeves, bushings, and O-rings for smooth operation. If these parts become rusted or corroded, the caliper will bind and stick, causing loss of braking power that is usually accompanied by rapid and unusual wear of brake pads. Special high-temperature brake grease must be used to lubricate these parts any time the caliper is

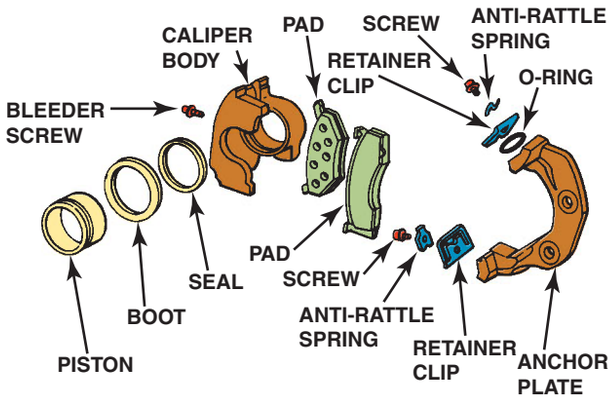


FIGURE 101–27 Exploded view of a typical sliding brake caliper.

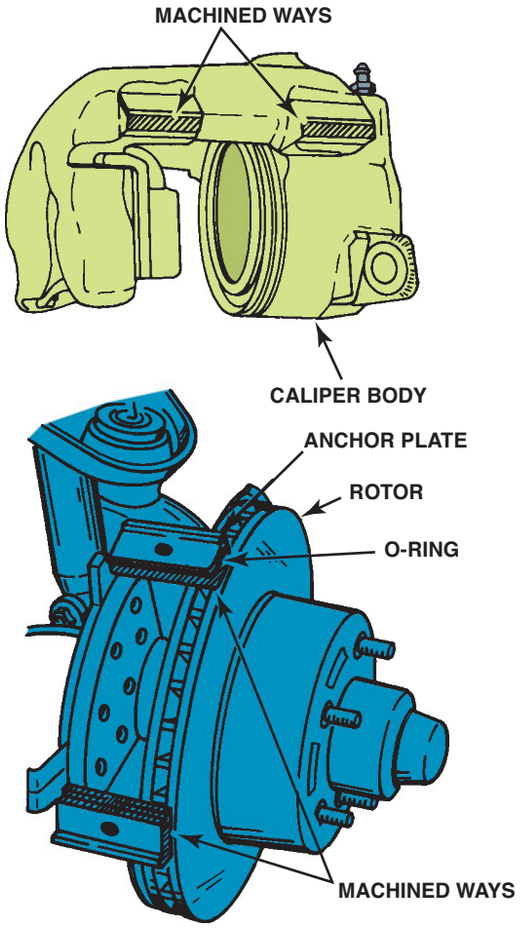
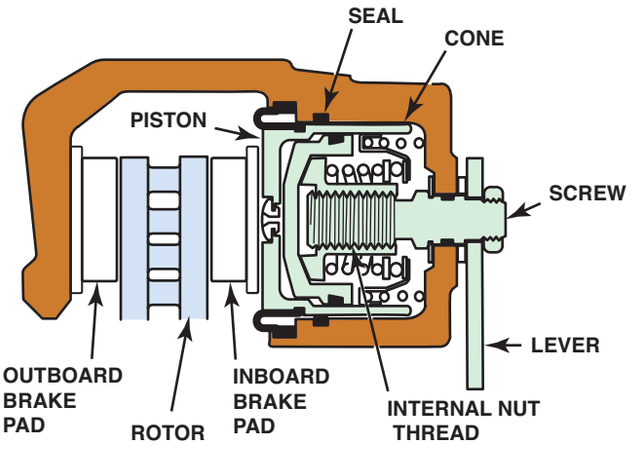


FIGURE 101–28 Sliding calipers move on machined ways.

disassembled. Many manufacturers recommend that floating caliper pins, sleeves, bushings, and O-rings be replaced whenever the caliper is serviced. These parts come in a "small parts kit" available from brake part suppliers.

SLIDING CALIPERS Unlike a floating caliper, the body of a **sliding caliper** mounts in direct metal-to-metal contact with the anchor plate. ● **SEE FIGURE 101–27.**

Instead of pins and bushings, sliding calipers move on **ways** cast and machined into the caliper body and anchor plate. ● **SEE FIGURE 101–28.** Retaining clips and the design of the caliper prevent the body from coming out of the ways once the caliper is assembled. On some calipers, the ways may have to be filed for proper



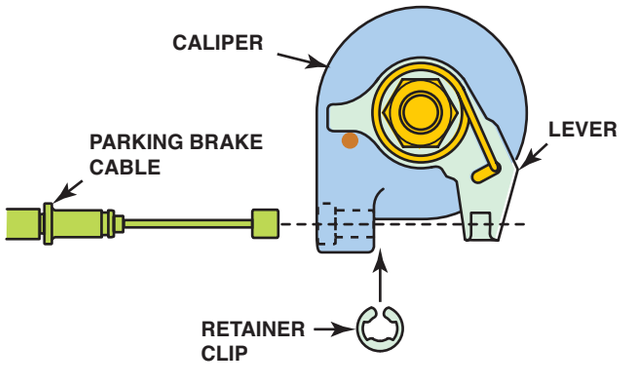


FIGURE 101–29 Exploded view of a typical rear disc brake with an integral parking brake. The parking brake lever mechanically pushes the caliper piston against the rotor.

clearance between the caliper body and anchor plate if the caliper is replaced.

Like floating calipers, sliding calipers depend on good lubrication of their ways for proper operation. If not properly coated with high-temperature brake grease, the ways can rust or corrode, causing the caliper to drag or seize.

REAR DISC BRAKES

In recent years, four-wheel disc brake systems have become more common. In most rear-wheel applications, drum brakes are adequate to provide the relatively small portion of a vehicle's total braking power required of them. Because rear drum brakes are lightly loaded, fade is a problem only in extreme conditions when the front brakes fade and force the rear brakes to take on a larger part of the braking load. The automatic adjusting ability of disc brakes is also less of an advantage in slow-wearing rear brakes.

REAR DISC PARKING BRAKES There are two methods of providing parking brakes when rear discs are installed on a vehicle.

1. Adapt the disc brake to also function as the parking brake. This is done by installing a series of cables, levers, and internal parts to mechanically actuate the brake caliper. ● **SEE FIGURES 101–29 AND 101–30.**
2. Use mechanically actuated drum brakes inside the rear rotors. ● **SEE FIGURE 101–31.**

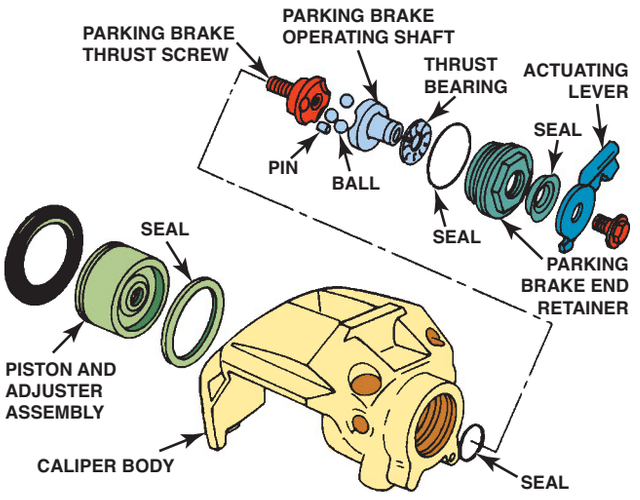


FIGURE 101–30 This single-piston brake caliper is mechanically actuated to serve as a parking brake.

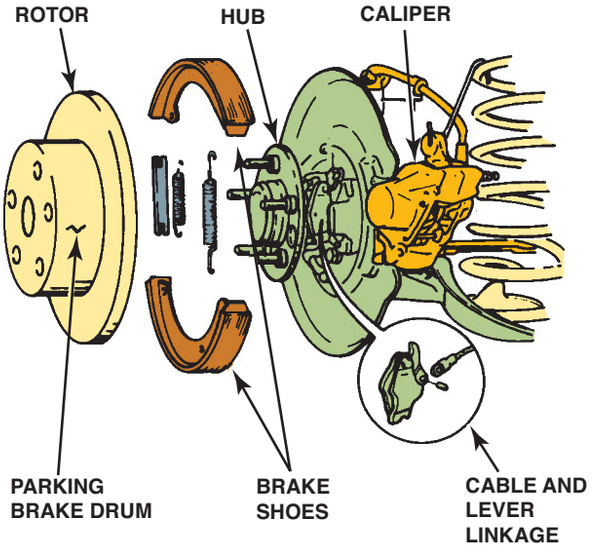


FIGURE 101–31 Drum parking brakes are fitted inside the rotors on this vehicle equipped with rear disc brakes.

REVIEW QUESTIONS

1. What are the advantages and disadvantages of disc brakes?
2. What parts are included in a typical disc brake?
3. How does a low-drag caliper work?
4. What mechanism is used to apply the parking brake on a vehicle equipped with rear disc brakes?
5. What do the abbreviations NAO, NAS, and CFRC mean?

CHAPTER QUIZ

1. What part causes the disc brake caliper piston to retract when the brakes are released?
   a. Return (retracting) spring
   b. The rotating rotor (disc) that pushes the piston back
   c. The square-cut O-ring
   d. The caliper bushings
2. Two technicians are discussing the reason that the brake fluid level in the master cylinder drops. Technician A says that it may be normal due to the wear of the disc brake pads. Technician B says that a low brake fluid level may indicate a hydraulic leak somewhere in the system. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. Two technicians are discussing a floating-type disc brake caliper. Technician A says that if the caliper slides are corroded, one pad may wear more than the other pad on the same wheel brake. Technician B says that if a caliper slide is corroded, reduced braking may occur. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. Technician A says that disc brakes are self-adjusting and the brake pedal height should not become lower as the disc brake pads wear. Technician B says that as the disc brake pads wear, the level of brake fluid in the master cylinder reservoir drops. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
5. Which type of disc brake caliper may leak brake fluid more often?
   a. Sliding
   b. Fixed
   c. Floating
   d. Single-piston
6. A quick-take-up master cylinder is required when what type of caliper design is used on a vehicle?
   a. Fixed
   b. Two-piston
   c. Sliding
   d. Low-drag
7. Technician A says that all vehicles equipped with rear disc brakes use a parking brake that is integrated in the caliper. Technician B says that all vehicles equipped with rear disc brakes use a small drum brake inside the rear rotor for a parking brake. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. The brake pad edge code letters “FF” mean _____.
   a. Brand name
   b. Coefficient of friction rating
   c. Quality factor
   d. Noise level rating
9. Semimetallic brake pads are made by a process called _____.
   a. Sintering
   b. Melting
   c. Grating
   d. Composition
10. Technician A says that riveted disc brake pads are often quieter than bonded disc brake pads. Technician B says integrally molded disc brake pads are molded into holes in the steel backing of the pads. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

chapter 102

DISC BRAKE DIAGNOSIS AND SERVICE

OBJECTIVES: **After studying Chapter 102, the reader will be able to:** • Prepare for the Brakes (A5) ASE certification test content area "C" (Disc Brake Diagnosis and Repair). • List the items that should be checked during a visual inspection. • Describe the caliper disassembly procedure. • Describe the caliper assembly procedure. • List the steps necessary to reduce brake noise.

KEY TERMS: Abutments 1134 • Antiseize compound 1137 • Bedded-in 1136 • Brake assembly fluid 1133 • Burnished 1136 • Constrained layer shims (CLS) 1137 • Lithium-based brake grease 1137 • Loaded calipers 1134 • Minimum thickness 1129 • MOS_2 (molybdenum disulfide) grease 1137 • Phenolic caliper pistons 1130 • Polyalphaolefin (PAO) 1137 • Reaction pads 1134 • Silicone grease 1137 • Synthetic grease 1137 • Ways 1134

DISC BRAKE DIAGNOSTIC PROCEDURES

When diagnosing disc brake concerns, perform the following steps:

STEP 1 The first step is to verify the customer complaint. This step usually includes test driving the vehicle to see if the complaint can be duplicated. If the problem cannot be duplicated, then the repair or service cannot be verified.

CAUTION: Do not test drive the vehicle on public roads if the red brake warning light is on. Perform a visual inspection to determine the reason for the warning light being on and correct before test driving the vehicle.

STEP 2 Check the brake pedal height and verify proper operation. If the brake pedal is low, count the number of "clicks" it takes to apply the parking brake. There should be 3 to 7 clicks. If there are over 10 clicks, check the rear brakes.

STEP 3 Safely hoist the vehicle and remove the wheels. Visually check the following:

- Flexible brake hoses for wear or damage
- Disc brake rotors for excessive rust or scoring
- Disc brake calipers for leakage or damage

STEP 4 Remove disc brake calipers and check the disc brake pads for proper lining thickness and check for cracks or other damage.

STEP 5 Replace all components that do not meet factory specifications.

STEP 6 Test drive the vehicle to verify that the repairs did correct the customer concern.

TECH TIP

Let the Owner Drive

When verifying the customer complaint, ask the owner or driver of the vehicle to drive. Often, the problem is best discovered if the vehicle is being driven exactly the same way as when the complaint first occurred. For example, the technician may brake harder or softer than the driver so the problem may not be detected.

VISUAL INSPECTION

Even with operating wear-indicating sensors, a thorough visual inspection is very important. ● **SEE FIGURE 102–1.** A lining thickness check alone should not be the only inspection performed on a disc brake. *A thorough visual inspection can only be accomplished by removing the friction pads.* ● **SEE FIGURE 102–2** for an example of a disc brake pad that shows usable lining thickness, but is severely cracked and *must* be replaced.

NOTE: Some disc brake pads use a heat barrier (thermo) layer between the steel backing plate and the friction material. The purpose of the heat barrier is to prevent heat from transferring into the caliper piston where it may cause the brake fluid to boil. Do not confuse the thickness of the barrier as part of the thickness of the friction lining material. The barrier material is usually a different color and usually can be distinguished from the lining material.

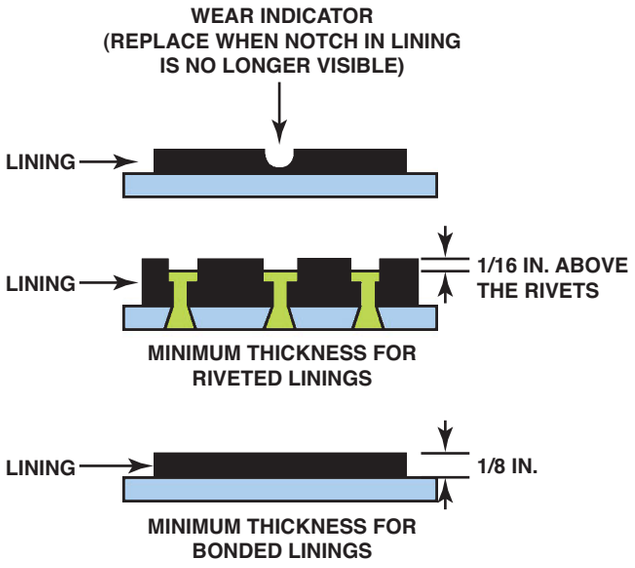


FIGURE 102–1 Minimum thickness for various types of disc brake pads. Pad wear sensors often make a "chirping" sound when the vehicle is moving if the pads are worn. Do not confuse that noise for a defective wheel bearing or other fault.

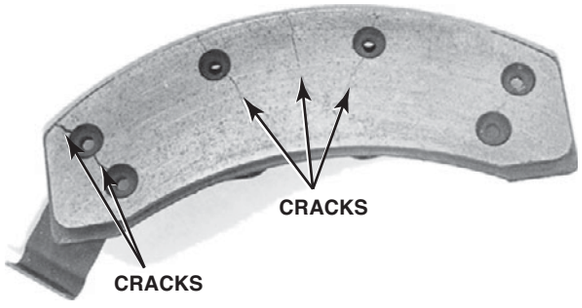


FIGURE 102–2 This cracked disc brake pad must be replaced even though it is thicker than the minimum allowed by the vehicle manufacturer and the wear sensor was not close to the rotor.

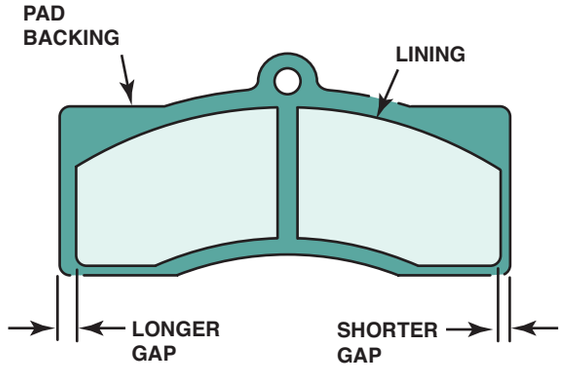


FIGURE 102–3 Be careful to observe the direction in which replacement linings are facing. Some vehicle manufacturers offset the friction material on the steel backing to help prevent or minimize tapered pad wear. Check service information for details as to which direction the pads should be installed.

Some disc brake pads may show more wear on the end of the pad that first contacts the rotor as compared to the trailing end of the pad. This uneven wear is caused by the force between the pad and the abutment (slide area). In designs that place the caliper piston exactly in the center of the leading edge of the pad that first contacts the rotor as it is revolving through the caliper, pressures are often one-third higher than the average pressure exerted on the entire pad. The result of this higher pressure is greater wear.

Brake engineers design brakes to minimize or eliminate tapered pad wear by offsetting the piston more toward the trailing edge of the shoe or by other caliper/pad mounting designs.

One method used to help reduce tapered pad wear is the design that offsets the friction material off center. Be certain to position the pads correctly or severe tapered pad wear will occur. ● **SEE FIGURE 102–3.**

Many calipers are equipped with a brake inspection opening that allows the technician to view the thickness of the brake pads. ● **SEE FIGURE 102–4.**

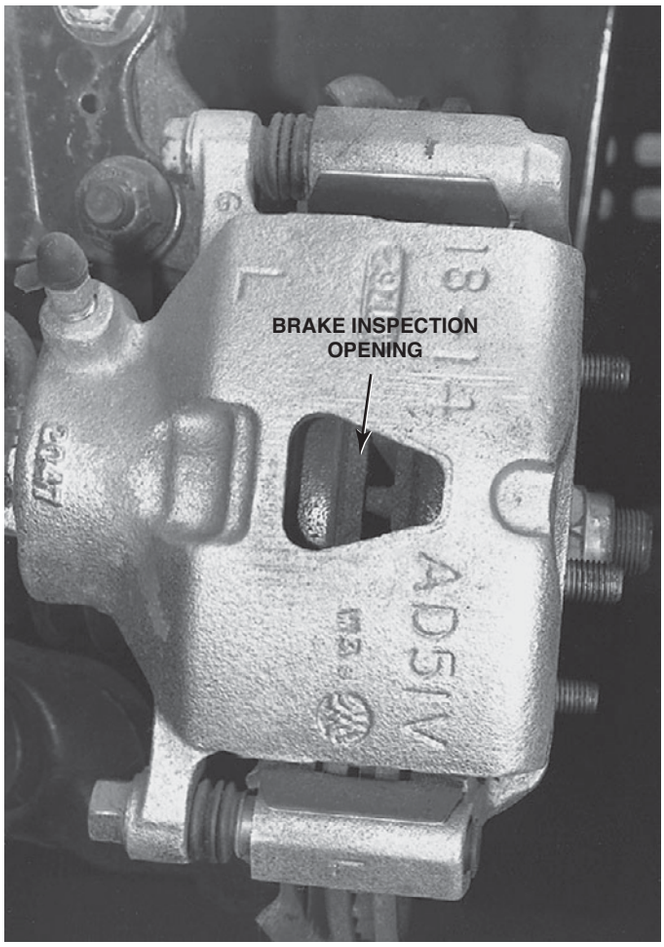


FIGURE 102–4 Most disc brake calipers have a brake inspection opening. For a thorough inspection, however, the caliper should be removed and the entire braking system thoroughly inspected.

TECH TIP

The Bleed and Squirt Test

If you suspect a brake is not being fully released, simply loosen the bleeder valve. If brake fluid squirts out under pressure, then the brake is being kept applied. Look for a defective flexible brake hose.

If the vehicle is off the ground, the wheels should be able to be rotated with the brakes off. If a wheel is difficult or hard to turn by hand and is easy to turn after opening the bleeder valve, then there is a brake fluid restriction between the master cylinder and the brake.

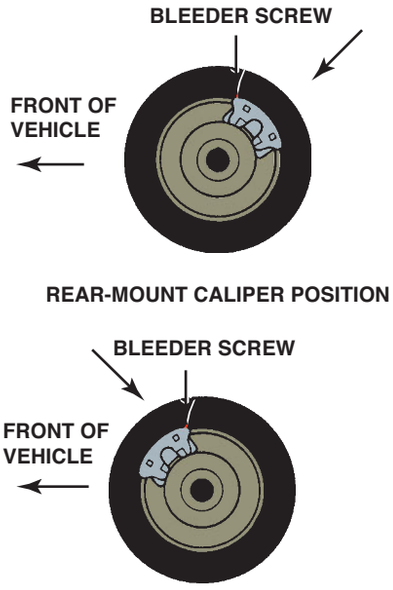


FIGURE 102–5 Both rear- and forward-mounted calipers have the bleeder valve at the top. Some calipers will fit on the wrong side of the vehicle, yet not be able to be bled correctly because the bleeder valve would point down, allowing trapped air to remain inside the caliper bore. If both calipers are being removed at the same time, mark them "left" and "right."

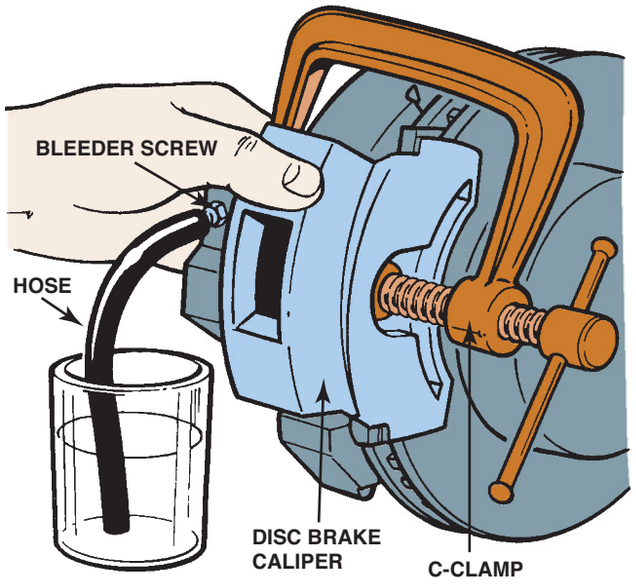


FIGURE 102–7 Most manufacturers recommend that the bleeder valve be opened and the brake fluid forced into a container rather than back into the master cylinder reservoir. This helps prevent contaminated brake fluid from being forced into the master cylinder where the dirt and contamination could cause problems.

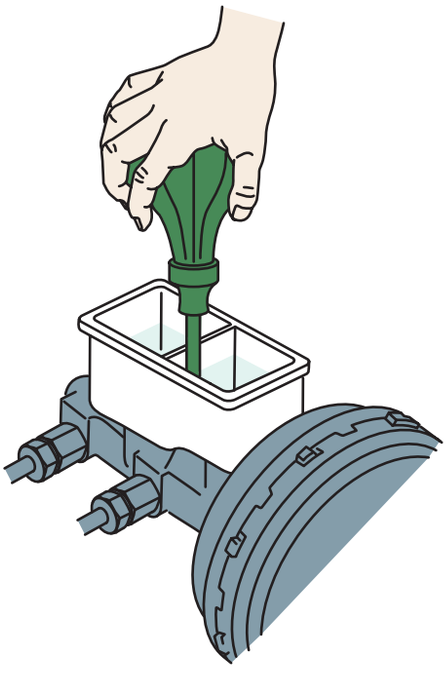


FIGURE 102–6 Many manufacturers recommend removing one-half of the brake fluid from the master cylinder before servicing disc brakes. Use a squeeze bulb and dispose of the used brake fluid properly.

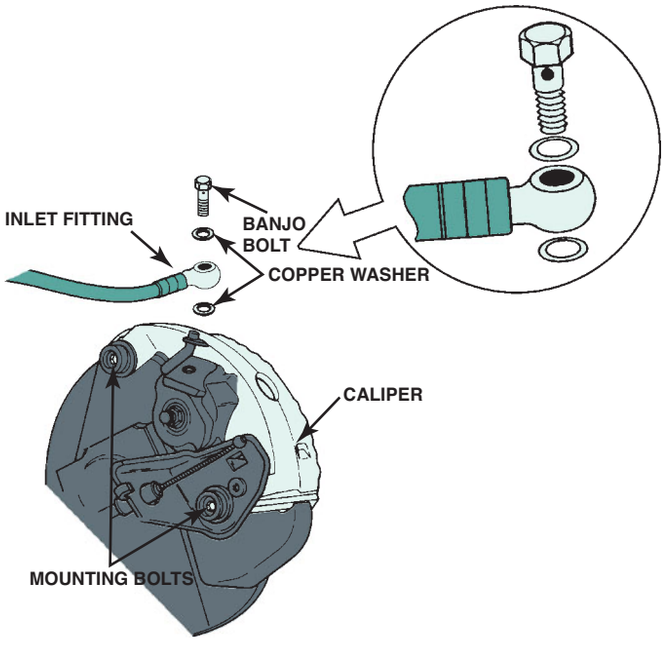


FIGURE 102–8 Many calipers use a hollow "banjo bolt" to retain the flexible brake line to the caliper housing. The fitting is usually round like a banjo. The copper washers should always be replaced and not reused.

DISC BRAKE CALIPER SERVICE

REMOVAL Hoist the vehicle and remove the wheel(s). Note the caliper mount position as shown in ● **FIGURE 102–5** before removing the caliper. Knowing whether the caliper is "rear-mount" position or "forward-mount" position is often needed when purchasing replacement calipers. Remove the caliper following the steps shown in ● **FIGURES 102–6 THROUGH 102–10.**

INSPECTION AND DISASSEMBLY Check for brake fluid in and around the piston boot area. If the boot is damaged or a fluid leak is visible, then a caliper assembly repair or replacement is required. ● **SEE FIGURES 102–11 AND 102–12.**

PHENOLIC CALIPER PISTONS. **Phenolic caliper pistons** are made from a phenol-formaldehyde resin combined with various reinforcing fibers. When phenolic brake caliper pistons were first used, the results were not good and the problem was blamed on "those *darn* plastic pistons." What was happening was that the pistons were

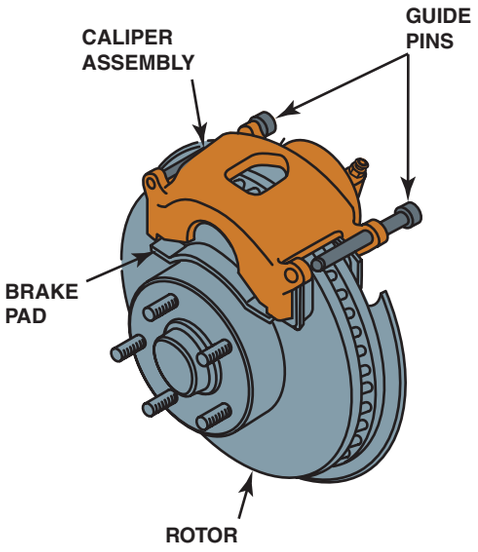


FIGURE 102–9 Caliper retaining bolts are often called guide pins. These guide pins are used to retain the caliper to the steering knuckle. These pins also slide through metal bushings and rubber O-rings.

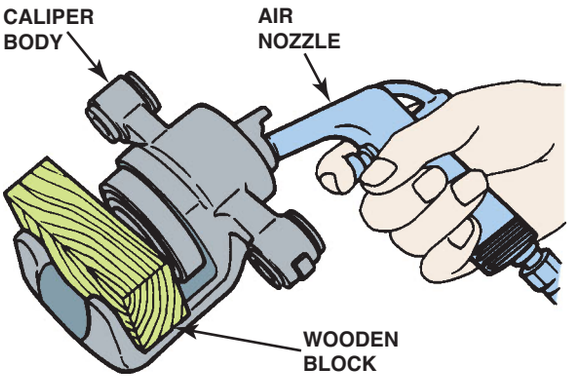


FIGURE 102–11 A wooden block or a folded shop cloth helps prevent damage when caliper pistons are removed. Use extreme care when removing a caliper piston using compressed air. The pressure applied can force the piston out of the caliper with tremendous force. Always follow service information instructions.

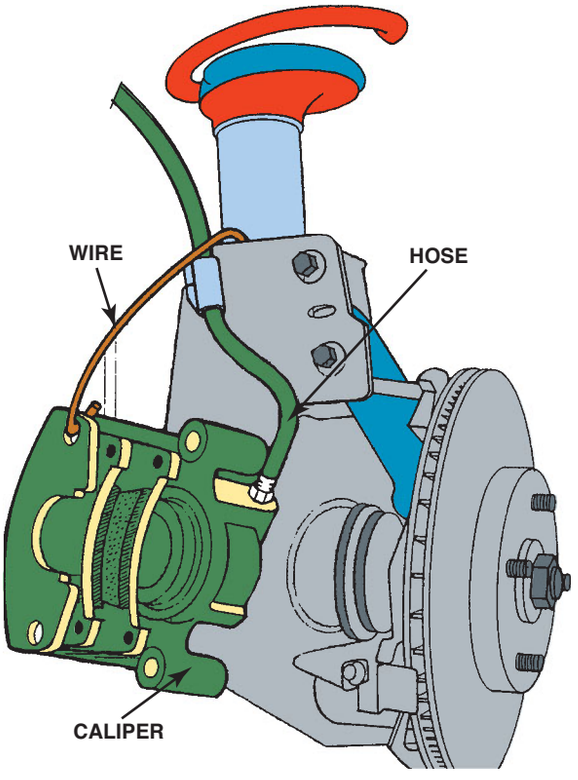


FIGURE 102–10 If the caliper is not being removed, it must be supported properly so that the weight of the caliper is not pulling on the flexible rubber brake line. A suitable piece of wire, such as a coat hanger, may be used.

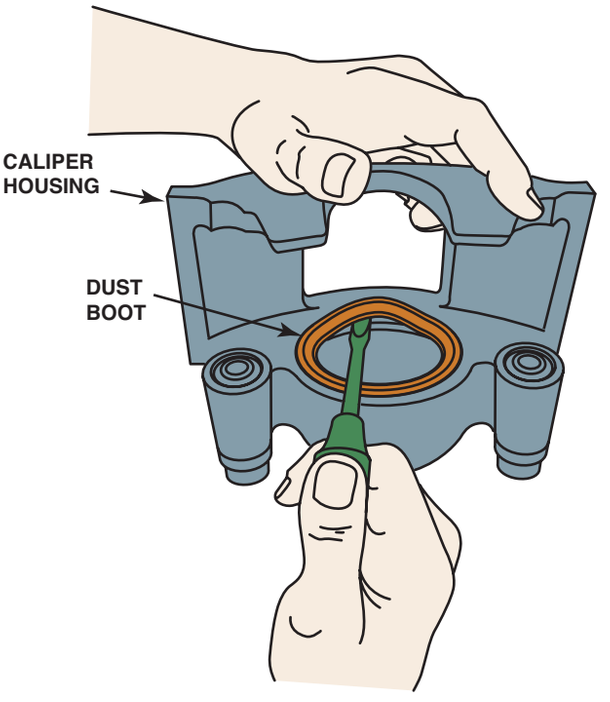


FIGURE 102–12 After the piston is removed from the caliper housing, the dust boot can often be removed using a straight-blade screwdriver.

becoming stuck in the caliper, which caused the brake pads to remain applied. This caused the brake pads to wear out very rapidly. The problem occurred because the phenolic pistons absorbed moisture and swelled in size.

NOTE: Uneven disc brake pad wear (inside pad compared to the outside pad) can be caused by a stuck caliper piston or if the caliper is unable to "float."

Phenolic caliper pistons are natural thermal insulators and help keep heat generated by the disc brake pads from transferring through the caliper piston to the brake fluid. Phenolic brake caliper pistons are also lighter in weight than steel caliper pistons and are usually brown in color. ● **SEE FIGURE 102–13.**

STEEL CALIPER PISTONS. Many manufacturers still use steel pistons. The stamped steel pistons are plated first with nickel, then chrome to achieve the desired surface finish. ● **SEE FIGURE 102–14.** Unlike phenolic caliper pistons, steel pistons can transfer heat from the brake pads to the brake fluid. The surface finish on a steel piston is critical. Steel can rust and corrode. Any surface pitting can cause the piston to stick.

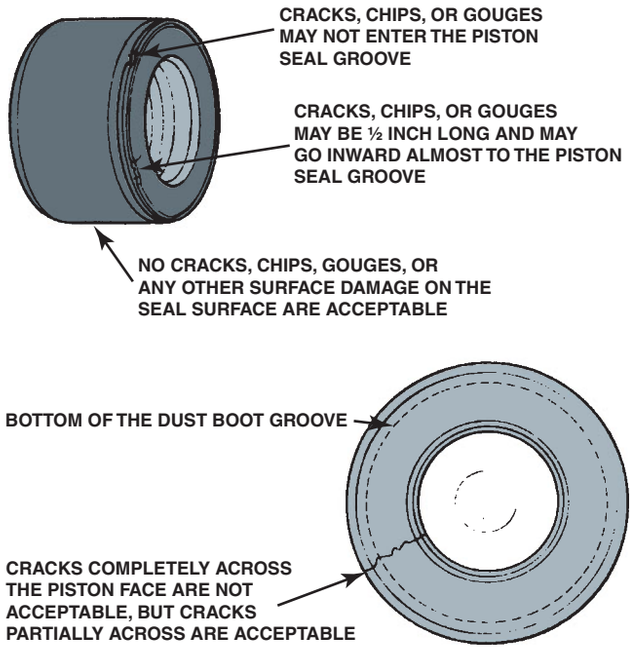


FIGURE 102–13 Phenolic (plastic) pistons should be carefully inspected.



FIGURE 102–14 If there are any surface flaws such as rust pits on the piston, it should be replaced.

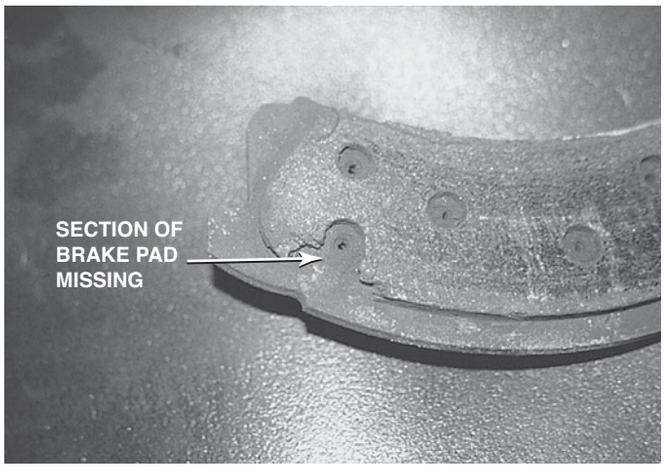


FIGURE 102–15 These pads were found to be cracked and a section was missing from a part of one pad.

REAL WORLD FIX

Three Brake Jobs in 40,000 Miles

A service technician was asked to replace the front disc brake pads on a Pontiac Grand Am because the sensors were touching the rotors and making a squealing sound. This was the third time that the front brakes needed to be replaced. Previous brake repairs had been limited to replacement of the front disc brake pads only.

When the caliper was removed and the pads inspected, it was discovered that a part of one pad had broken and a piece of the lining was missing. ● **SEE FIGURE 102–15.**

Then the technician spotted something at the rear of the vehicle that told the whole story—a trailer hitch.

The owner confirmed that a heavy jet ski was towed in hilly terrain. The technician recommended overhauling the front disc brake calipers to prevent the possibility of the front pads dragging. The technician also recommended an inspection of the rear brakes. The rear brakes were glazed and out-of-adjustment. The technician received permission to replace the rear brakes, overhaul both front calipers, and install quality disc brake pads. When the customer returned, the technician advised the customer to use the transmission on long downhill roads to help keep the brakes from overheating and failing prematurely.

NOTE: Care should be taken when cleaning steel pistons. Use crocus cloth to remove any surface staining. Do not use sandpaper, emery cloth, or any other substance that may remove or damage the chrome surface finish.

SERVICING DISC BRAKE CALIPERS

INSPECTION After removing the caliper piston then remove the square-cut O-ring. ● **SEE FIGURE 102–16.** Then the caliper should be thoroughly cleaned in denatured alcohol and closely examined. If the caliper bore is rusted or pitted, some manufacturers recommend that a special hone be used, as shown in ● **FIGURE 102–17.**

Some manufacturers do *not* recommend honing the caliper bore because the actual sealing surface in the caliper is between the piston seal and the piston itself. This is the reason why the surface condition of the piston is so important.

CALIPER ASSEMBLY To assemble the disc brake caliper, perform the following steps:

STEP 1 Carefully clean the caliper bore with clean brake fluid from a sealed container. Coat a new piston seal with clean brake fluid and install it in the groove inside the caliper bore, as shown in ● **FIGURE 102–18**.

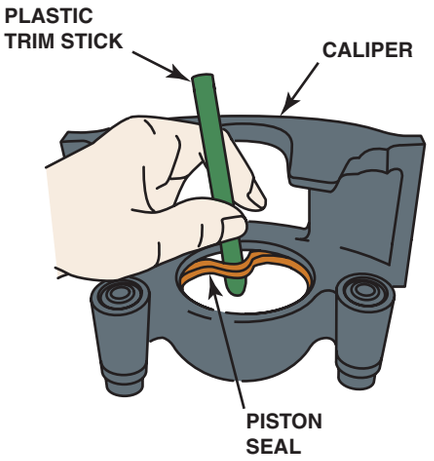


FIGURE 102–16 Removing the square-cut O-ring seal from the caliper bore. Use a wooden or plastic tool to prevent damage to the seal groove.

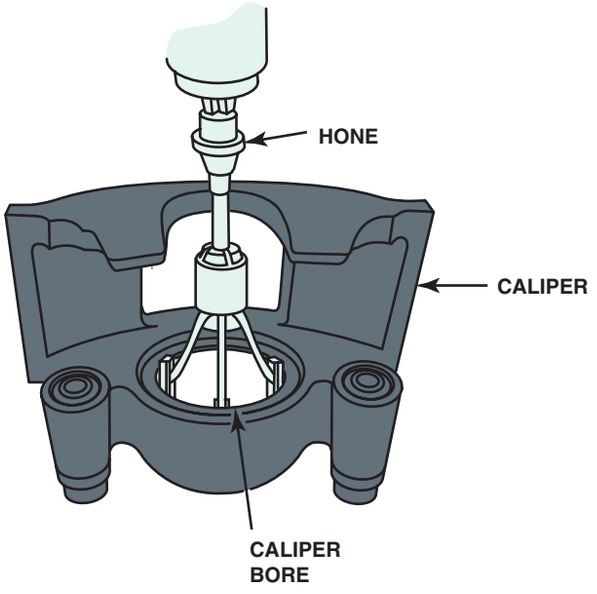


FIGURE 102–17 Some manufacturers recommend cleaning the inside of the caliper bore using a honing tool as shown. Even though the caliper piston does not contact the inside of this bore, removing any surface rust or corrosion is important to prevent future problems. If the honing process cannot remove any pits or scored areas, the caliper should be replaced.

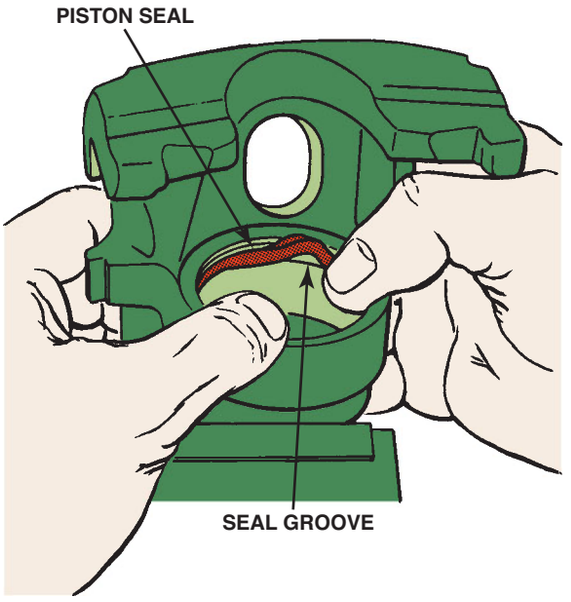


FIGURE 102–18 Installing a new piston seal. Never reuse old rubber parts. A caliper overhaul kit includes just two items: the square-cut piston seal O-ring and dust boot.



FIGURE 102–19 Brake assembly fluid or clean brake fluid from a sealed container can be used to lubricate the caliper seal and caliper pistons before assembly.

STEP 2 Check the piston-to-caliper bore clearance. Typical piston-to-caliper bore clearance is as follows.

- steel piston 0.002–0.005 in. clearance (0.05–0.13 mm)
- phenolic piston 0.005–0.010 in. clearance (0.102–0.25 mm)

STEP 3 Coat a new piston boot with brake fluid or **brake assembly fluid.** ● **SEE FIGURE 102–19**. Brake assembly fluid is similar to brake fluid but has antiwear additives.

STEP 4 Install the piston into the caliper piston, as shown in ● **FIGURES 102–20 AND 102–21**.

STEP 5 Some caliper boots require a special boot-seating tool, as shown in ● **FIGURE 102–22**.

STEP 6 Always lubricate caliper bushings, shims, and other brake hardware as instructed by the manufacturer. ● **SEE FIGURE 102–23**.

STEP 7 The pads should also be securely attached to the caliper as shown in ● **FIGURES 102–24 AND 102–25**.

CAUTION: Installing disc brake pads on the wrong side of the vehicle (left versus right) will often prevent the sensor from making noise when the pads are worn down.

CALIPER MOUNT SERVICE When the hydraulic force from the master cylinder applies pressure to the disc brake pads, the entire caliper tends to be forced in the direction of rotation of the

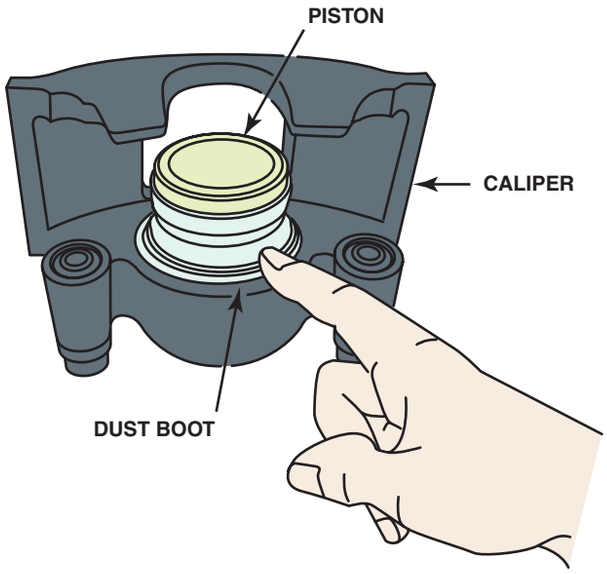


FIGURE 102–20 Installing the caliper piston. Many calipers require that the dust boot be installed in the groove of the piston and/or caliper before installing the piston.

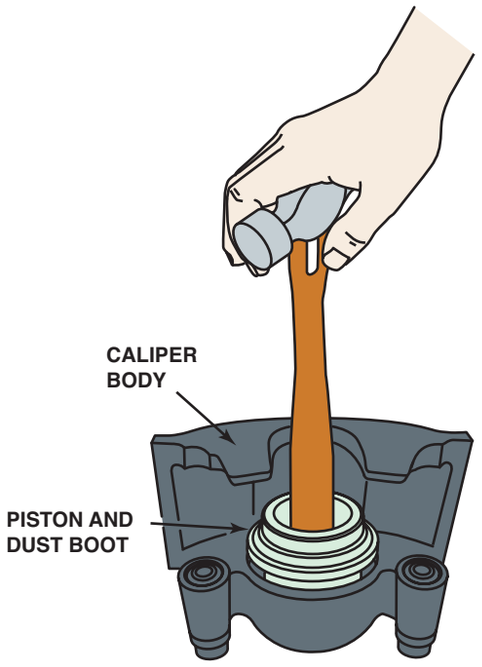


FIGURE 102–21 Installing a piston into a caliper. Sometimes a C-clamp is needed to install the piston. Both the piston and the piston seal should be coated in clean brake fluid before assembly.

TECH TIP

Using "Loaded Calipers" Saves Time

Many technicians find that disassembly, cleaning, and rebuilding calipers can take a lot of time. Often the bleeder valve breaks off or the caliper piston is too corroded to reuse. This means that the technician has to get a replacement piston, caliper overhaul kit (piston seal and boot), plus the replacement friction pads and hardware kit.

To save time (and sometimes money), many technicians are simply replacing the old used calipers with "loaded calipers." **Loaded calipers** are remanufactured calipers that include (come loaded with) the correct replacement friction pads and all the necessary hardware. ● **SEE FIGURE 102–26.**

Therefore, only one part number is needed for each side of the vehicle for a complete disc brake overhaul.

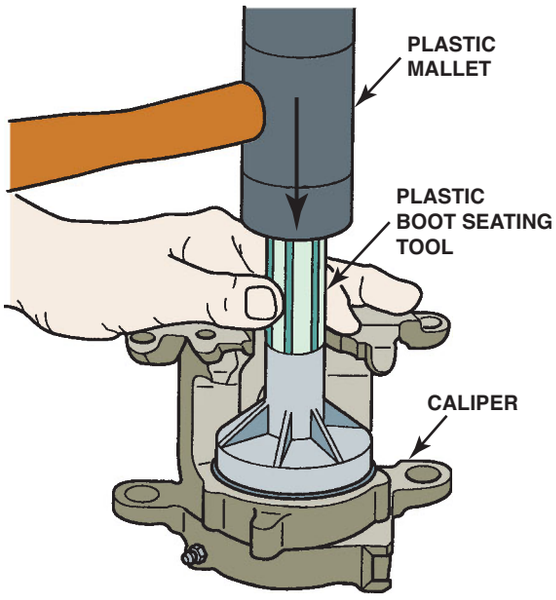


FIGURE 102–22 Seating the dust boot into the caliper housing using a special plastic seating tool.

rotor. All calipers are mounted to the steering knuckle, caliper support bracket, or axle housing. ● **SEE FIGURE 102–27.**

All braking force is transferred through the caliper to the mount. The places where the caliper contacts the caliper mount are called the **abutments, reaction pads,** or **ways.** The sliding surfaces of the caliper support should be cleaned with a wire brush and coated with a synthetic grease or antiseize compound according to manufacturers' recommendations. ● **SEE FIGURE 102–28.**

ROTATING PISTONS BACK INTO THE CALIPER

Many disc brake calipers used on the rear wheels require that the piston be rotated to reseat the pistons. When the parking brake is applied, the actuating screw moves the piston outward, forcing the pads against the disc brake rotor. The piston is kept from rotating because of an antirotation device or notches on the inboard pad and piston.

When the disc brake pads are being replaced, use a special tool to rotate the piston back into the brake calipers. Insert the tip of the tool in the holes or slots in the piston. Exert inward pressure while turning the piston. Make sure that the piston is retracting into the caliper and continue to turn the piston until it bottoms out.

NOTE: Some pistons are activated with left-handed threads.

After replacing the pads back into the caliper, check that the clearance does not exceed 1/16 in. (1.5 mm) from the rotor. Clearance greater than 1/16 in. may allow the adjuster to be pulled out of the piston when the service brake is applied. If the clearance

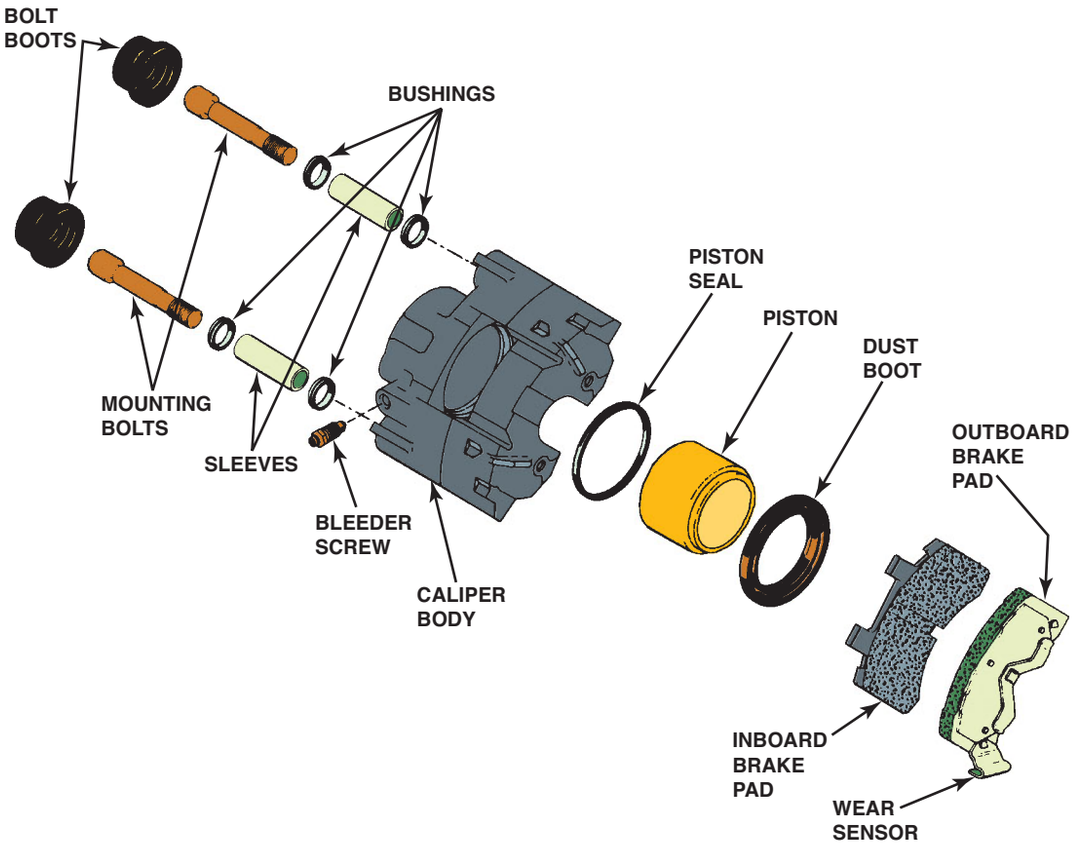


FIGURE 102–23 All rubber bushings should be lubricated with silicone brake grease for proper operation.

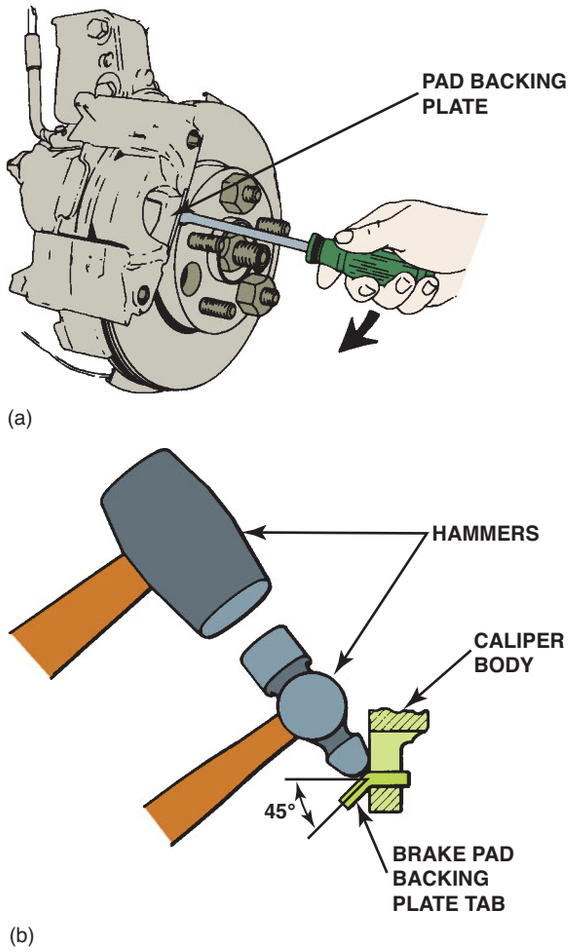


FIGURE 102–24 (a) Using a screwdriver to force the outboard pad into proper position before bending the retaining tabs. (b) Use two hammers to bend the tab where it extends through the hole in the caliper body.

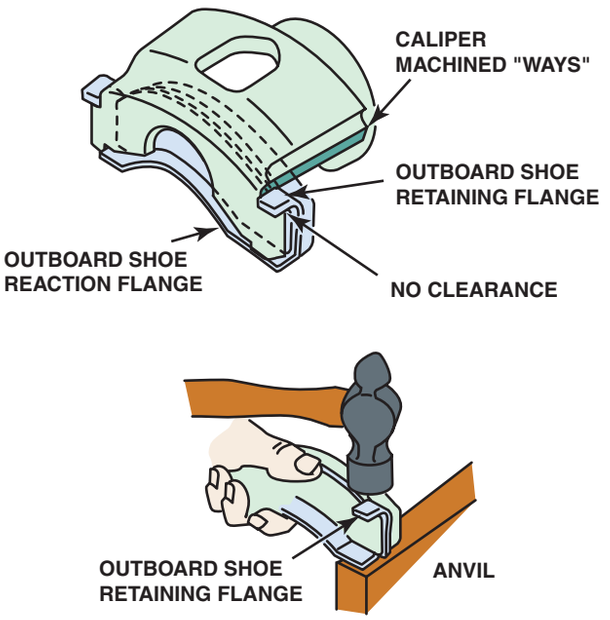


FIGURE 102–25 Often, a hammer is necessary to bend the retainer flange to make certain that the pads fit tightly to the caliper. If the pads are loose, a "click" may be heard every time the brakes are depressed. This click occurs when the pad(s) move and then hit the caliper or caliper mount. If the pads are loose, a clicking noise may be heard while driving over rough road surfaces.

is greater than 1/16 in., readjust by rotating the piston outward to reduce the clearance. ● **SEE FIGURE 102–29.**

TEST DRIVE AFTER BRAKE REPLACEMENT After installing replacement disc brake pads or any other brake work, depress the brake pedal several times before driving the vehicle. This is a very important

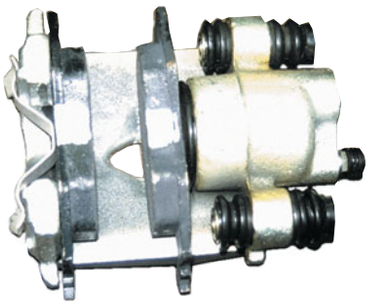


FIGURE 102–26 A loaded caliper includes all hardware and shims with the correct pads all in one convenient package, ready to install on the vehicle.

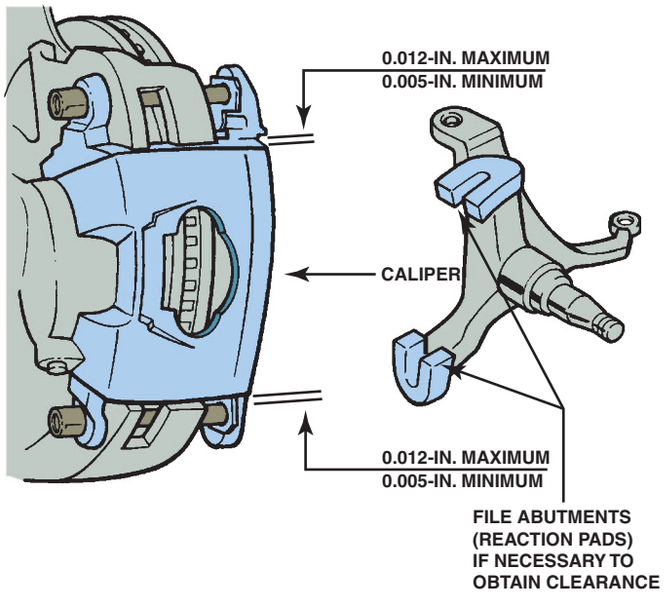


FIGURE 102–27 Floating calipers must be able to slide during normal operation. Therefore, there must be clearance between the caliper and the caliper mounting pads (abutments). Too little clearance will prevent the caliper from sliding and too much clearance will cause the caliper to make a clunking noise when the brakes are applied.



FIGURE 102–28 Using an air-powered sanding disc to clean the caliper mount pads.

step! New brake pads are installed with the caliper piston pushed all the way into the caliper. The first few brake pedal applications usually result in the brake pedal going all the way to the floor. The brake pedal must

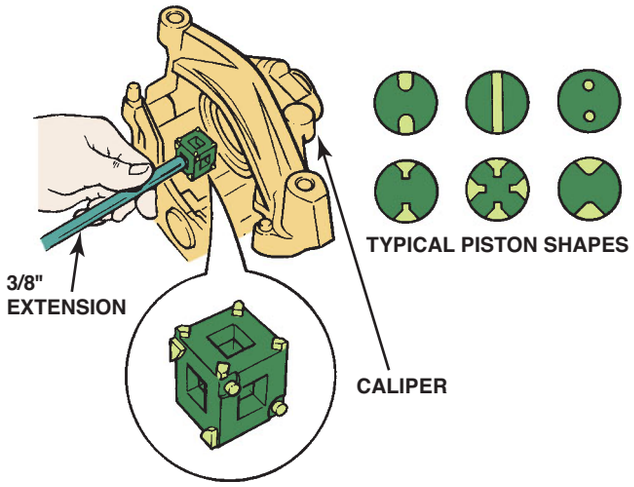


FIGURE 102–29 Determine which face of the special tool best fits the holes or slots in the piston. Sometimes needle-nose pliers can be used to rotate the piston back into the caliper bore.



FIGURE 102–30 Note the twisted flexible brake line. This was caught by an automotive instructor before the brake work on the vehicle was completed. The twisted brake line can cause brake hose failure if not corrected.

TECH TIP

Always Double-Check Your Work

Whenever reassembling brakes, it is easy to twist the flexible brake hose as shown in ● **FIGURE 102–30.** To prevent possible brake hose failure and possibly an accident, always double-check that the ribs on the brake hose are straight. The ribs allow the service technician to easily spot if the hose has been twisted.

be depressed ("pumped") several times before enough brake fluid can be moved from the master cylinder into the calipers to move the piston tight against the pads and the pads against the rotors.

CAUTION: Never allow a customer to be the first to test drive the vehicle after brake work has been performed.

BEDDING-IN REPLACEMENT BRAKE PADS Some manufacturers recommend that their replacement brake pads be **bedded-in** or **burnished** before returning the vehicle to the owner. This break-in

TECH TIP

Increasing Pad Life

Many vehicles seem to wear out front disc brakes more often than normal. Stop-and-go city-type driving is often the cause. Driving style, such as rapid stops, also causes a lot of wear to occur.

The service technician can take some actions to increase brake pad life that are easier than having to cure the driver's habits. These steps include the following.

1. Make sure the rear brakes are properly adjusted and working correctly. If the rear brakes are not functioning, all of the braking is accomplished by the front brakes alone.

   NOTE: Remind the driver to apply the parking brake regularly to help maintain proper rear brake clearance on the rear brakes.

2. Use factory brake pads or premium brake pads from a known manufacturer. Tests performed by vehicle manufacturers show that many aftermarket replacement brake pads fail to deliver original equipment brake pad life.



FIGURE 102–31 For best braking performance, purchase replacement disc brake pads that include all clips and shims specified by the vehicle manufacturer. Some pads even come with a package of the specified grease to use on the shims to reduce the possibility of brake noise.

process varies with the manufacturer, but usually involves stopping the vehicle from 30 mph (48 km/h) up to 30 times, allowing the brakes to cool 2 to 3 minutes between stops. This break-in procedure helps the replacement pads to conform to the rotor and helps cure the resins used in the manufacture of the pads. Failure to properly break in new pads according to the manufacturer's recommended procedure could result in a hard brake pedal complaint from the driver and/or reduced braking effectiveness.

Even if the brake pad manufacturer does not recommend a break-in procedure, high-speed stops and overheating of the brakes should be avoided as much as possible during the first 50 to 100 stops.

DISC BRAKE SQUEAL CORRECTION

CAUSES OF BRAKE SQUEAL Disc brakes tend to create brake noise (squeal). The cause and correction of brake noise is a major concern for both the vehicle manufacturers and the service technicians. The greatest customer complaint about brake work involves brake noise. Noise is caused by moving air, which is a result of moving brake components.

CORRECTING DISC BRAKE SQUEAL Brake squeal can best be *prevented* by careful attention to details whenever servicing any disc brake. Some of these precautions include the following:

- **Keep the Disc Brake Pads Clean.** Grease on brake lining material causes the friction surface to be uneven. When the brakes are applied, this uneven brake surface causes the brake components to move.
- **Use Factory-Type Clips and Anti-Squeal Shims.** The vehicle manufacturer has designed the braking system to be as quiet as possible. To assure that the brakes are restored to like-new performance, all of the original hardware should be used. Many original equipment brake pads use **constrained layer shims (CLS)** on the back of the brake pads. These shims are constructed with dampening material between two layers of steel. ● **SEE FIGURE 102–31.**

  NOTE: Many aftermarket disc brake pads do *not* include replacement hardware that usually includes noise-reducing shims and clips. One of the advantages of purchasing original equipment (OE) disc brake pads is that they usually come equipped with all necessary shims and often with special grease that is recommended to be used on metal shims.

- **Lubricate All Caliper Slide Points as per Manufacturer's Recommendation.** Lubrication of moving or sliding components prevents noise from being generated as the parts move over each other. Many vehicle manufacturers recommend one or more of the following greases:
  1. **Lithium-based brake grease**
  2. **Silicone grease**
  3. **Molybdenum disulfide (MOS_2) grease** ("Molykote") often referred to as "moly" grease
  4. **Synthetic grease** (usually **polyalphaolefin [PAO]**) sometimes mixed with graphite, Teflon, and/or MOS_2
  5. **Antiseize compound**

  The lubricant should be applied on both sides of shims used between the pad and the caliper piston.

CAUTION: Lubricant should only be applied to the non-friction (steel) side of the disc brake pads.

- **Machine the Brake Rotor as Little as Possible and with the Correct Surface Finish.** Machining the brake rotor reduces its thickness. A thinner rotor will vibrate at a different frequency than a thicker rotor. For factors that can help or hurt brake squeal, ● **SEE CHART 102–1.**

Vehicle manufacturers also change brake pad (lining) composition and the shape of the pads to help eliminate brake noise. The change of shape changes the frequency of the sound. Noise is vibration, but much of the vibration generated is not heard because the noise is beyond the normal frequency to be heard. Most people can hear from 20 to 20,000 cycles per second (called hertz). To stop brake noise, the manufacturer can change the frequency of the vibration to above or below the hertz range that can be heard. ● **SEE FIGURE 102–32.**

NOTE: All metal-to-metal contacts *must* be lubricated to help prevent brake noise.

FACTOR	INCREASE NOISE	REDUCE NOISE
Brake pad thickness	Thinner (worn) pads	Thicker (new) pads
Rotor (disc) thickness	Thinner (worn) rotor	Thicker (new) rotor
Brake pad material	Harder	Softer
Lubrication of parts	Dry—not lubricated	Properly lubricated
Dampening	No dampening	Dampening material behind the pads
Pad mounting	Pad tabs not bent over	Pad tabs securely crimped
Antirattle clips	Worn, defective, or not lubricated	New and properly lubricated

CHART 102–1

The causes of brake noise can have many reasons and corrections.

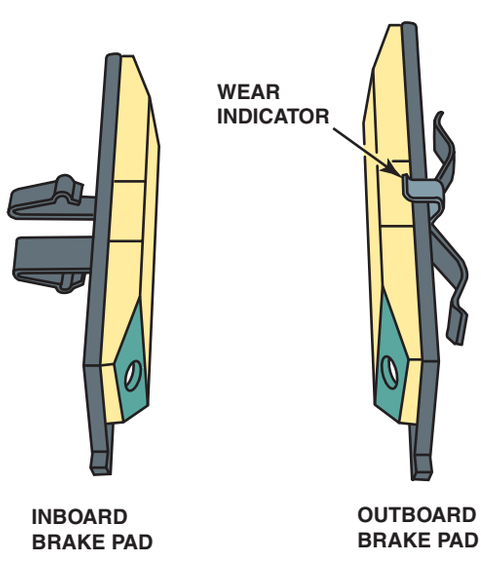


FIGURE 102–32 Notice the beveled pads. The shape of the pad helps reduce brake noise.

DISC BRAKE SYMPTOM GUIDE

PULLS TO ONE SIDE DURING BRAKING

Possible causes of this include the following:

1. Incorrect or unequal tire pressures
2. Front end out of alignment
3. Unmatched tires on the same axle

TECH TIP

The Screwdriver Trick

A low brake pedal on GM vehicles equipped with rear disc brakes is a common customer complaint. Often the reason is a lack of self-adjustment that *should* occur whenever the brake pedal (or parking brake) is released. During brake release, the pressure is removed from the caliper piston and the spring inside the caliper piston is free to adjust. Often this self-adjustment does not occur and a low brake pedal results.

A common trick that is used on the vehicle assembly line is to use a screwdriver to hold the piston against the rotor while an assistant releases the brake pedal. ● **SEE FIGURE 102–33.**

As the brake pedal is released, the adjusting screw inside the caliper piston is free to move. Sometimes, it may be necessary to tap on the caliper itself with a dead-blow hammer to free the adjusting screw. Repeat the process as necessary until the proper brake pedal height returns.

If this method does not work, replace the caliper assembly.

In summary, recall these steps.

STEP 1 Have an assistant depress the brake pedal.

STEP 2 Using a screwdriver through the hole in the top of the caliper, hold the piston against the rotor.

NOTE: Be careful not to damage the dust boot.

STEP 3 While still holding the piston against the rotor, have the assistant release the brake pedal. The adjusting screw adjusts when the brake pedal is *released* and a slight vibration or sound will be noticed as the brake is released. This vibration or sound is created by the self-adjusting mechanism inside the caliper piston taking up the excess clearance.

STEP 4 Repeat as necessary until normal brake pedal height is achieved.

4. Restricted brake lines or hoses
5. Stuck or seized caliper or caliper piston
6. Defective or damaged shoe and lining (grease or brake fluid on the lining, or a bent shoe)
7. Malfunctioning rear brakes
8. Loose suspension parts
9. Loose calipers

BRAKE ROUGHNESS OR CHATTER (PEDAL PULSATES)

Possible causes of this include the following:

1. Excessive lateral runout of rotor
2. Parallelism of the rotor not within specifications
3. Wheel bearings not adjusted correctly
4. Rear drums out-of-round
5. Brake pads worn to metal backing plate

EXCESSIVE PEDAL EFFORT

Possible causes of this include the following:

1. Binding or seized caliper mounting
2. Binding brake pedal mechanism
3. Improper rotor surface finish
4. Malfunctioning power brake
5. Partial system failure
6. Excessively worn shoe and lining
7. Piston in the caliper stuck or sluggish
8. Fading brakes due to incorrect lining

EXCESSIVE PEDAL TRAVEL

Possible causes of this include the following:

1. Partial brake system failure
2. Insufficient fluid in the master cylinder
3. Air trapped in the system
4. Bent shoe and lining
5. Excessive pedal effort
6. Excessive parking brake travel (four-wheel disc brakes, except Corvette)

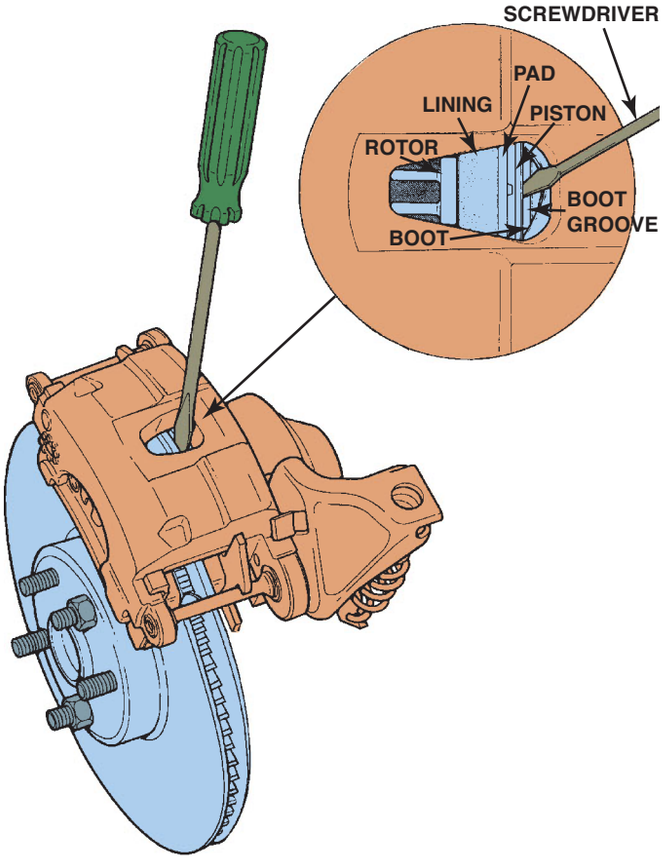
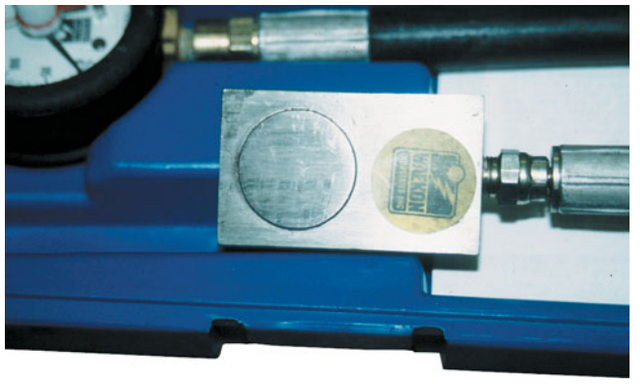


FIGURE 102–33 The screwdriver blade is used to keep the piston applied to allow self-adjustment to occur when the brake pedal is released.



(a)



(b)

FIGURE 102–34 (a) A brake pressure tester. (b) The small "pads" can be placed between the caliper piston and the rotor to check for applied pressure and inserted between the caliper and the rotor on the outside of the rotor to test the pressure—the pressure should be the same if the caliper is able to slide on its pins or slides.

TECH TIP

Pressure Testing Can Help Find Problems

A stuck caliper or caliper slide is often difficult to see or diagnose as a problem because the movement of the broken pads is so little. Using a pressure gauge between the caliper piston and the rotor (inboard) or between the rotor and the caliper (outboard) can tell the service technician if there is a difference between the left and the right side brakes. ● **SEE FIGURE 102–34.**

DRAGGING BRAKES Possible causes of this include the following:

1. Pressure trapped in the brake lines (to diagnose, momentarily open the caliper bleeder valve to relieve the pressure)
2. Restricted brake tubes or hoses
3. Improperly lubricated caliper mounting system
4. Improper clearance between the caliper and torque abutment surfaces
5. Check valve installed in the outlet of the master cylinder to the disc brakes
6. Stuck caliper caused from rusted sliding points or rusty mounting bolts/bushings.
7. Stuck caliper piston

FRONT DISC BRAKES VERY SENSITIVE TO LIGHT BRAKE APPLICATIONS Possible causes of this include the following:

1. Metering valve not holding off the front brake application
2. Incorrect lining material
3. Improper rotor surface finish
4. Check other causes listed under “PULLS”
5. Contaminated brake pad lining material from wheel bearing grease.

REAR DRUM BRAKES SKIDDING UNDER HARD BRAKE APPLICATIONS Possible causes of this include the following:

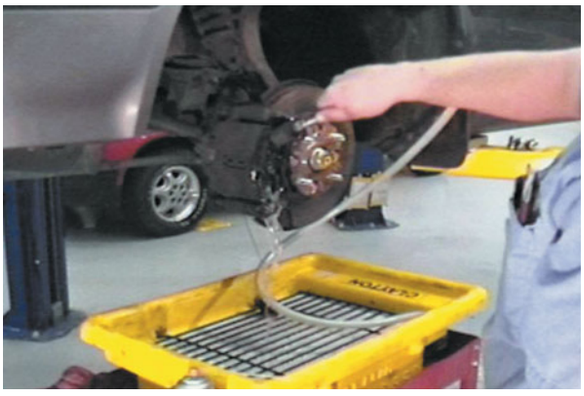
1. Proportioning valve
2. Contaminated rear brake lining
3. Caliper or caliper piston stuck or corroded



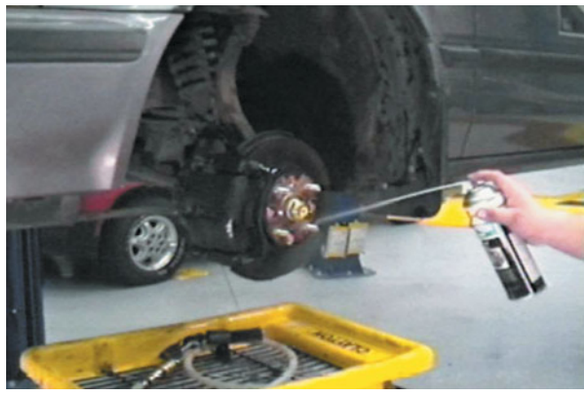
1 After properly setting the hoist pads under the vehicle, raise the vehicle to chest level and remove the lug nuts.



2 Remove the wheel/tire assembly and place it where it will not get in the way or be damaged.



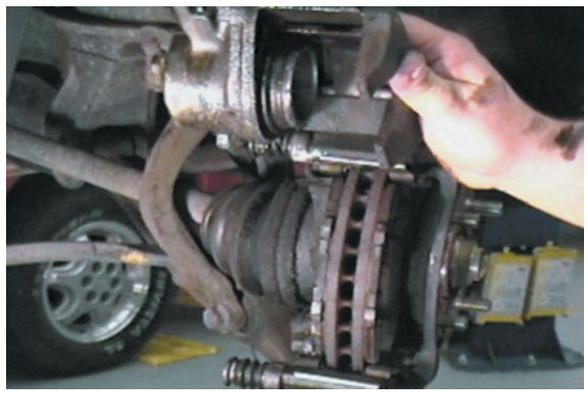
3 It is recommended that the entire brake assembly be washed using a commercially available cleaner to avoid the possibility of allowing brake dust from becoming airborne.



4 If a commercial brake cleaning unit is not available, use brake cleaner from an aerosol or pressurized container.

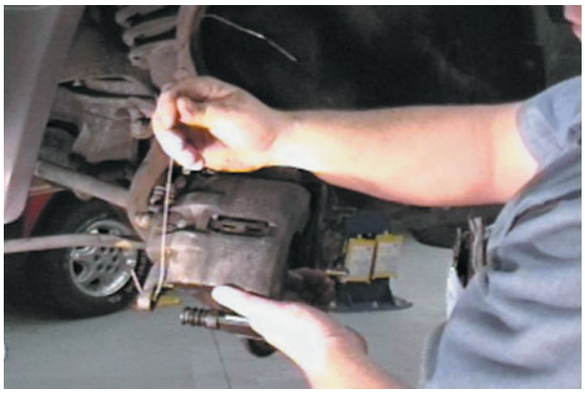


5 To service the front disc brake pads on this vehicle, loosen the upper caliper retainer bolt and remove the lower bolt.

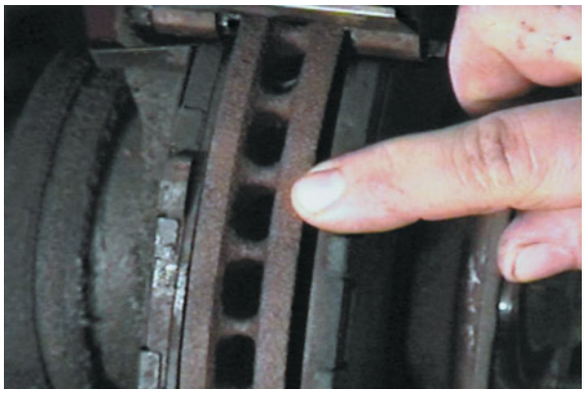


6 After the lower caliper bolt has been removed, the caliper assembly can be lifted upward by pivoting on the upper retaining bolt.

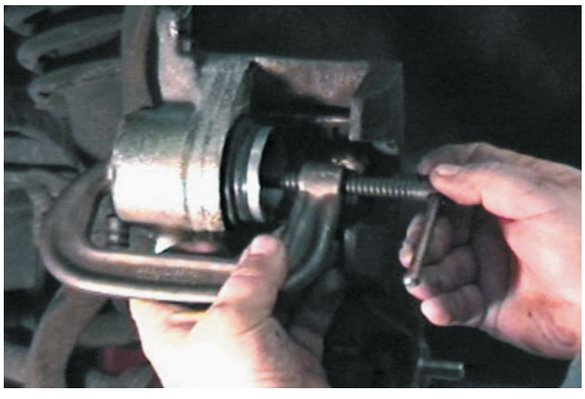
CONTINUED ▶



7 Use mechanic's wire to hold the caliper in the raised position to allow access to the disc brake pads.



8 Notice that both the inboard and outboard pad remain attached to the steering knuckle. The pads and shims can be lifted off.



9 A C-clamp can be used to push the piston into the caliper, but be sure to open the bleeder valve first.



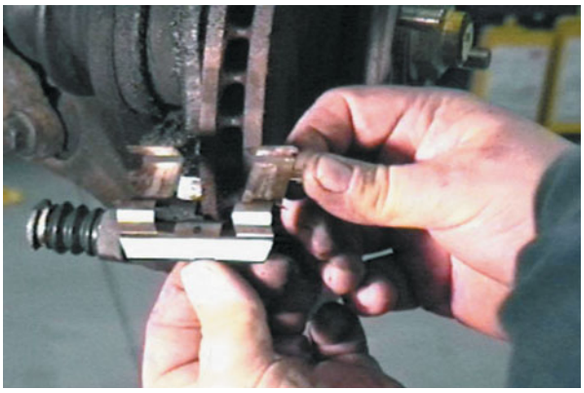
10 The bleeder valve should be opened to allow the old brake fluid to flow out of the caliper and not be forced up into the ABS hydraulic unit or master cylinder.



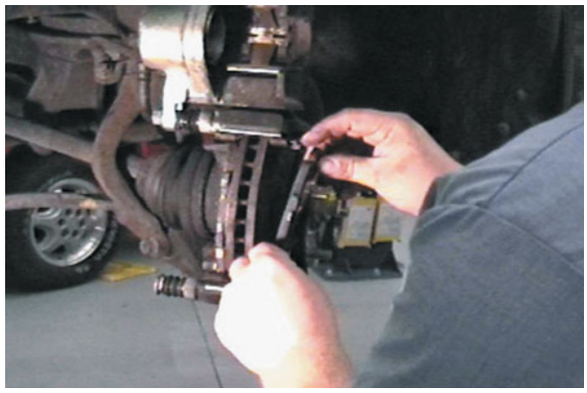
11 Often factory replacement disc brake pads include noise-dampening shims, antirattle clips, and special "moly" disc brake grease that is to be used on the shims.



12 All hardware, including this anchor shim, should be replaced.



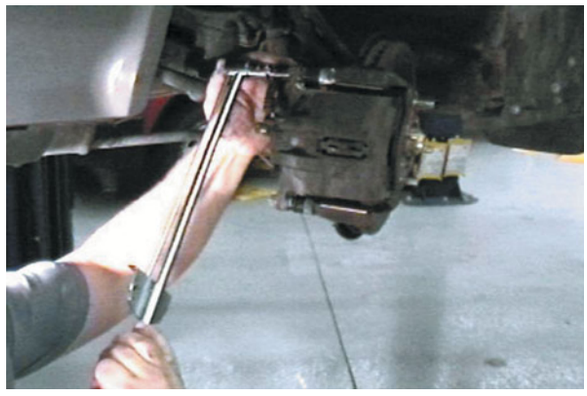
13 Install new shims after thoroughly cleaning the steering knuckle area of any rust using a wire brush or other suitable tool.



14 The replacement disc brake pads are installed next to the rotor and held in place by the tension of the anchor shims.



15 After double-checking that all shims, clips, and spacers are correctly installed, lower the calipers and install this lower attaching bolt.



16 Torque the retaining bolts to factory specifications. Repeat the process on the other side and bleed the hydraulic system.



17 Reinstall the wheel/tire assembly.



18 Torque the lug nuts to factory specifications or use a torque-limiting adapter. Test drive the vehicle before returning it to the customer.

REVIEW QUESTIONS

1. List what parts are included in a typical overhaul kit for a single-piston floating caliper.
2. Describe how to remove caliper pistons and perform a caliper overhaul.
3. Explain what causes disc brake squeal and list what a technician can do to reduce or eliminate the noise.

CHAPTER QUIZ

1. Uneven disc brake pad wear is being discussed. Technician A says the caliper piston may be stuck. Technician B says the caliper may be stuck on the slides and unable to "float." Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. A "chirping" noise is heard while the vehicle is moving forward, but stops when the brakes are applied. Technician A says that the noise is likely caused by the disc brake pad wear sensors. Technician B says the noise is likely a wheel bearing because the noise stops when the brakes are applied. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. Technician A says that disc brake pads should be replaced when worn to minimum allowable thickness. Technician B says the pads should be removed and inspected whenever there is a brake performance complaint. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. A typical disc brake caliper overhaul (OH) kit usually includes what parts?
   a. Square-cut O-ring seal and dust boot
   b. Replacement caliper piston and dust boot
   c. Dust boot, return spring, and caliper seal
   d. Disc brake pad clips, dust boot, and caliper piston assembly
5. Technician A says that a lack of lubrication on the back of the disc brake pads can cause brake noise. Technician B says that pads that are not correctly crimped to the caliper housing can cause brake noise. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. Two technicians are discussing ways of removing a caliper piston. Technician A says to use compressed air. Technician B says to use large pliers. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. Which is *not* a recommended type of grease to use on brake parts?
   a. Silicone grease
   b. Wheel bearing (chassis) grease
   c. Synthetic grease
   d. Antiseize compound
8. Technician A says that a loaded caliper includes an overhauled caliper assembly but no brake pads or hardware. Technician B says that a loaded caliper includes the pads and all needed hardware. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. A vehicle is hoisted during routine service and the service technician discovers that the left front wheel does not turn when force is applied. Technician A says that the hoist (lift) pads could be against the left front tire. Technician B says that there could be a brake fluid restriction between the master cylinder and the brake. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. Technician A says that a steel piston should be cleaned with sandpaper to remove rust. Technician B says that the brake assembly fluid or clean brake fluid should be used to lubricate the caliper pistons before installing in the caliper. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

chapter 103

PARKING BRAKE OPERATION, DIAGNOSIS, AND SERVICE

OBJECTIVES: **After studying Chapter 103, the reader will be able to:** • Prepare for the Brakes (A5) ASE certification test content area "E" (Miscellaneous Systems Diagnosis and Repair). • Describe what is required of a parking brake. • Describe the parts and operation of the parking brake as used on a rear drum brake system. • Describe how a parking brake functions when the vehicle is equipped with rear disc brakes. • Explain how to adjust a parking brake properly.

KEY TERMS: Application cables 1148 • Control cables 1148 • Electric parking brake (EPB) 1156 • Equalizer 1148 • Intermediate lever 1148 • Red brake warning lamp 1147 • Transfer cable 1148 • Vacuum servo 1147

PARKING BRAKE STANDARDS

BACKGROUND Before 1967, most vehicles had only a single master cylinder operating all four brakes. If the fluid leaked at just one wheel, the operation of all brakes was lost. This required the use of a separate method to stop the vehicle in case of an emergency. This alternative method required that a separate mechanical method be used to stop the vehicle using two of the four wheel brakes. After 1967, federal regulations required the use of dual or tandem master cylinders where half of the braking system has its own separate hydraulic system. In case one-half of the system fails, a dash brake warning lamp lets the driver know that a failure has occurred and the vehicle stops with one-half of the brake system operating. The term *parking brake* has replaced the term *emergency brake* since the change to dual master cylinder design.

FMVSS 135 According to Federal Motor Vehicle Safety Standard (FMVSS) 135, the parking brake must hold a fully loaded (laden) vehicle stationary on a slope of 20% up or down grade. The hand force required cannot exceed 80 lb (18 N) or a foot force greater than 100 lb (22 N). ● **SEE FIGURE 103–1** for a typical parking brake system.

PEDALS, LEVERS, AND HANDLES

Parking brakes are applied by a pedal, a lever, or a handle from inside the vehicle. Foot pedals and floor-mounted levers are the most common means of applying parking brakes. ● **SEE FIGURES 103–2 AND 103–3.** All parking brake controls incorporate a *ratchet* mechanism to lock the brake in the applied position. ● **SEE FIGURE 103–4.**

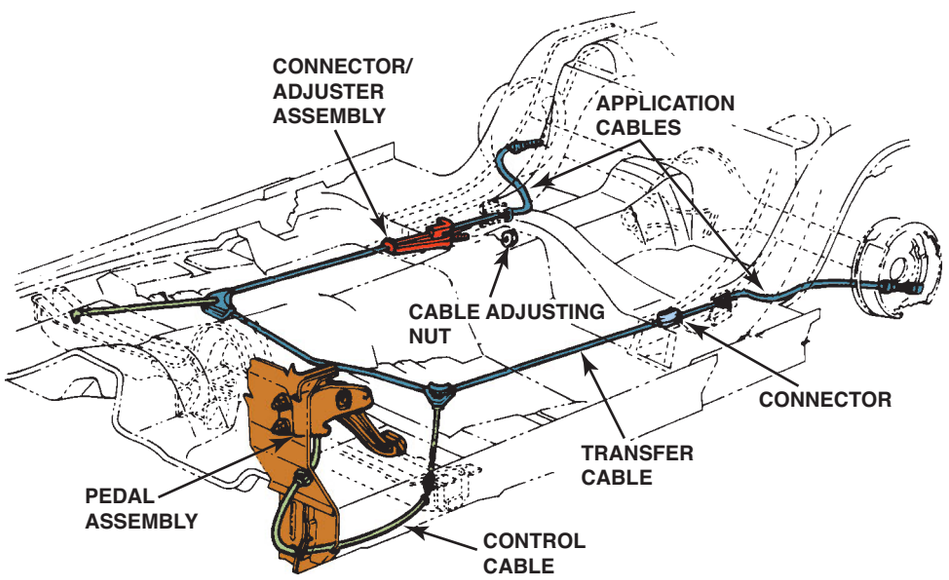


FIGURE 103–1 Typical parking brake cable system showing the foot-operated parking brake lever and cable routing.

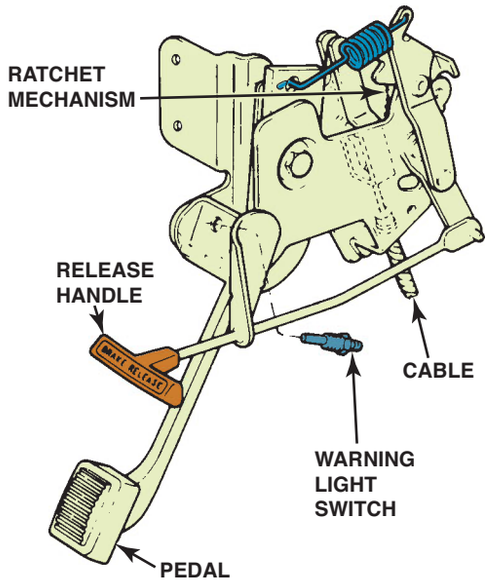


FIGURE 103–2 A typical parking brake pedal assembly.

All parking brakes are applied manually and the release procedure varies with the design of the parking brake control.

PARKING BRAKE PEDALS A parking brake pedal is applied by depressing it with a foot. The ratchet engages automatically and the pedal remains in the depressed position. The pedal is released by a pull or a small T-handle or lever under the dash. This disengages the ratchet mechanism, and allows a return spring to move the pedal to the unapplied position. On some vehicles, the release lever is integrated into the underside of the dash and connects to the release mechanism through a rod or cable. ● **SEE FIGURE 103–5.**

Some vehicles were equipped with a special pedal design that enabled them to meet federal regulations on parking brake holding power while keeping maximum pedal application force within legal limits. This type of pedal had a high leverage ratio and a special ratchet mechanism that locked the brake pedal in the applied position, but allowed the pedal to return after it had been depressed. Two full pedal strokes, or several partial strokes, were required to fully apply the parking brake. The brake was released by a single pull on a T-handle or release lever.

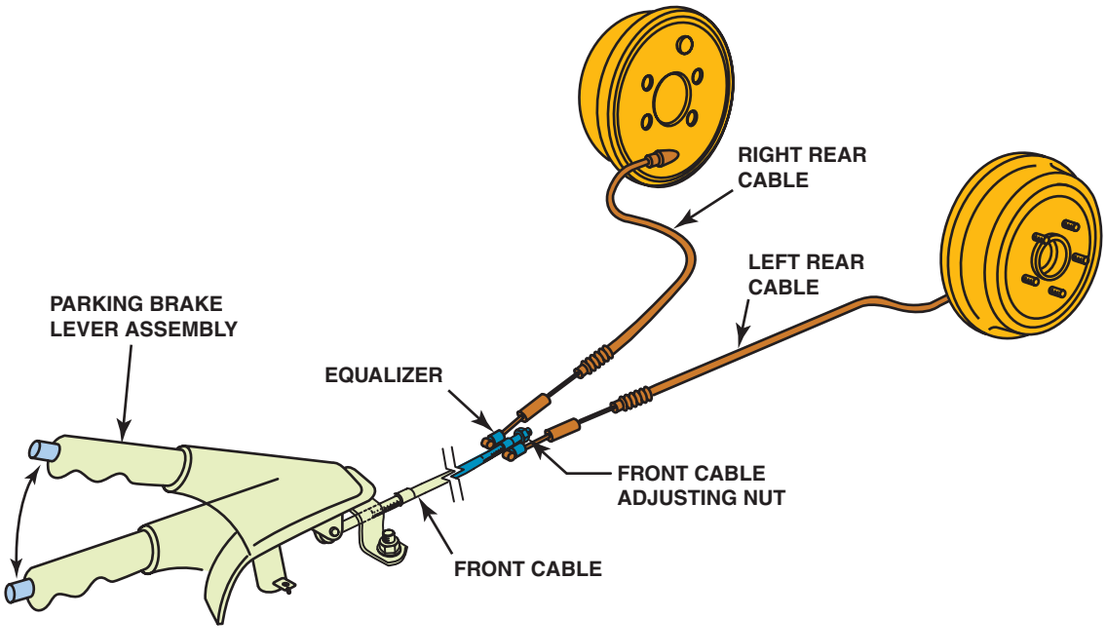


FIGURE 103–3 Typical hand-operated parking brake. Note that the adjustment for the cable is underneath the vehicle at the equalizer.

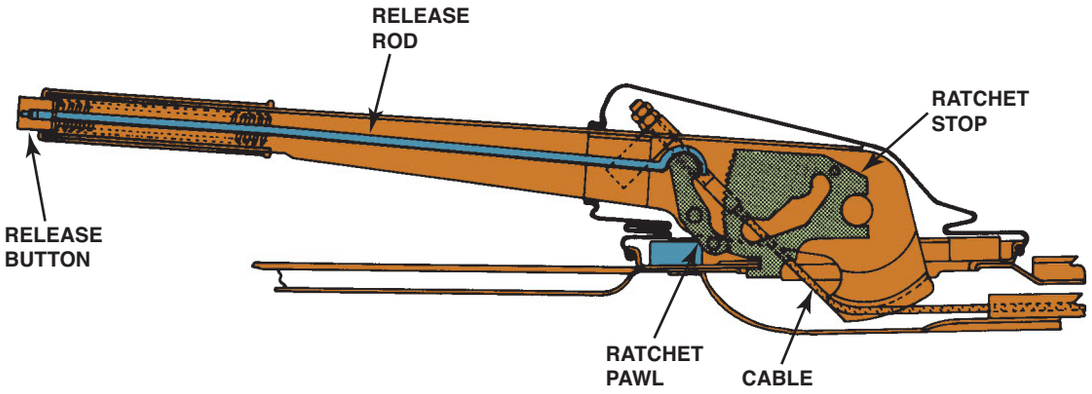


FIGURE 103–4 A ratchet mechanism is used to lock parking brakes in the applied position.

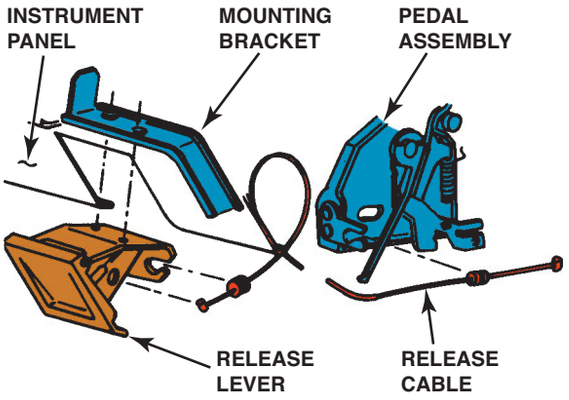


FIGURE 103–5 A remote-mounted parking brake release lever.

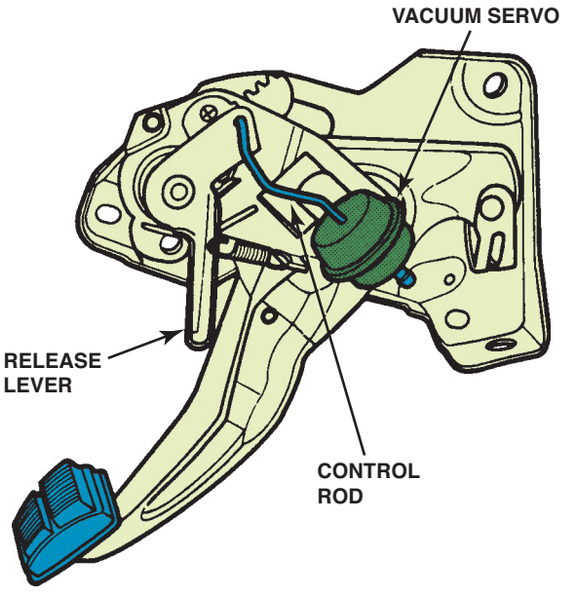


FIGURE 103–6 Automatic parking brake release mechanisms usually use a vacuum servo to operate the release lever.

REAL WORLD FIX

Pump to Release?

A customer called and asked a dealer for help because the parking brake could not be released. The service technician discovered that the customer was attempting to release the parking brake by depressing the parking brake pedal, as was done on the customer's previous vehicle. The service technician simply pulled on the release lever and the parking brake was released.

Some vehicles were equipped with a system that required the driver to depress the parking brake pedal to release the parking brake once it was set. The rubber pad on the parking brake pedal usually states "push to release."

AUTOMATIC PARKING BRAKE RELEASE Some vehicles with pedal-operated parking brakes have an automatic release mechanism that disengages the parking brake using a **vacuum servo** controlled by an electrical solenoid. ● **SEE FIGURE 103–6.**

A metal rod connects the vacuum servo to the upper end of the parking brake release lever. When the engine is running (to provide vacuum) and the shifter is placed in gear, an electrical contact closes to energize the solenoid and route vacuum to the servo. The servo diaphragm then retracts the rod, which releases the parking brake. ● **SEE FIGURE 103–7.**

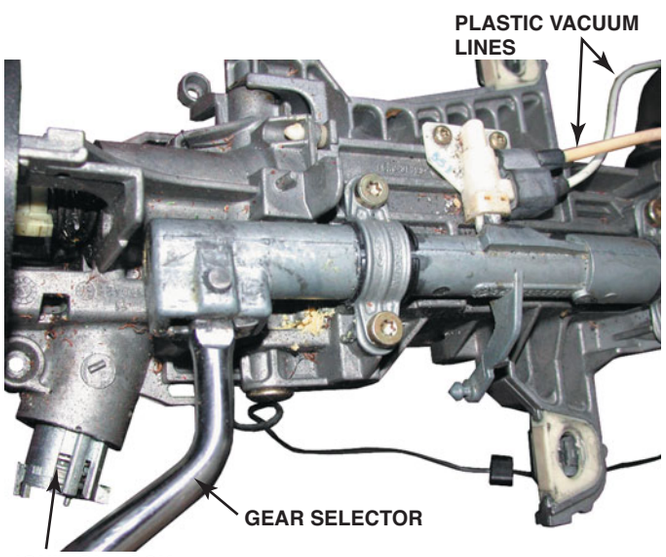


FIGURE 103–7 The two plastic vacuum tubes on the steering column are used to release the parking brake when the gear selector is moved from park into a drive gear.

PARKING BRAKE WARNING LAMP

A **red brake warning lamp** lights on the dash if any of the following events occur.

- On most vehicles, this is the same lamp that lights when there is a hydraulic or brake fluid level problem.
- The warning lamp for the parking brake warns the driver that the parking brake is applied or partially applied. This warning helps prevent damage or overheating to the brake drums and linings or rear discs and pads that could occur if the vehicle was driven with the parking brake applied.

If the red BRAKE warning lamp is on, check the parking brake to see if it is fully released. If the BRAKE lamp is still on, the parking brake switch may be defective, out of adjustment, or there may be a hydraulic problem.

PARKING BRAKE LINKAGES

Parking brake linkages transmit force from the pedal, lever, or handle inside the vehicle to the brake friction assemblies.

LINKAGE RODS Parking brake linkage rods made from solid steel are commonly used with floor-mounted actuating levers to span the short distance to an intermediate lever or an equalizer.

LINKAGE CABLES

The typical parking brake cable is made of woven-steel wire encased in a reinforced rubber or plastic housing. The housing is fixed in position at both ends, and is routed under the vehicle through mounting brackets that hold the cable in position, yet allow a small amount of movement. The cable slides back and forth inside the housing to transmit application force, and depending on the linkage design, the outer housing may play a part in parking brake application as well.

Parking brake linkages use control cables, transfer cables, and application cables.

- **Control cables** attach to the parking brake pedal, lever, or handle inside the vehicle.
- A **transfer cable** transmits force to an intermediate lever or equalizer to the application cables.
- The **application cables** use the force passed through the linkage to apply the rear wheel brake assembly. ● **SEE FIGURE 103–8.**

Parking brake cables are subject to damage from water, dirt, and other debris thrown up under the vehicle by the tires. Most parking brake cables do not require lubrication because they are lined with nylon or Teflon, and any cable housing ends located under the vehicle are protected by rubber or nylon seals.

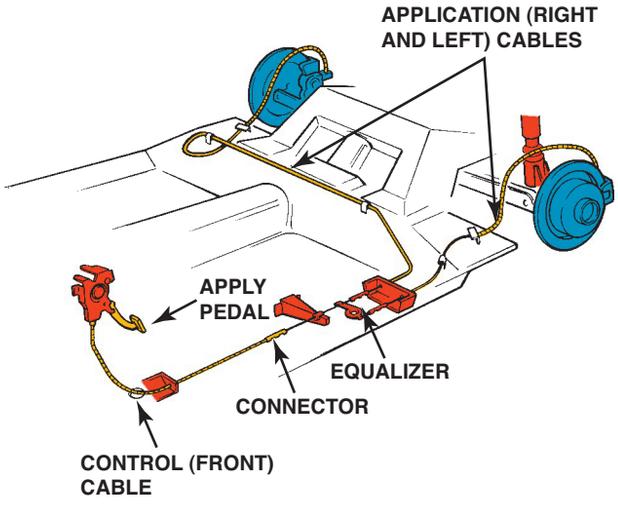


FIGURE 103–8 The cable from the activating lever to the equalizer is commonly called the control cable. From the equalizer, the individual brake cables are often called application cables. These individual cables can usually be purchased separately.

TECH TIP

Look for Swollen Parking Brake Cables

Always inspect parking brake cables for proper operation. A cable that is larger in diameter in one section indicates that it is rusting inside and has swollen. ● **SEE FIGURE 103–9.**

A rusting parking brake cable can keep the rear brake applied even though the parking brake lever has been released. This can cause dragging brakes, reduced fuel economy, and possible vehicle damage due to overheated brakes.

LINKAGE LEVERS

Unfortunately, the amount of physical force a driver can apply to the parking brake control is often not enough to apply the parking brake. For this reason, all parking brake linkages contain one or more levers that increase application force.

The parking brake pedals, floor-mounted levers, and pivoting under dash handles described earlier are all types of levers used to increase parking brake application force. A lever in the parking brake linkage under the vehicle is called an **intermediate lever.** ● **SEE FIGURE 103–10.**

To further increase parking brake application force, intermediate levers provide leverage in addition to that supplied by the parking brake control.

LINKAGE EQUALIZERS

In some parking brake linkages, the rods or cables to the two friction assemblies are adjusted separately. If the adjustments are unequal, one brake will apply before the other, preventing full lining-to-drum contact at the opposite wheel and greatly reducing the holding power of the parking brake. To prevent unequal application, most parking brake linkages use an **equalizer** to balance the force from the parking brake control, and transmit an equal amount to each friction assembly.

Equalizers come in many shapes and sizes, but the simplest is the cable guide attached to a threaded rod. ● **SEE FIGURE 103–11.**



FIGURE 103–9 Notice how rust inside the covering of this parking brake cable has caused the cable to swell.

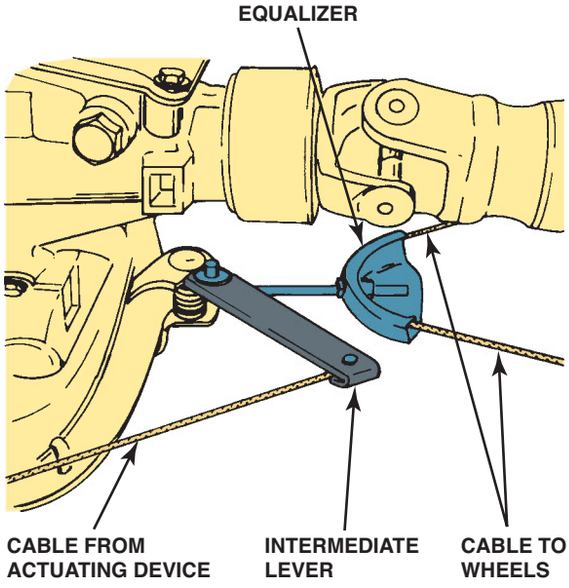


FIGURE 103–10 Intermediate levers in the parking brake linkage increase the application force.

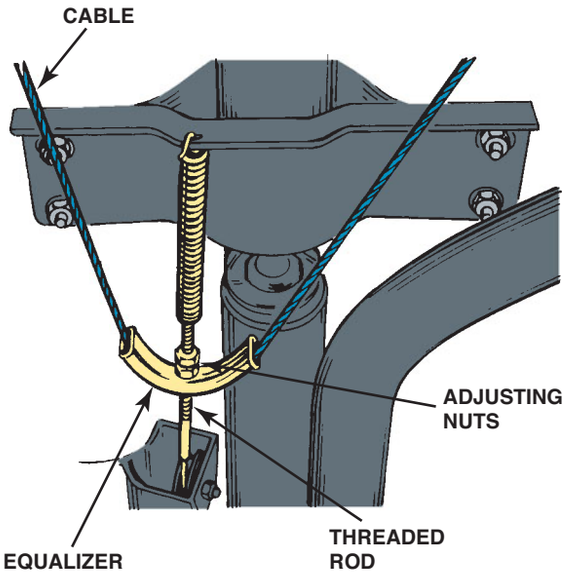


FIGURE 103–11 A cable guide is a common type of parking brake linkage equalizer.

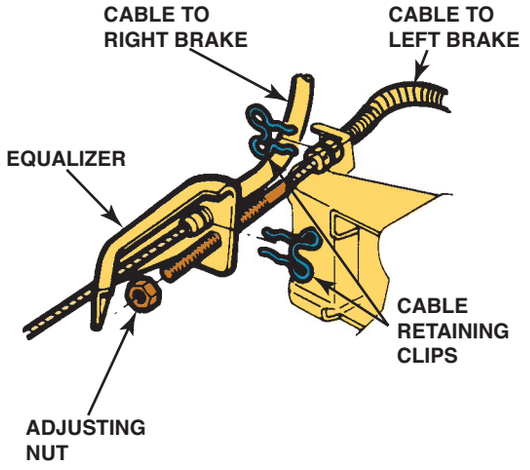


FIGURE 103–12 Some parking brake equalizers are installed in the brake cable.

This type of equalizer pivots or allows the inner cable to slide back and forth to even out application force.

Another type of equalizer installs in a long application cable that runs from the linkage at the front of the vehicle to one rear brake. ● **SEE FIGURE 103–12.**

LINKAGE DESIGN The number of different parking brake linkage designs is almost as great as the number of vehicle models on the road. Most linkages combine intermediate levers and equalizers in various ways and use from one to four cables to actuate the friction assemblies. ● **SEE FIGURE 103–13.**

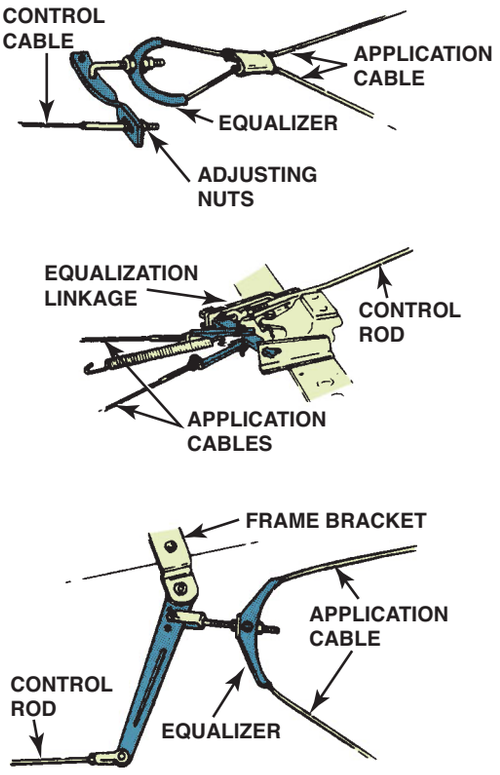


FIGURE 103–13 Many parking brake linkages use both an intermediate lever and an equalizer.

FRONT AND REAR ENTRY PARKING BRAKE CABLES

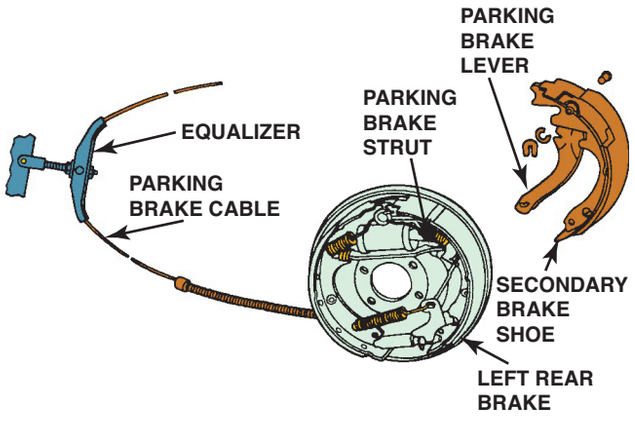
The parking brake standard requires that the vehicle be held stationary on a 20% grade facing either uphill or downhill. Many drum parking brake systems attach the parking brake lever on the secondary (rearward) shoe and push the primary (forward facing) brake shoe against the drum. The parking brake cable enters the backing plate from the front of the vehicle (front entry). Because the primary shoe is attached to the secondary shoe on dual-servo brakes, any forward motion of the vehicle tends to wedge the primary shoe into the brake drum *and* force the rear secondary lining also against the drum.

Applying only the forward brake shoe tends to hold the vehicle best when the vehicle is being held on a hill with the front pointing downward. To help provide the same holding power for a vehicle being held from backing up, some vehicles reverse the parking brake arrangement for the right side. Instead of having the parking brake cable enter the backing plate from the front, this style has the cable entering from the rear (rear entry). In this case, the right rear brake has the parking brake lever installed on the *primary* shoe. This creates a reverse servo action when the vehicle is parked with the rear facing downward.

NOTE: An easy way to remember how to reassemble a drum brake is to realize that the parking brake lever is usually attached to the secondary (rearward) brake shoe. The parking brake strut attaches between the shoes with the spring toward the front of the vehicle (remember, "spring forward").

DRUM PARKING BRAKES

Drum parking brakes are the most common types on vehicles and light trucks. Drum brakes make excellent parking brakes because they have a high static coefficient of friction combined with self-energizing action and, in the case of dual-servo brakes, servo action that increases their application force.



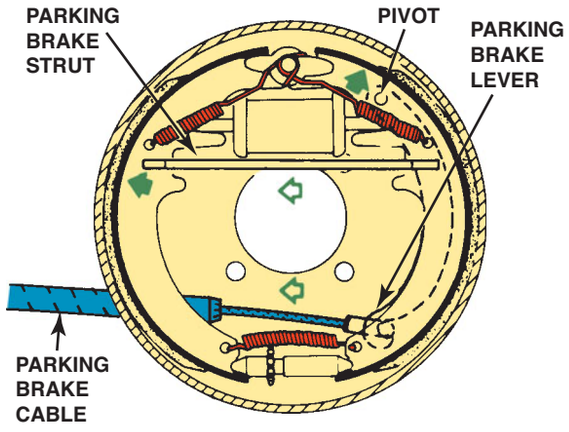


FIGURE 103–15 The parking brake cable pulls on the parking brake lever, which in turn forces the brake shoe against the drum.

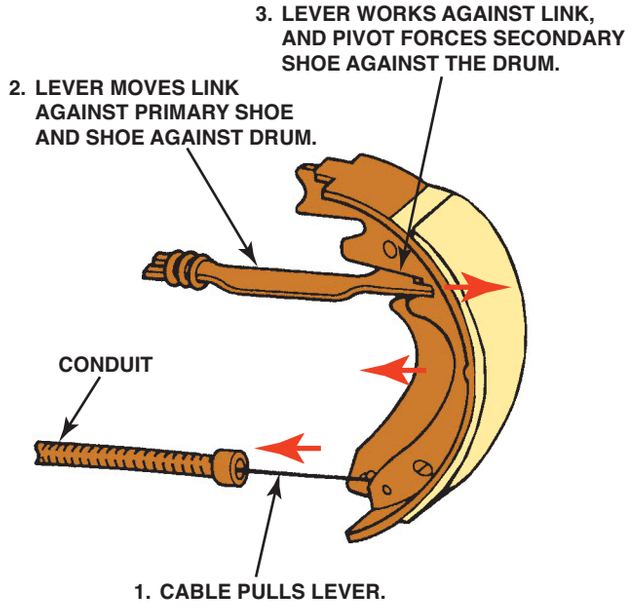


FIGURE 103–14 Notice the spring at the end of the parking brake strut. This antirattle spring keeps tension on the strut. The parking brake lever is usually attached with a pin and spring (wavy) washer and retained by a horseshoe clip.

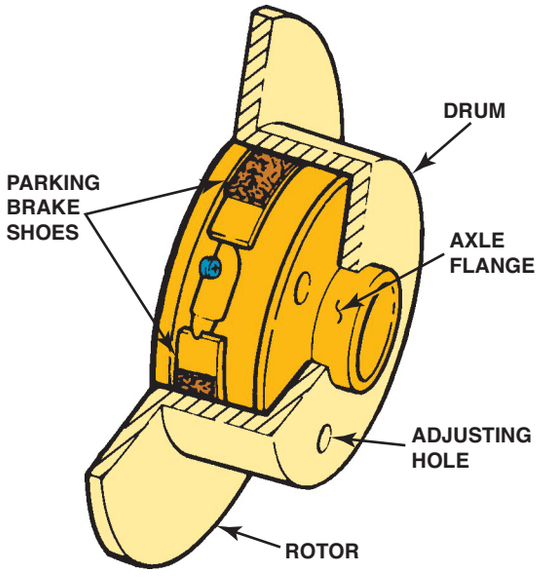


FIGURE 103–16 The inside "hat" of the disc brake rotor is the friction surface for the parking brake shoes.

INTEGRAL DRUM PARKING BRAKES

Integral drum parking brakes mechanically apply the rear drum service brakes to serve as the parking brakes. ● **SEE FIGURE 103–14.**

Integral drum parking brakes are the most common type not only because of their natural superiority in this application, but because it is simple and inexpensive to design a parking brake linkage into a drum brake.

The typical integral drum parking brake has a pivoting lever mounted on one brake shoe, and a strut placed between the lever and the other shoe. The strut may be fitted with a spring that takes up slack to prevent noise when the parking brake is not applied. The end of the lever opposite the pivot is moved by the parking brake cable, which enters through an opening in the backing plate. All integral drum parking brakes operate in essentially the same manner. ● **SEE FIGURE 103–15.**

When the parking brake control is operated, the cable pulls the end of the lever away from the shoe it is attached to. The lever pivots at the attaching point and moves the strut to apply the forward shoe. Once the forward brake shoe lining contacts the drum, the strut can travel no farther. The lever then pivots on the strut and forces the lining of the reverse shoe against the drum.

REAR DISC AUXILIARY DRUM PARKING BRAKES

Rear disc service brakes with fixed calipers commonly have a parking brake drum formed into the hub of the brake rotor. ● **SEE FIGURE 103–16.** Inside the drum is a small dual-servo drum brake friction assembly that serves as the parking brake. The rotor splash shield, or a special mounting bracket, provides the backing plate for the friction assembly. Rear disc auxiliary drum parking brakes use the dual-servo friction assembly design because it provides the most holding power, and does so equally in both forward and reverse directions. Dual-servo parking brake friction assemblies operate in essentially the same manner as service brakes except that the wheel cylinder is eliminated and the friction assembly is actuated mechanically. ● **SEE FIGURE 103–17.**

CALIPER-ACTUATED DISC PARKING BRAKES

BASIC OPERATION

Caliper-actuated disc parking brakes are used on vehicles whose rear disc brakes are equipped with floating or sliding brake calipers. The single-piston construction of these

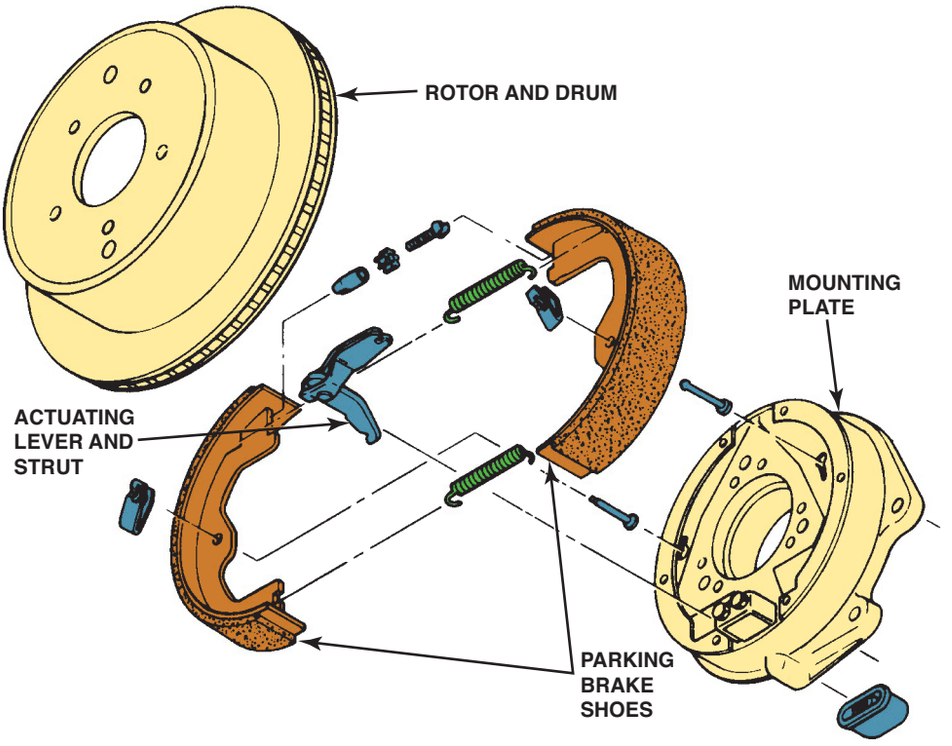


FIGURE 103–17 A typical rear disc brake auxiliary drum brake friction assembly.

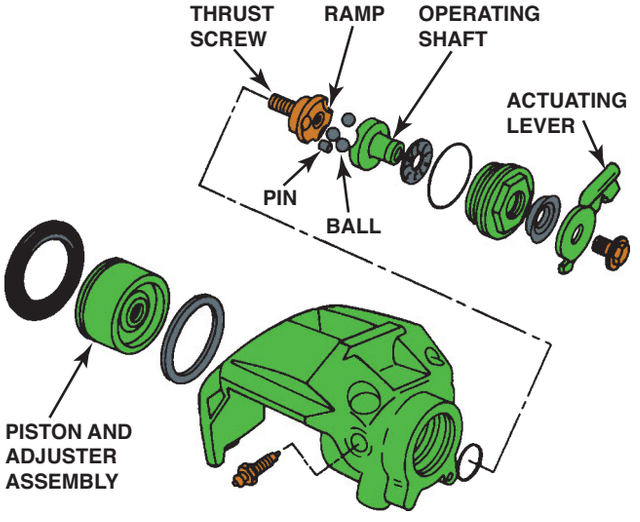


FIGURE 103–18 A Ford rear brake caliper ball and ramp-type apply mechanism.

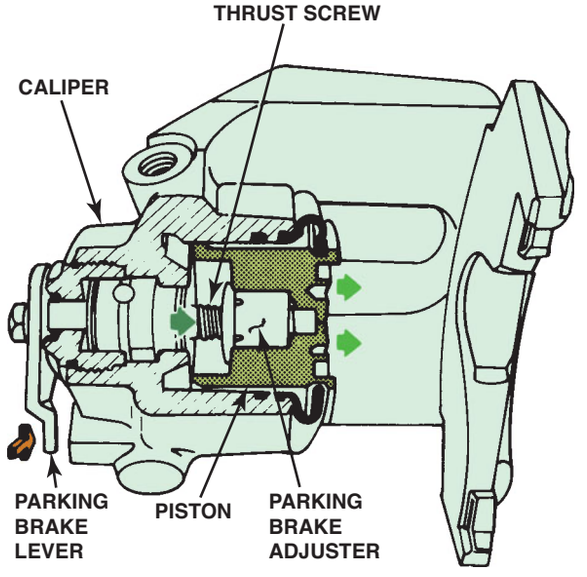


FIGURE 103–19 Operation of a ball and ramp-type rear disc brake caliper parking brake.

calipers makes them easier to mechanically actuate than multiple-piston fixed calipers. In this design, a special mechanism in the caliper applies the caliper piston mechanically. The mechanism is operated by a parking brake cable attached to a lever that protrudes from the inboard side of the caliper.

BALL AND RAMP ACTUATION The ball and ramp actuating system found in Ford rear brake calipers has three steel balls located in ramp-shaped detents between two plates. ● **SEE FIGURE 103–18.** One plate has a thrust screw attached that is threaded into an adjuster mechanism in the caliper piston. The other plate is part of the operating shaft that extends out of the caliper. The actuating lever is mounted to the end of this shaft.

As the parking brake cable moves the lever and rotates the operating shaft, the balls ride up the ramps and force the two plates apart. The operating shaft plate cannot move because it butts against the caliper body. The thrust screw plate, which is pinned to the caliper body to prevent it from rotating, is driven away from the operating shaft and toward the rotor where the thrust screw moves the caliper piston to apply the brake. ● **SEE FIGURE 103–19.**

Adjustment of the ball and ramp linkage within the caliper is automatic, and takes place during service brake application. When the caliper piston moves away from the thrust screw, an adjuster nut inside the piston rotates on the thrust screw to take up any slack created by wear. ● **SEE FIGURE 103–20.** A drive ring on the nut prevents it from rotating in the opposite direction when the parking brake is applied.

SCREW, NUT, AND CONE ACTUATION

General Motors' rear disc parking brake uses a screw, nut, and cone mechanism to apply the caliper piston. ● **SEE FIGURE 103–21.**

In this design, the actuator screw with the parking brake lever attached to it extends through the caliper body. The caliper piston contains a specially shaped nut that threads onto the actuator screw when the piston is installed in the bore. The nut butts against the backside of the cone, and is splined to the cone so that it cannot rotate unless the cone does so as well. The cone is a slip fit in the piston, and is free to rotate unless it is held tightly against a clutch surface located near the outer end of the piston bore.

When the parking brake is applied, the cable moves the lever and rotates the actuator screw. ● **SEE FIGURE 103–22.** The nut then unthreads along the screw, and jams the cone against the clutch surface of the caliper piston. This prevents the cone from rotating because the caliper piston is keyed to the brake pad, which is fixed in the caliper. Because the cone cannot rotate, movement of the nut along the actuator thread forces the cone and piston outward against the inboard pad to apply the brake.

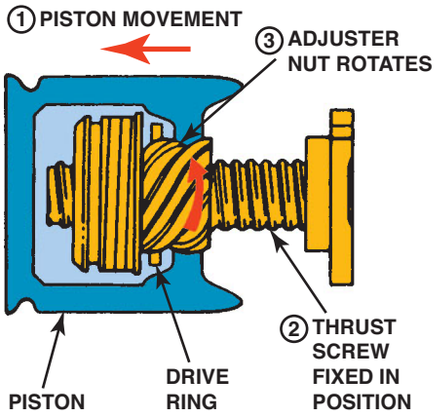


FIGURE 103–20 Automatic adjustment of a ball and ramp-type rear disc brake parking brake occurs when the service brakes are applied.

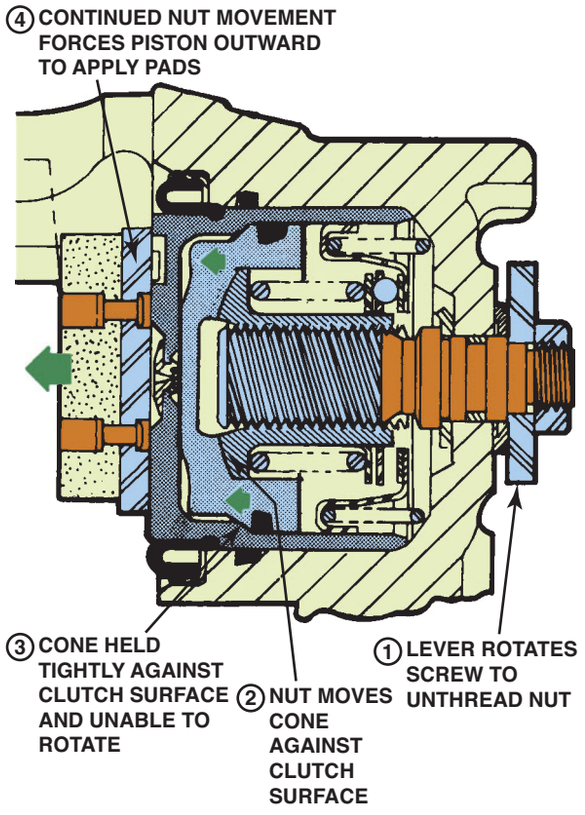


FIGURE 103–22 Parking brake application of a General Motors rear drive brake caliper.

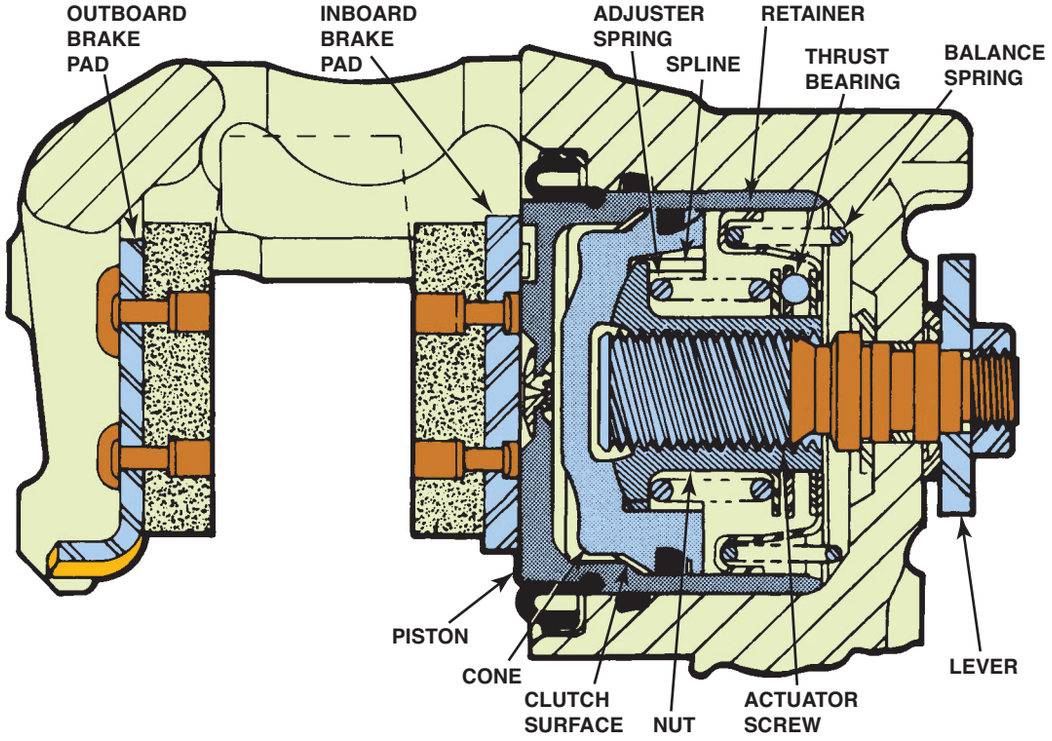


FIGURE 103–21 A typical General Motors rear disc brake with an integral parking brake. This type uses a screw, nut, and cone mechanism to apply the caliper piston.

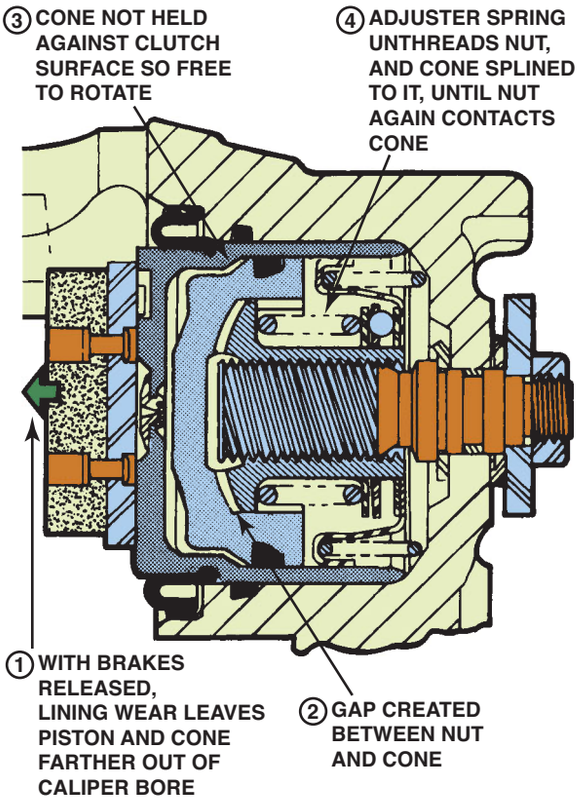


FIGURE 103–23 Automatic adjustment of a General Motors rear disc brake caliper.

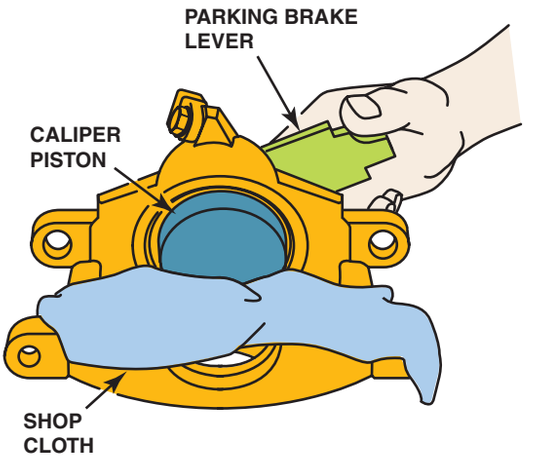


FIGURE 103–24 Removing the piston from a typical General Motors rear disc brake caliper.

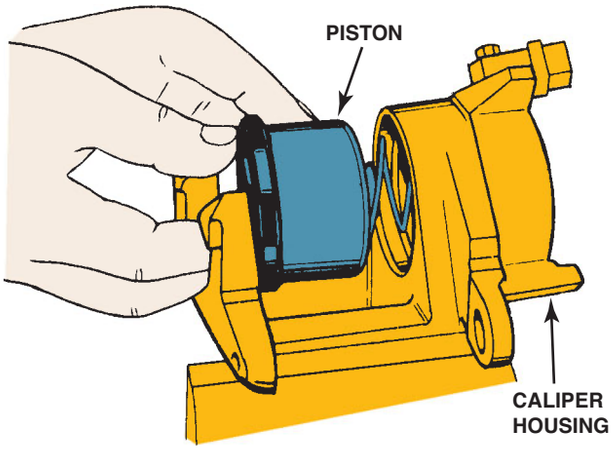


FIGURE 103–25 Installing the piston into a General Motors rear disc brake caliper.

Adjustment of the screw, nut, and cone mechanism occurs automatically during normal operation as the service brakes are released. ● **SEE FIGURE 103–23.** When the service brakes are applied, the cone and piston move outward in the bore under hydraulic pressure. The nut, however, remains fixed because the actuator screw does not rotate. As long as there is brake application pressure, the cone is held tightly against the clutch surface of the piston, which prevents the cone, and the nut splined to it, from rotating.

The result of the above actions is that a gap develops between the outer end of the nut and the backside of the cone when the brakes are applied. If sufficient brake lining wear has occurred, a gap remains after seal deflection retracts the piston and cone when the brakes are released. Once the brakes are released, the cone is no longer held against the clutch surface, and becomes free to rotate in the piston. At this point, the adjuster spring, which exerts strong axial pressure on the nut, causes the nut and cone to unthread along the actuator screw and take up any clearance between the cone and piston.

The balance spring between the piston and the caliper bore has two purposes.

1. It prevents excessive piston retraction when the brakes are released.
2. It counterbalances the pressure of the adjuster spring.

Note that the outer end of the nut is in constant contact with the cone whenever the service brakes are not applied. If the automatic adjusting system fails, the tension of the adjuster spring against the thrust bearing at the back of the piston will retract the cone and piston from the rotor until the cone does contact the nut, resulting in a low brake pedal.

REAR DISC BRAKE SERVICE

Most rear disc brake calipers are replaced as an assembly if a fault is found. The calipers should also be replaced in pairs to provide equal braking force during operation.

Always follow the instructions in service information regarding precautions and brake bleeding procedures to follow when replacing rear disc brake caliper that have integral parking park mechanisms.

Rebuilding rear disc brake calipers can be done but there are issues because of all the components that may be needed as well the need for accurate fit for them to work properly. Always follow the instructions in service information when rebuilding a rear disc brake caliper assembly. ● **SEE FIGURES 103–24 THROUGH 103–31.**

PARKING BRAKE CABLE ADJUSTMENT

Most manufacturers specify a minimum of 3 or 4, and a maximum of 8 to 10, clicks when applying the parking brake. Check service information for the vehicle being serviced for the exact specifications and

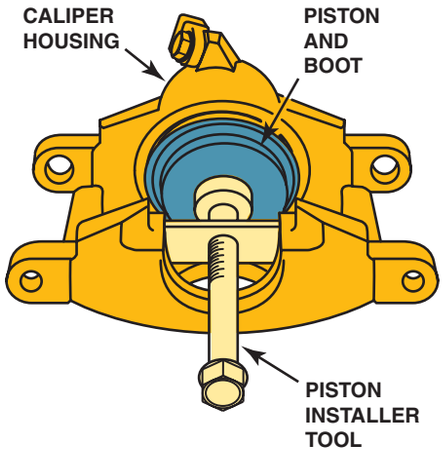


FIGURE 103–26 A piston installation tool is often needed to complete the installation of the piston in a General Motors rear disc brake.

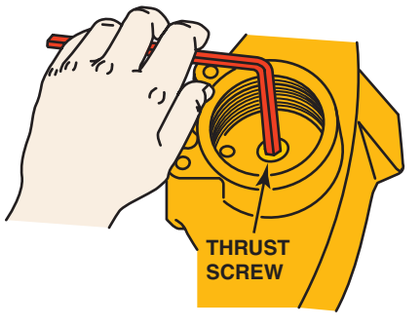


FIGURE 103–29 Unscrew the thrust screw from the piston with an Allen (hex) wrench. After removing the thrust screw, push the piston out of the caliper bore.

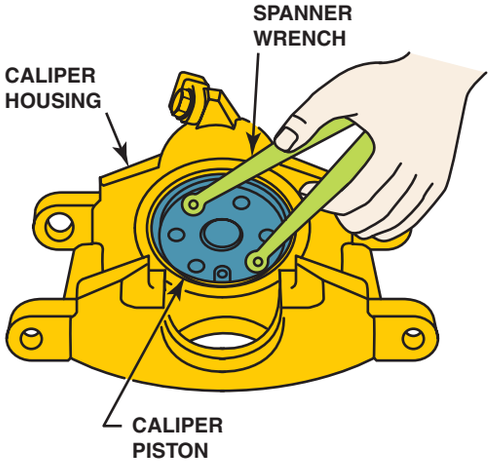


FIGURE 103–27 A spanner wrench (or needle-nose pliers) can be used to rotate the caliper piston prior to installing the disc brake pads. A notch on the piston must line up with a tab on the back of the brake pad to keep the piston from rotating when the parking brake is applied.

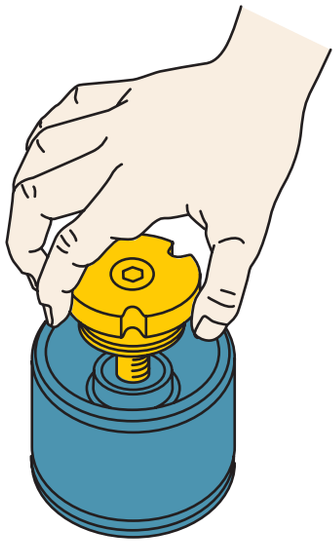


FIGURE 103–30 To test the piston adjuster, thread the thrust screw into the piston. Hold the piston and pull the thrust screw outward 1/4 in. (6 mm). The adjuster nut should not turn when the thrust screw retracts. Replace the piston assembly if not functioning correctly.

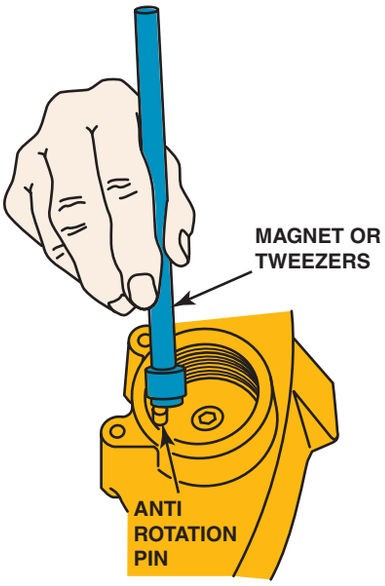


FIGURE 103–28 After removing the parking brake lever and thrust bearing, remove the antirotation pin.

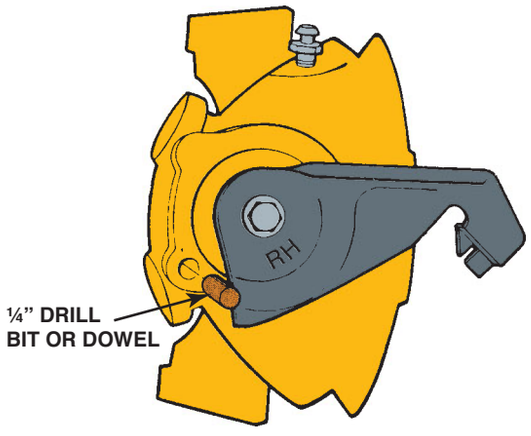


FIGURE 103–31 To adjust the parking brake cable on a Ford vehicle equipped with rear disc brakes, start by loosening the cable adjustment until the cables to the calipers are slack. Tighten until the caliper lever moves. Position a 1/4-in. drill bit or dowel into the caliper alignment hole. Adjustment is correct if the parking brake lever does not hit the 1/4-in. dowel.

TECH TIP

The Parking Brake "Click" Test

When diagnosing any brake problem, apply the parking brake and count the "clicks." This method works for both hand- and foot-operated parking brakes. Most vehicle manufacturers specify a maximum of 10 clicks. If the parking brake travel exceeds this amount, the rear brakes may be worn or out of adjustment.

CAUTION: Do not adjust the parking brake cable until the rear brakes have been thoroughly inspected and adjusted.

If the rear brake lining is usable, check for the proper operation of the self-adjustment mechanism. If the rear brakes are out of adjustment, the service brake pedal will also be low. This 10-click test is a fast and easy way to determine if the problem is due to rear brakes.

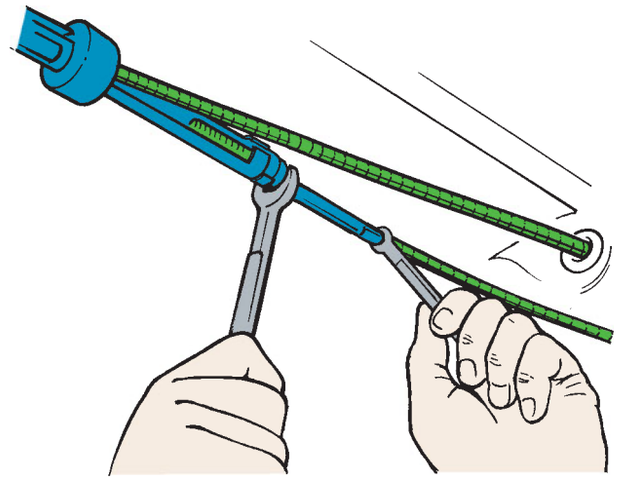


FIGURE 103–32 After checking that the rear brakes are okay and properly adjusted, the parking brake cable can be adjusted. Always follow the manufacturer's recommended procedure.

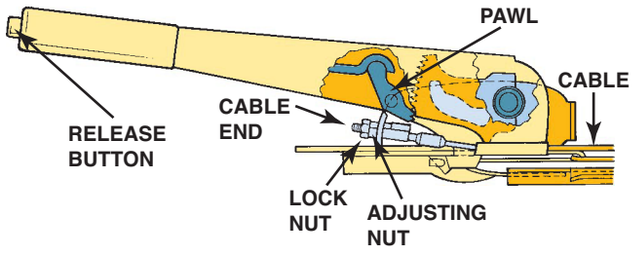


FIGURE 103–33 Many hand-operated parking brakes are adjusted inside the vehicle.

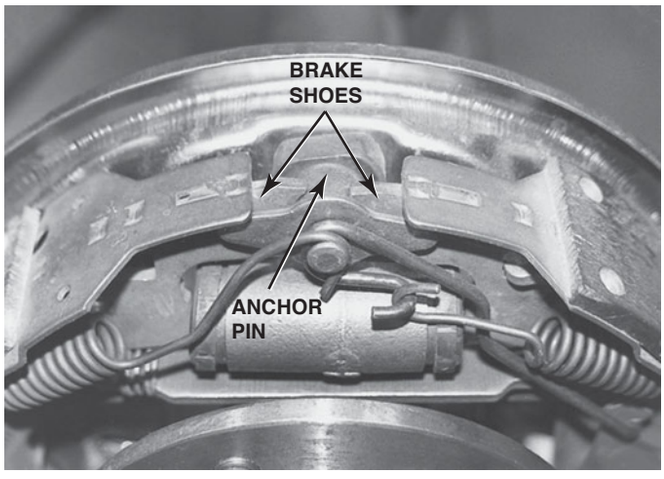


FIGURE 103–34 Always check that both brake shoes contact the anchor pin.

adjustment procedures. Most vehicle manufacturers specify that the rear brakes be inspected and adjusted correctly before attempting to adjust the parking brake cable. Always follow the manufacturer's recommended procedure exactly.

Below is a general procedure for parking brake adjustment.

1. Make certain that the rear service brakes are adjusted correctly and the lining is serviceable.
2. With the drums installed, apply the parking brake 3 or 4 clicks. There should be a slight drag on both rear wheels.
3. Adjust the cable at the equalizer (equalizes one cable's force to both rear brakes) if necessary until there is a slight drag on both rear brakes. ● **SEE FIGURES 103–32 AND 103–33.**
4. Release the parking brake. Both rear brakes should be free and not dragging. Repair or replace rusted cables or readjust as necessary to ensure that the brakes are not dragging.

NOTE: The rear parking brake adjustment should always be checked whenever replacing the rear brake linings. It may be necessary to loosen the parking brake cable adjustment to allow clearance to get the drum over the new linings. This could happen because someone may have adjusted the parking brake cable during the life of the rear linings. ● **SEE FIGURE 103–34.**

With new thicker linings, the parking brake adjustment can keep the brake shoes pushed outward toward the drum.

To prevent possible parking brake cable adjustment problems when installing new rear brakes, always observe the following:

1. Both brake shoes should make contact with the anchor pin at the top. If not, check the parking brake cable for improper adjustment or improper installation of the brake shoes.
2. Feel the tension of the parking brake cable underneath the vehicle. It should be slightly loose (with the parking brake "off").
3. Lubricate the parking brake cable to ensure that water or ice will not cause rust or freezing of the cable. This is necessary because even though the parking brake lever is released inside the vehicle, a stuck parking brake cable could cause the linings to remain out against the drums.
4. If the parking brake needs to be adjusted (will not hold on a hill or requires excessive lever movement), always check and adjust the rear brake adjustment before adjusting the parking brake cable. ● **SEE FIGURE 103–35.**

   NOTE: Some vehicles are equipped with an automatic adjusting parking brake lever/cable. Simply cycling the parking brake on/off/on three times is often all that is required to adjust the parking brake cable.
5. Replace any stuck, corroded, or broken parking brake cable.

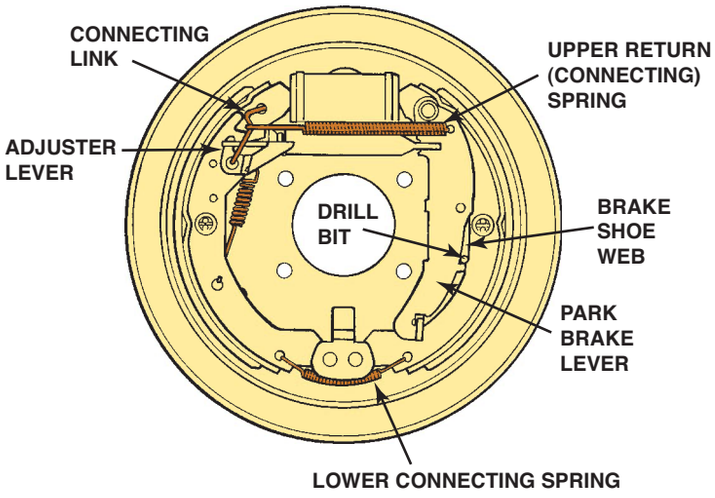


FIGURE 103–35 A 1/8-in. (3-mm) drill bit is placed through an access hole in the backing plate to adjust this General Motors leading-trailing rear parking brake. Adjust the parking brake cable until the drill can just fit between the shoe web and the parking brake lever.



FIGURE 103–37 An electric parking brake button on the center console of a Jaguar.

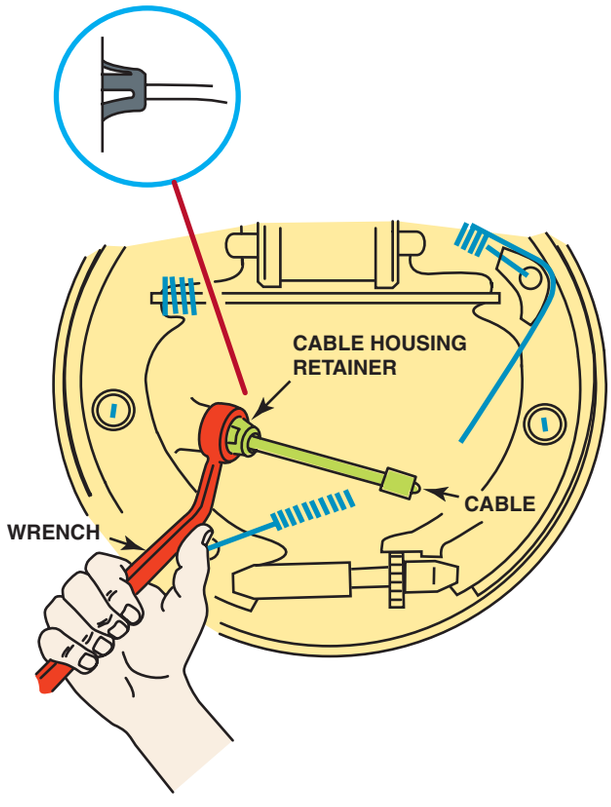


FIGURE 103–36 Many parking brake cables can be removed easily from the backing plate using a 1/2-in. (13-mm) box-end wrench. The wrench fits over the retainer finger on the end of the parking brake cable.

TECH TIP

The Hose Clamp or Wrench Trick

It is often difficult to remove a parking brake cable from the backing plate due to the design of the retainer. The many fingers used to hold the cable to the backing plate can be squeezed all at once if a hose clamp is used to compress the fingers. A wrench as shown in ● **FIGURE 103–36** can also be used.

ELECTRIC PARKING BRAKE

Electric parking brake (EPB) systems are available using two different designs including:

1. A cable-pulling type that uses an electric motor to pull the parking brake cable rather than a mechanical handle or foot pedal.
2. A more advanced unit uses a computer-controlled motor attached to the brake caliper to activate it.

Some vehicles already use an electric parking brake (EPB) that can be activated when the vehicle stops and then goes off as soon as the gas pedal is pressed, preventing the vehicle from moving while stopped. ● **SEE FIGURE 103–37.**

REVIEW QUESTIONS

1. Describe how a typical parking brake functions on a vehicle equipped with rear drum brakes.
2. Describe how a typical parking brake functions on a vehicle equipped with an integral rear disc brake system.
3. Explain how to adjust a parking brake cable properly.

CHAPTER QUIZ

1. Technician A says that the parking brake cable should be adjusted at each wheel. Technician B says that the parking brake cable adjustment is usually done after adjusting the rear brakes. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. Technician A says that the parking brake hand lever can turn on the red brake warning lamp. Technician B says that a foot-operated parking brake can turn on the red brake warning lamp. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. Technician A says that if the parking brake cable is adjusted too tight, the rear brakes may drag and overheat. Technician B says that the parking brake is adjusted properly if the cable is tight when in the released position. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. On most drum brake systems, the parking brake lever and strut transfer the pulling force of the parking brake cable against the _____.
   a. Primary shoe
   b. Secondary shoe
5. On most vehicles, the antirattle spring (strut spring) should be installed on the parking brake strut toward the _____ of the vehicle.
   a. Front
   b. Rear
6. In a typical integral rear disc brake caliper, the parking brake cable moves the _____.
   a. Caliper
   b. Actuator screw
   c. Auxiliary piston
   d. Rotor
7. The rear brakes should be inspected, and adjusted if necessary, if the parking brake requires more than _____.
   a. 5 clicks
   b. 10 clicks
   c. 15 clicks
   d. 20 clicks
8. A rear drum brake is being inspected. The primary shoe is not contacting the anchor pin at the top. Technician A says that this is normal. Technician B says that the parking brake cable may be adjusted too tight or is stuck. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. Technician A says that a hose clamp can be used to compress the retainer fingers of a parking brake cable in order to remove it from the backing plate. Technician B says a box-end wrench can be used instead of a hose clamp. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. Technician A says that an electric parking brake (EPB) uses an electric motor to pull on the parking brake cable. Technician B says that some electric parking brake systems use a computer-controlled motor attached to the caliper. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

chapter 104

MACHINING BRAKE DRUMS AND ROTORS

OBJECTIVES: **After studying Chapter 104, the reader will be able to:** • Prepare for the Brakes (A5) ASE certification test content area "E" (Miscellaneous Systems Diagnosis and Repair). • Discuss the construction of brake drums and rotors. • Explain the formation of hard spots in drums and rotors. • Describe how to measure and inspect drums and rotors before machining. • Discuss how surface finish is measured and its importance to satisfactory brake service. • Demonstrate how to machine a brake drum and rotor correctly.

KEY TERMS: Bellmouth 1160 • Composite rotors 1164 • Convection 1158 • Discs (disks) 1164 • Eccentric distortion 1160 • Elastic limit 1160 • Hard spots 1159 • Heat checking 1159 • Hot spots 1159 • Lateral runout (LRO) 1166 • Microinches (μ in.) 1168 • Out-of-round 1160 • Parallelism 1167 • Ra 1168 • Scoring 1158 • Scratch cut 1162 • Self-aligning spacer (SAS) 1162 • Tinnerman nuts 1161 • Thickness variation (TV) 1167 • Total indicator runout (T.I.R.) 1166

BRAKE DRUMS

CAST-IRON DRUMS Brake drums are constructed of cast iron where the lining contacts the drum, with mild steel centers. The drum is drilled for the lug studs. Cast iron contains approximately 3% carbon, which makes the drum hard, yet brittle. For this reason it is recommended that any pounding needed to remove drums be done on the center mild steel portion, which, due to its material characteristics, can take this force without damage. This 3% carbon content of the cast iron also acts as a lubricant, which prevents noise during braking. Also, the rubbing surface can be machined without the need of a coolant (as would be required if constructed of mild steel). Because of these properties, cast iron is used on the friction surface of all drums. ● **SEE FIGURE 104–1.**

ALUMINUM DRUMS Even aluminum brake drums use cast iron for the friction surface area. Besides saving weight, aluminum brake drums transfer heat to the surrounding air faster than cast iron or steel.

Brake drums and rotors are the major energy-absorbing parts of the braking system. Friction between the friction material and the drum or rotor creates heat. This heat is absorbed by the drum or rotor and travels from the friction surface to the remainder of the drum or rotor by heat **convection.** As energy continues to be absorbed, the drum or rotor increases in temperature. Airflow across the drum or rotor helps to dissipate the heat and keep the temperature rise under control. ● **SEE FIGURE 104–2.**

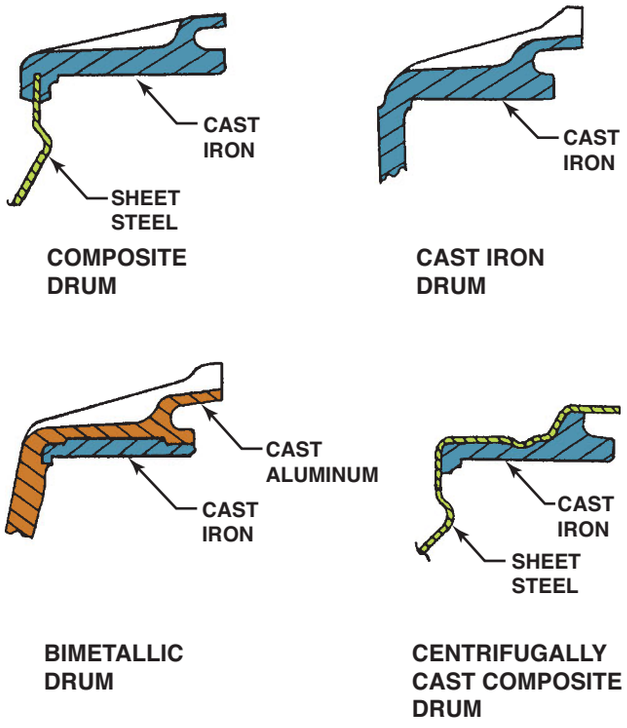


FIGURE 104–1 Types of brake drums. Regardless of the design, all types use cast iron as a friction surface.

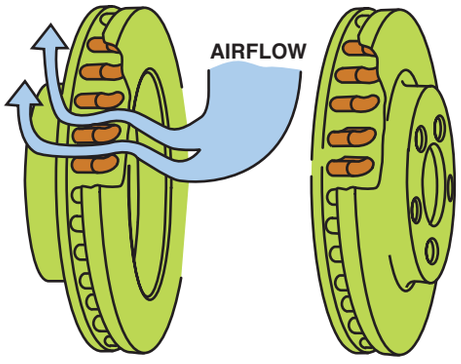


FIGURE 104–2 The airflow through cooling vents helps brakes from overheating.

BRAKE DRUM AND ROTOR DAMAGE

Besides wear, drums and rotors often experience damage to their friction surfaces. Because drum and rotor damage is caused by extremes of operation, it is most commonly found on front brakes, which experience more severe use than rear brakes.

SCORING **Scoring** is an extreme form of drum and rotor wear consisting of scratches, deep grooves, and a generally rough finish on the friction surface. ● **SEE FIGURE 104–3.**

There are a number of causes for scoring including:

1. The most common is brake linings that have worn to the point where a rivet, lining table, or pad backing plate contacts the drum or rotor.
2. Certain friction materials are more likely to score drums and rotors than others, and glazed linings that have hardened from exposure to extreme heat can also cause scoring.
3. Drum brakes are more likely to become scored than disc brakes because their closed construction holds dirt, sand, and abrasive dust inside the friction assembly. This allows the contaminants to be scrubbed repeatedly between the linings and drum.
4. Severe drum scoring often results when metal parts of the friction assembly fatigue, break loose, and are trapped between the linings and drum.

A scored drum or rotor will cause very rapid lining wear, often accompanied by a growling or grinding noise, particularly if there is metal-to-metal contact between the shoe and drum or pad and

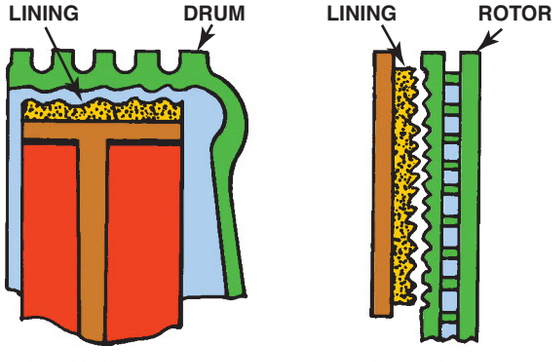


FIGURE 104–3 Scored drums and rotors often result in metal-to-metal contact.

rotor. Scoring can be machined out of a drum or rotor so long as the amount of metal removed is within the allowable limits.

CRACKING Cracks in a brake drum or rotor are caused by the stress of severe braking or an impact during an accident. ● **SEE FIGURE 104–4.** Generally, drums and rotors that have been previously

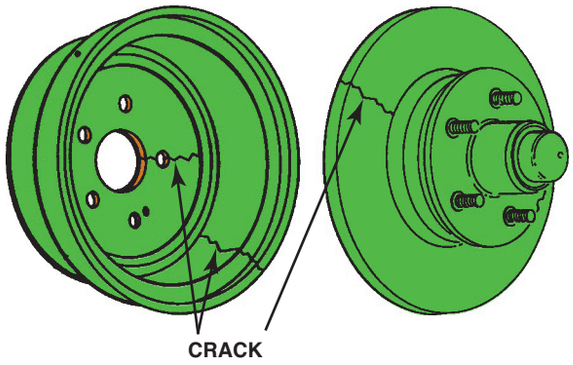


FIGURE 104–4 Cracked drums or rotors must be replaced.

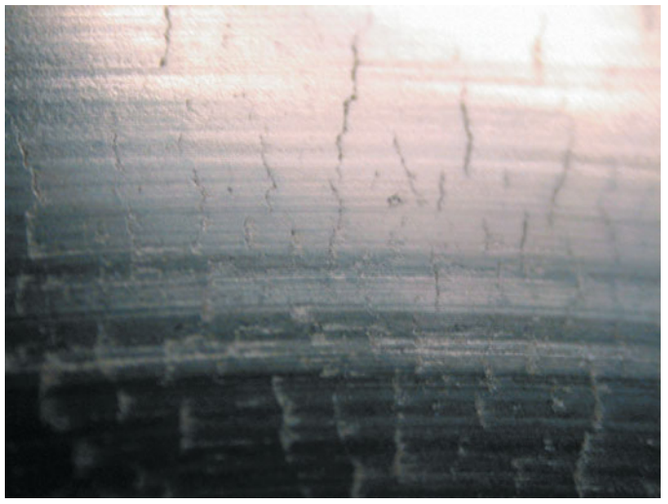


FIGURE 104–5 A heat-checked surface of a disc brake rotor.

TECH TIP

The Tap Test

Using a steel hammer, lightly tap a brake drum or rotor. It should ring if it is not cracked. If a dull thud is heard, the drum or rotor is likely cracked and should be replaced.

machined are more susceptible to cracking than new parts. Cracks can appear anywhere on a drum or rotor, although on drums they are most often found near the bolt circle on the web, or at the open edge of the friction surface. Rotors generally crack first at the edge of their friction surfaces.

HEAT CHECKING A lesser form of drum and rotor cracking is called **heat checking,** which consists of many small, interlaced cracks on the friction surface. ● **SEE FIGURE 104–5.** These cracks typically penetrate only a few thousandths of an inch into the metal and seldom pass through the structure of the drum or rotor. Heat checking is usually caused by a driver who leaves one foot on the brake pedal while applying the accelerator with the other. Heat checking can also be caused by repeated heavy braking or numerous panic stops made in rapid succession.

Light heat checking can often be machined away. In more severe cases the drum or rotor must be replaced.

HARD AND HOT SPOTS Earlier it was stated that cast-iron drums and rotors are durable because the friction, heat, and pressure of braking cause a tough "skin" to form on their friction surfaces.



FIGURE 104–6 These dark hard spots are created by heat that actually changes the metallurgy of the cast-iron drum. Most experts recommend replacement of any brake drum that has these hard spots.

However, if brake temperatures become too great, localized impurities in the metal can be burned away, altering the structure of the metal and causing **hard spots,** also called **hot spots,** to appear. Hard spots are roughly circular, bluish gold, glassy-appearing areas on the friction surface. ● **SEE FIGURE 104–6.**

Hard spots create a number of problems including the following:

- They are harder than surrounding areas of the friction surface, and do not wear at the same rate. Once the spots begin to stand out from the rest of the friction surface, they cause rapid brake lining wear.
- The friction coefficient of hard spots is less than that of surrounding areas so braking power is reduced or becomes uneven. This can cause the brakes to chatter, or result in a hard or pulsating brake pedal.
- A drum or rotor is more likely to crack in the area of hard spots than elsewhere.

Most vehicle manufacturers recommend that the drum or rotor should be replaced if hard spots are found.

BRAKE DRUM DISTORTION

To ensure smooth brake application without pedal pulsation or other problems, brake drum friction surfaces must remain a fixed position in relation to the shoes. In some cases, a position variation of less than a thousandth of an inch will create braking problems. Distortion puts the drum friction surfaces out of proper alignment with the shoes.

DRUM DISTORTION The friction surface of a brake drum in perfect condition is parallel to the axis of the axle, and rotates in a precise circle centered on the axle or hub. All brake drums suffer from distortion during brake operation, but they usually return to their original shape once the brakes are released. When the friction surface does not return to its proper shape, is no longer parallel to the axle, or does not rotate in a precise circle around the axle, the drum is distorted.

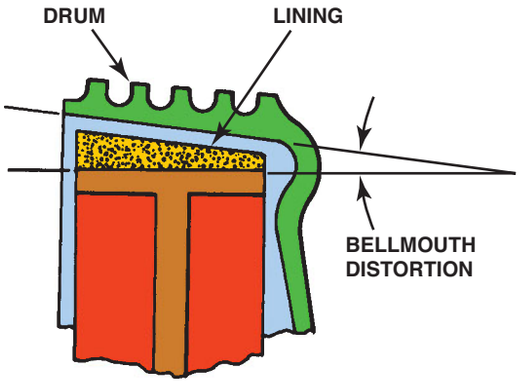


FIGURE 104–7 Bellmouth brake drum distortion.

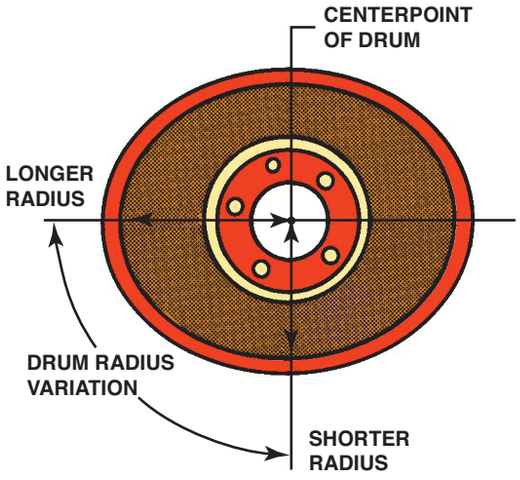


FIGURE 104–8 Out-of-round brake drum distortion.

BELLMOUTH DRUMS When an open edge of a brake drum friction surface has a larger diameter than the closed edge, the drum is suffering from **bellmouth** distortion. ● **SEE FIGURE 104–7.** Bellmouth distortion is caused by poor drum rigidity combined with high heat and brake application force.

Bellmouth distortion occurs when a drum suffers mechanical fade and its open edge, unsupported by the drum web, expands more than its closed edge. When the brakes are applied harder to compensate for the fade, the shoes distort the open edge of the drum so far outward that the **elastic limit** of its metal is exceeded. Once this happens, the drum will not return to its original shape after it cools. Repeated occurrences of this process eventually cause the drum to take on a bellmouth shape.

Bellmouth distortion is especially common on wide drums and commonly occurs when a drum has had too much metal machined from it. If new shoes are installed in a bellmouthed drum, brake fade and unusual lining wear will result.

OUT-OF-ROUND DRUMS Uneven heat distribution can sometimes cause **out-of-round** distortion in which the drum radius varies when measured at different points around its circumference. ● **SEE FIGURE 104–8.** Out-of-round distortion can take place when a vehicle drives through a puddle after a series of hard stops and cold water splashed on the brakes causes rapid and uneven cooling of the drums. It can also result if the parking brake is firmly applied after a series of hard stops before the drums have had a chance to cool. In this case, the shoes extend out against the heat-expanded drum and prevent it from contracting to its original circular shape as it cools. Instead, the extended shoes force the drum into an out-of-round shape.

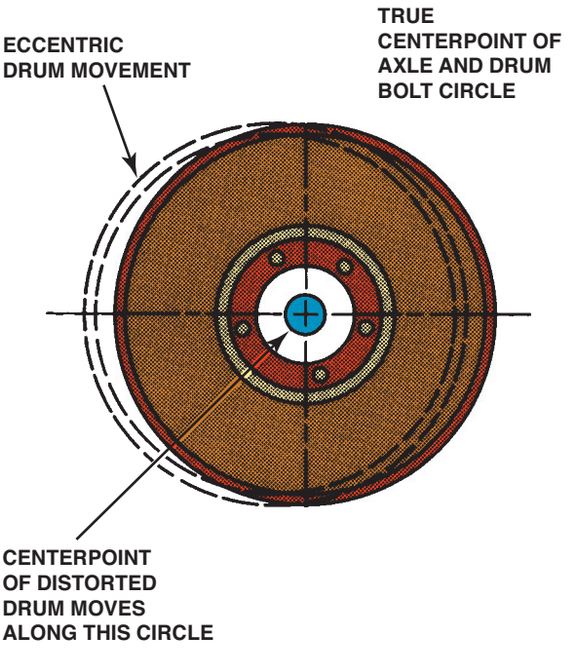


FIGURE 104–9 Eccentric brake drum distortion.

TECH TIP

Storing Drums and Rotors

A common cause of distortion in new brake drums and rotors is improper storage. Drums and rotors should always be stored lying flat; they should never be stood on edge. Distortion of new drums and rotors is common, so they should be routinely checked before installation.

TECH TIP

The Parking Brake Trick

Whenever attempting to diagnose a brake pedal pulsation, drive to a deserted area or parking lot and try stopping the vehicle using the parking brake. If a vibration occurs, the problem is due to a fault with the rear brakes. If a vibration does not occur except when using the service brakes, the problem is most likely due to a fault with the front brakes.

The most common symptom of an out-of-round drum is a pulsating brake pedal when the brakes are applied at all speeds. Out-of-round drums can also cause a vibration or brake chatter at speeds above approximately 40 mph (60 km/h). In more extreme cases, an out-of-round drum can result in erratic braking action, and possibly cause the brakes to grab with every revolution of the wheel.

ECCENTRIC DRUMS **Eccentric distortion** exists when the geometric center of the circle described by the brake drum friction surface is other than the center of the axle or the bolt circle of the drum web. ● **SEE FIGURE 104–9.** This type of distortion causes the drum to rotate with a camlike motion. An eccentric drum will result in a pulsating brake pedal similar to that caused by an out-of-round drum.

Eccentric distortion is often caused by overtightened or unevenly tightened lug nuts or bolts. Not only will this cause an

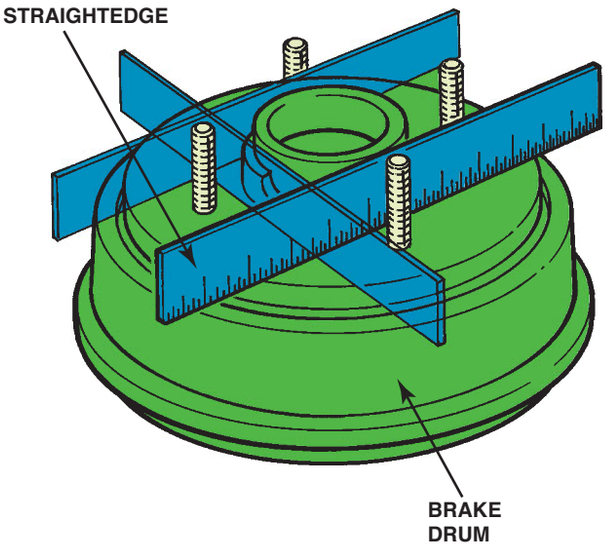


FIGURE 104–10 A straightedge can be used to check for brake drum warpage.

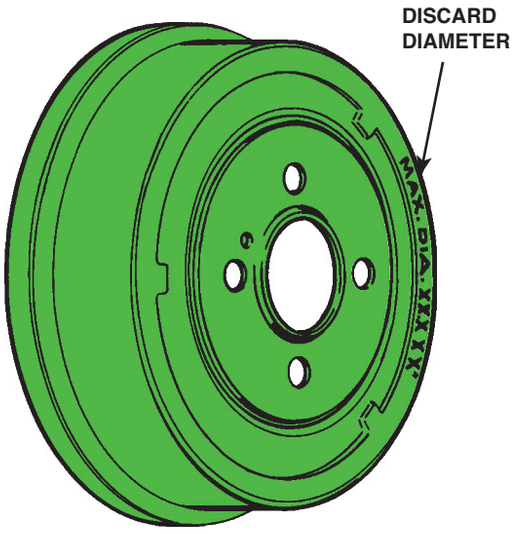


FIGURE 104–11 Discard diameter and maximum diameter are brake drum machining and wear limits.

immediate problem, but it can lead to additional problems later. If a vehicle is driven for an extended time with an eccentric drum, the linings may slowly wear the friction surface "round" again. However, as soon as tension on the lug nuts or bolts is released, the drum will relax back to its original shape creating an out-of-round condition that was not apparent before the wheel was removed.

REMOVING DRUMS

TINNERMAN NUTS Metal clips called **tinnerman nuts** are installed at the factory to keep the brake drums from falling off during vehicle assembly. These clips can be removed and do not need to be reinstalled since the wheel lug nuts hold onto the brake drum.

DRUM REMOVAL TIPS Brake drums are often hard to remove. To help remove brake drums try some of the following tips:

- Use penetrating oil around the hub to help loosen the rust that often forms in this area making drum removal difficult.
- Use a brake adjusting tool ("spoon") to loosen the brake adjuster to move the brake shoes further away from the drum.
- Use a mallet or hammer to tap the brake drum to jar it loose from the hub being careful to avoid exerting to much force that it could damage or warp the drum.

BRAKE DRUM INSPECTION The first inspection step after removing a brake drum is to check it for warpage using a straightedge, as shown in ● **FIGURE 104–10.**

A warped drum is often a source of vibration. A brake drum that is out-of-round can cause a brake pedal pulsation during braking.

"MACHINE TO" VERSUS "DISCARD"

Brake drums can usually be machined a maximum of 0.060 in. (1.5 mm) oversize (for example, a 9.500-in. drum could wear or be machined to a maximum inside diameter of 9.560 in.) unless otherwise stamped on the drum. Most brake experts recommend that both drums on the same axle be within 0.010 in. (0.25 mm) of each other. *The maximum specified inside diameter (ID) means the maximum wear inside diameter.* ● **SEE FIGURE 104–11.**

Always leave at least 0.015 in. (0.4 mm) after machining (resurfacing) for wear. Many manufacturers recommend that 0.030 in. (0.8 mm) be left for wear.

TECH TIP

Mark It to Be Sure

Most experts recommend that brake rotors, as well as drums and wheels, be marked before removing them for service. Many disc brake rotors are directional and will function correctly only if replaced in the original location. A quick-and-easy method is to use correction fluid. This alcohol-based liquid comes in small bottles with a small brush inside, making it easy to mark rotors with an "L" for left and an "R" for right. Correction fluid (also called "white-out" or "liquid paper") can also be used to make marks on wheel studs, wheels, and brake drums to help ensure reinstallation in the same location.

REASONS FOR EQUAL DRUM INSIDE DIAMETER There are several reasons why the service technician should check and make sure that both brake drums on the same axle are close to the same inside diameter (ID).

- **Reason 1.** Since heat is generated by braking, if there is less material (larger ID), the drum will tend to expand more rapidly than a drum with more material (smaller ID).
- **Reason 2.** If one drum expands more than the drum on the other side of the vehicle, unequal braking forces result.
- **Reason 3.** The drum that is larger in ID will expand away from the brake linings more than the other side.

  For example:

Left Drum	Right Drum
9.500 in.	9.560 in.

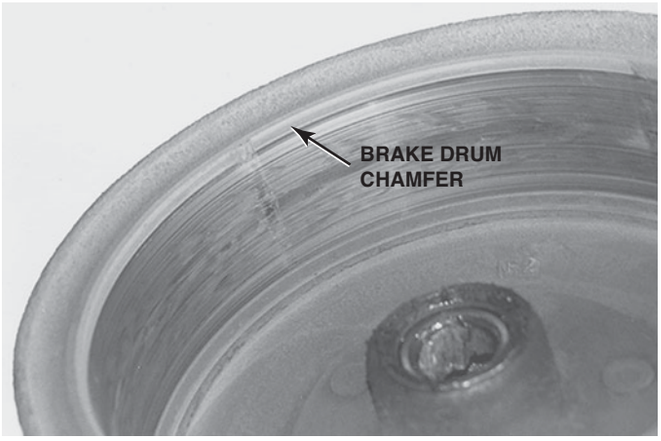


FIGURE 104–12 Most brake drums have a chamfer around the edge. If the chamfer is no longer visible, the drum is usually worn (or machined) to its maximum allowable ID.

TECH TIP

Brake Drum Chamfer

Look at the chamfer on the outer edge of most brake drums. When the chamfer is no longer visible, the brake drum is usually at or past its maximum ID. ● **SEE FIGURE 104–12.** Although this chamfer is not an accurate gauge of the ID of the brake drum, it still is a helpful indicator to the technician.

In this example, when the drums get hot (heavy braking), the vehicle will tend to pull to the left.

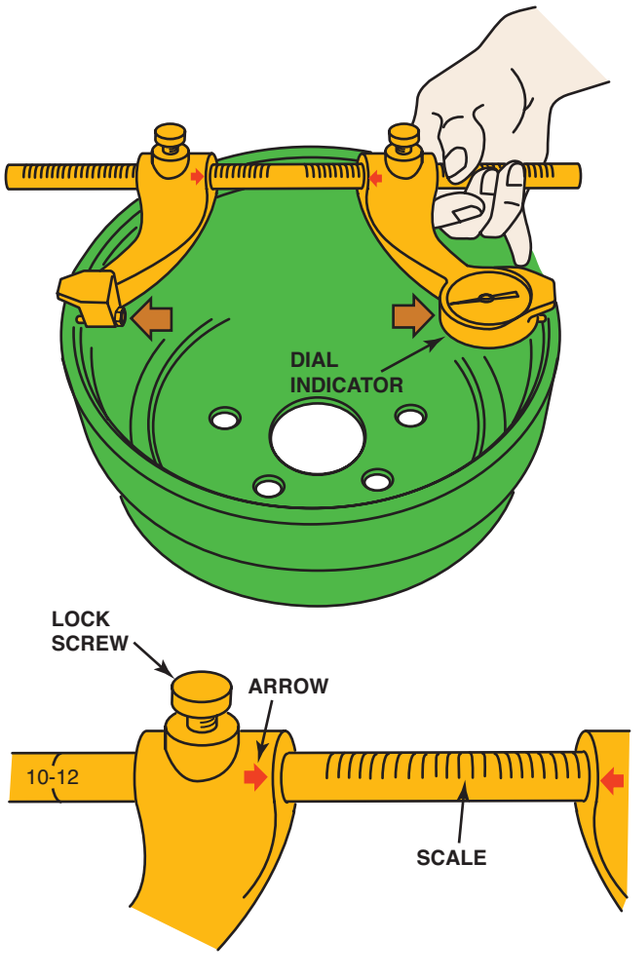


FIGURE 104–13 Typical needle-dial brake drum micrometer. The left movable arm is set to the approximate drum diameter and the right arm to the more exact drum diameter. The dial indicator (gauge) reads in thousandths of an inch.

MACHINING BRAKE DRUMS

MEASURING A DRUM Before measuring a brake drum, be sure it is not cracked by tapping it with a steel hammer. The brake drum should ring like a bell. If the brake drum makes a dull thud sound, discard the drum. Brake drums are usually measured using a micrometer especially designed for brake drums. ● **SEE FIGURE 104–13.**

Compare the micrometer reading to the discard diameter. Both drums should be measured whenever they are removed for any brake service or inspection.

BRAKE LATHE A brake lathe is a machine on which the brake drum or rotor is mounted on a spindle and rotates it in the same relationship as it does on the vehicle. A sharp carbide tool bit is then moved across the friction surface which removes metal, thus removing scratches, and scoring. It is critical that the drum and/or rotor be mounted on the spindle exactly in the same center line as it rotates on the vehicle. Various machine adapters, cones and collets are used to hold the brake drum or rotor. Always follow the operating instructions for the brake lathe being used.

MACHINING A DRUM PROCEDURE Always start any machining operation by making certain that the brake drum is clean and that excess grease is removed from the hub. If the drum has a hub with bearings, check the outer bearing races (cups) for wear and replace as necessary before placing the drum on the brake lathe. Also, carefully inspect and clean the lathe spindle shaft and cones before use. Use a **self-aligning spacer (SAS)** to be assured of even force being applied to the drum by the spindle nut. Always follow the instructions for the lathe you are using.

Hubless drums use a hole in the center of the brake drum for centering. Always check that the center hole is clean and free of burrs or nicks. Typical drum brake machining steps include the following:

STEP 1 Mount the drum on the lathe and install the silencer band as shown in ● **FIGURES 104–14 AND 104–15.**

STEP 2 Turn the drum by hand before turning on the lathe to be sure everything is properly mounted. Advance the tool bit manually until it just contacts the drum. This is called a **scratch cut.** ● **SEE FIGURE 104–16.**

STEP 3 Stop the lathe and back off the tool bit. Loosen the arbor nut, rotate the drum one-half turn (180°) on the arbor, and retighten the arbor nut. ● **SEE FIGURE 104–17.**

Turn the lathe on and make a second scratch cut.

a. If the scratch cuts are side-by-side, the lathe is okay and machining can begin.

b. If the scratch cuts are opposite, remove the drum and check for nicks, burrs, or chips on the mounting surfaces.

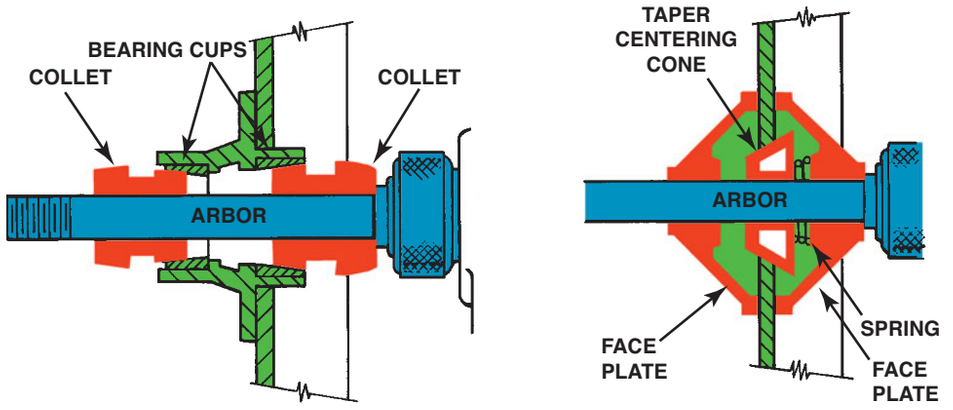


FIGURE 104–14 (a) A rotor or brake drum with a bearing hub should be installed on a brake lathe using the appropriate size collet that fit the bearing cups (races). (b) A hubless rotor or brake drum requires a spring and a tapered centering cone. A faceplate should be used on both sides of the rotor or drum to provide support. Always follow the operating instructions for the specified setup for the brake lathe being used.

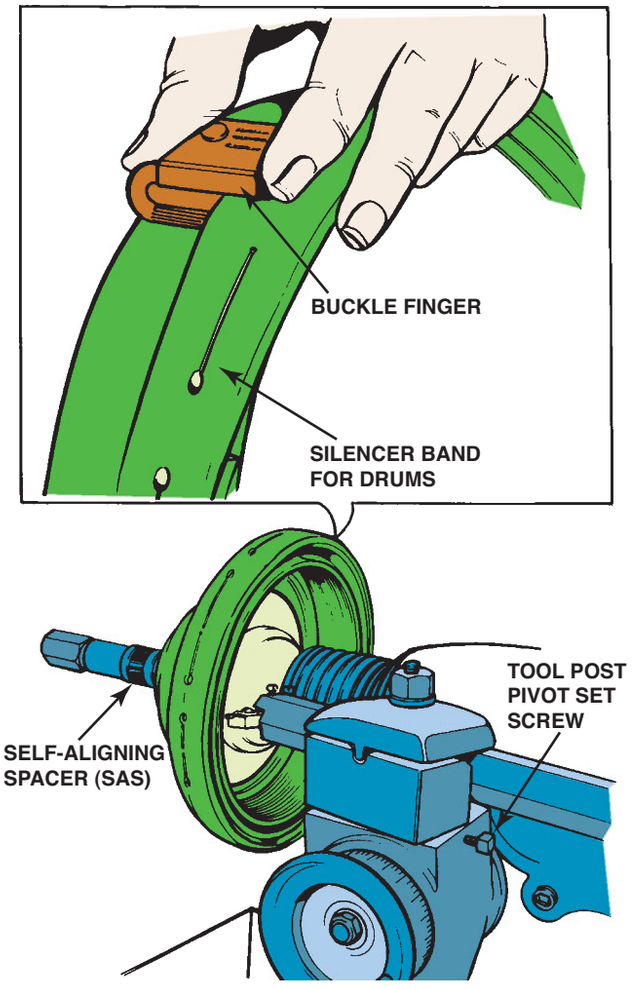


FIGURE 104–15 A self-aligning spacer (SAS) should always be used between the drum or rotor and the spindle retaining nut to help ensure an even clamping force and to prevent the adapters and cone from getting into a bind. A silence band should always be installed to prevent turning-tool chatter and to ensure a smooth surface finish. (*Courtesy of Ammco Tools, Inc.*)

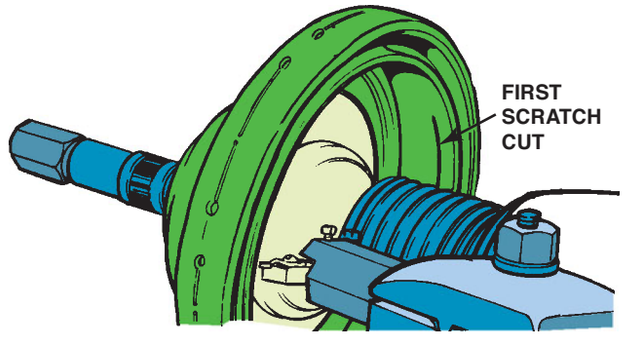


FIGURE 104–16 After installing a brake drum on the lathe, turn the cutting tool outward until the tool just touches the drum. This is called a scratch cut. (*Courtesy of Ammco Tools, Inc.*)

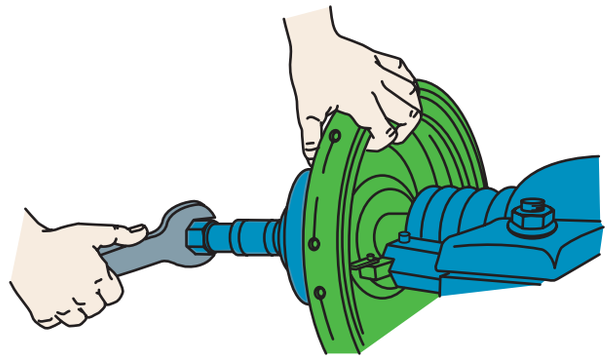


FIGURE 104–17 After making a scratch cut, loosen the retaining nut, rotate the drum on the lathe, and make another scratch cut. If both cuts are in the same location, the drum is installed correctly on the lathe and drum machining can begin. (*Courtesy of Ammco Tools, Inc.*)

STEP 4 Start the lathe and set the depth of the cut. ● **SEE FIGURES 104–18 AND 104–19.**

The maximum rough cut depends on the lathe type. The minimum cut is usually specified as no less than 0.002 in. (0.05 mm). A shallower cut usually causes the tool bit to slide over the surface of the metal rather than cut into the metal.

● **SEE FIGURE 104–20** for an example of a drum machined without properly positioning the antichatter (vibration) strap.

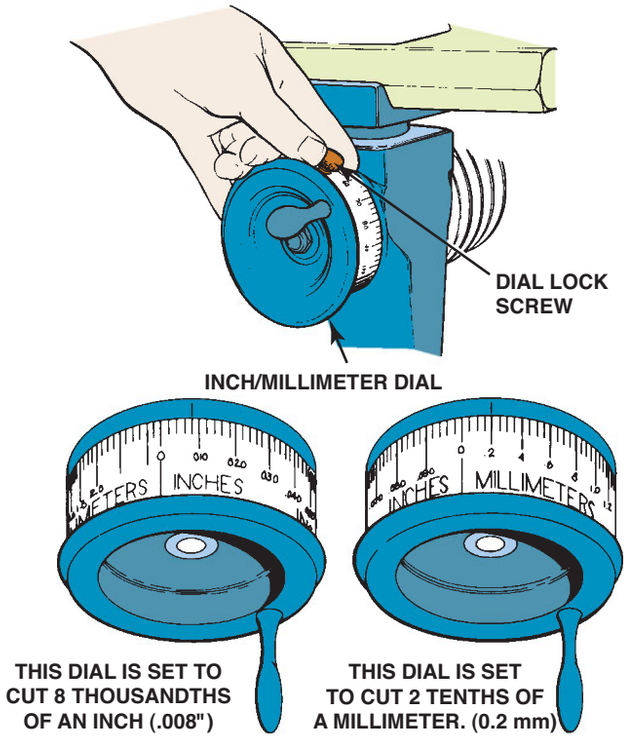


FIGURE 104–18 Set the depth of the cut indicator to zero just as the turning tool touches the drum. (*Courtesy of Ammco Tools, Inc.*)

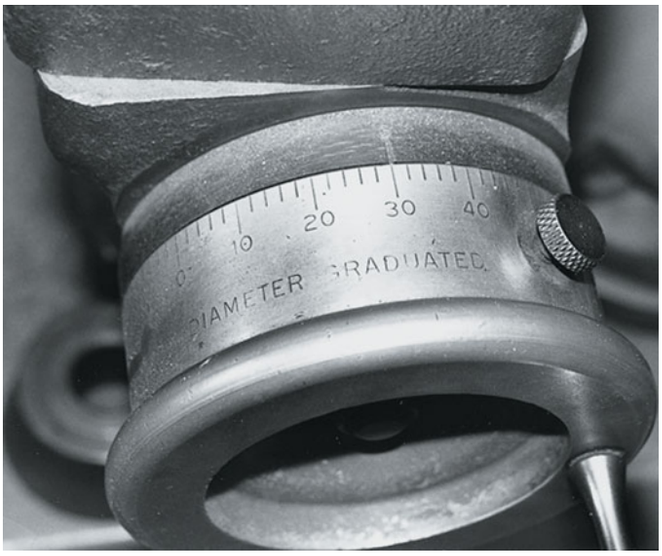


FIGURE 104–19 This lathe has a dial that is "diameter graduated". This means that a reading of 0.030 in. indicates a 0.015 in. cut that increases the inside diameter of the brake drum by 0.030 in.

DISC BRAKE ROTORS

Disc brake rotors use cast gray iron at the area that contacts the friction pad. Rotors, also called **discs** or **disks,** have mass (weight) that absorbs heat. The heavier the rotor, the more heat can be absorbed. Vehicle downsizing has resulted in the use of thinner- and lighter-weight rotors. As the weight of the rotor decreases, the less heat the rotor can "store" or absorb, resulting in the rotor getting hotter. As the rotor gets hotter, the rotor expands and "grows" larger where it is the hottest. If the rotor is allowed to cool gradually, the rotor simply returns to its original shape. If, however, the rotor is exposed to water, it may cool rapidly, causing the rotor to distort.

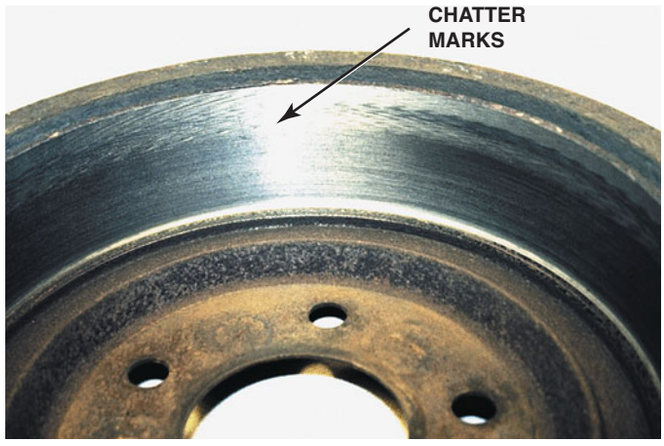


FIGURE 104–20 Notice the chatter marks at the edge of the friction-area surface of the brake drum. These marks were caused by vibration of the drum because the technician failed to wrap the dampening strap (silencer band) over the friction-surface portion of the brake drum.



FIGURE 104–21 This excessively worn (thin) rotor was removed from the vehicle in this condition. It is amazing that the vehicle was able to stop with such a thin rotor.

STYLES OR ROTORS

Rotors are made in several styles, including the following:

1. **Solid.** These are used on the rear of many vehicles equipped with rear disc brakes and on the front of some small and midsize vehicles. Solid rotors are usually used on the rear where only 20% to 40% of the braking occurs. Solid rotors are much thinner than vented rotors. ● **SEE FIGURE 104–21** for an example of an excessively worn solid rotor.
2. **Vented.** These are used on the front of most vehicles. The internal vanes allow air to circulate between the two friction surfaces of the rotor. Rotors can either be straight vane design, as shown in ● **FIGURE 104–22**, or directional vane design, as shown in ● **FIGURE 104–23.**

COMPOSITE ROTORS

Composite rotors use a steel center section with a cast iron wear surface. These composite rotors are lighter in weight than conventional cast-iron rotors. ● **SEE FIGURE 104–24.**



FIGURE 104–22 Severely worn vented disc brake rotor. The braking surface has been entirely worn away exposing the cooling fins. The owner brought the vehicle to a repair shop because of a "little noise in the front." Notice the straight vane design.

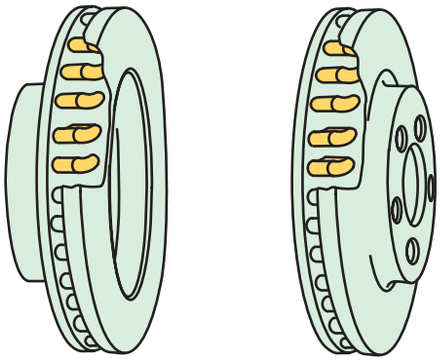


FIGURE 104–23 Directional vane vented disc brake rotors. Note that the fins angle toward the rear of the vehicle. It is important that this type of rotor be reinstalled on the correct side of the vehicle.

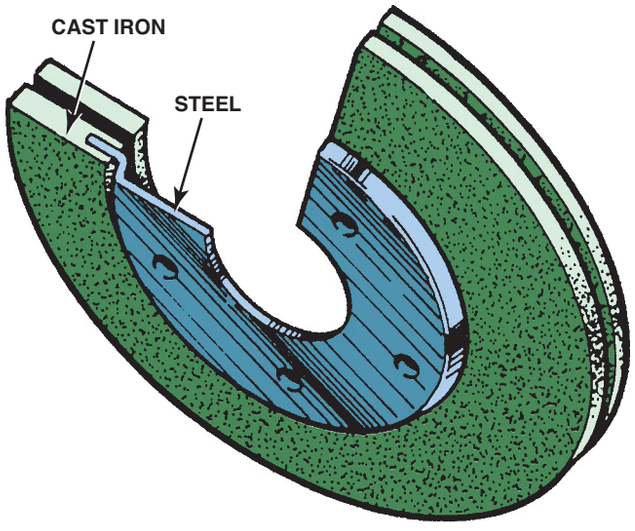


FIGURE 104–24 Typical composite rotor that uses cast iron friction surfaces and a steel center section.

The light weight of composite rotors makes them popular with vehicle manufacturers. However, technicians should be aware that full-contact adapters that simulate the actual wheel being bolted to the rotor must be used when machining composite rotors. If composite rotors are machined incorrectly, they must usually be replaced.



FIGURE 104–25 This Porsche is equipped with high-performance brakes including cross-drilled brake rotors.

FREQUENTLY ASKED QUESTION

What Does "Cross-Drilled" and "Slotted" Mean?

The expression "cross-drilled" and "slotted" refers to two separate processes. The first procedure involves drilling rows of holes through the friction surfaces of the rotor. The second procedure refers to milling a series of specially machined grooves from the center of the disc toward the edge. When the friction surfaces of a rotor are smooth and flat, there is no means of escape for the gases and dust, which build up between pad and rotor. This is not a huge problem in normal driving, but is an important consideration in street performance applications.

The drill holes (which are sometimes called "gas relief openings") provide an exit route for the dust and gas. The holes are also commonly labeled "cooling holes" because of the improvements they make in this area. Better cooling means less fade during repeated heavy brake application. They also help dissipate water when driving in poor weather. ● **SEE FIGURE 104–25.**

Slotting increases the bite of the pads and is even more effective than cross-drilling in combating the problem known as "out-gassing." This is when, at very high braking temperatures, the bonding agents used in some brake pads produce a gas. Under extreme conditions, this gas can create a gas cushion between pad and rotor, giving a driver a normal pedal feel but reducing the amount of friction being generated. The slots pump away gas and restore full contact. The "micro-shaving" effect of the slots also serves to deglaze the pads and this is why the edges of the slots are not chamfered or "radiused." It also tends to even out the wear across the brake pad faces, increasing the effective contact area.

ALUMINUM METAL MATRIX COMPOSITE ROTORS

Some disc brake rotors are manufactured from an aluminum metal matrix composite alloy reinforced with 20% silicon carbide particulate. Aluminum composites combine the light weight and thermal conductivity of aluminum with the stiffness and wear resistance of a ceramic to create a disc brake rotor with excellent heat dissipation and service life.

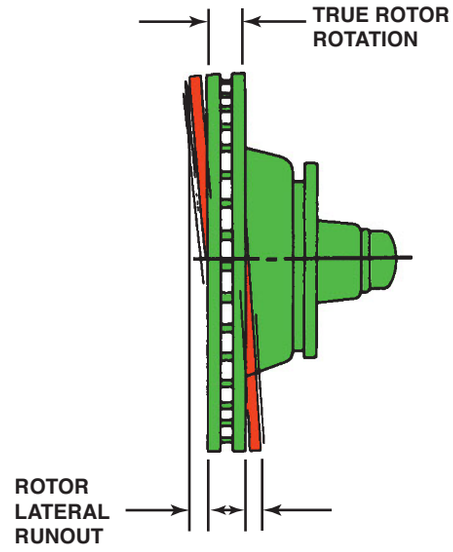


FIGURE 104–26 Brake rotor lateral-runout distortion.

These rotors can be distinguished from conventional cast-iron rotors in several ways. At first glance the rotors are silver gray with a dark gray or black transfer layer (from the brake pad) on the rubbing surface. Unlike cast iron, these rotors will show no signs of rust and are nonmagnetic. When removed from the vehicle, the aluminum composite rotors can be further distinguished by their light weight, usually under 6 lb (2.7 kg) versus over 12 lb (5.4 kg) for cast-iron rotors on the typical passenger vehicle.

Servicing these rotors is slightly different from cast-iron rotors. The dark transfer layer on the rubbing surface does not harm rotor performance and should not be removed unless the rotor needs to be machined due to being warped. Carbide tools can be used to machine a single set of aluminum composite rotors. If a shop receives these rotors on a regular basis, a polycrystalline diamond (PCD)-tipped tool is a good investment. Although more expensive initially, the PCD tool can last 100 times longer than a carbide tool.

DISC BRAKE ROTOR DISTORTION

CAUSES OF ROTOR DISTORTION The friction surfaces of a rotor in perfect condition are perpendicular to the axle centerline, and have no side-to-side movement. Unlike brake drums, rotors do not suffer distortion as a routine part of brake operation. However, distortion can occur during braking if there is a problem with the friction assembly, such as a frozen caliper piston that creates unequal application force on the two sides of the rotor.

Friction surface distortion is much more significant in a disc brake rotor than in a brake drum because the design of the friction assembly magnifies the effect of any wear. The hydraulic principles dictate that small movements of the large pistons in the brake calipers are converted into large movements of the small pistons in the master cylinder. Even very small amounts of distortion in a disc brake rotor can cause large amounts of pedal pulsation.

ROTOR LATERAL RUNOUT **Lateral runout,** often abbreviated **LRO or T.I.R.** for **total indicator runout,** is side-to-side wobble of the rotor as it rotates on the spindle. ● **SEE FIGURE 104–26.**

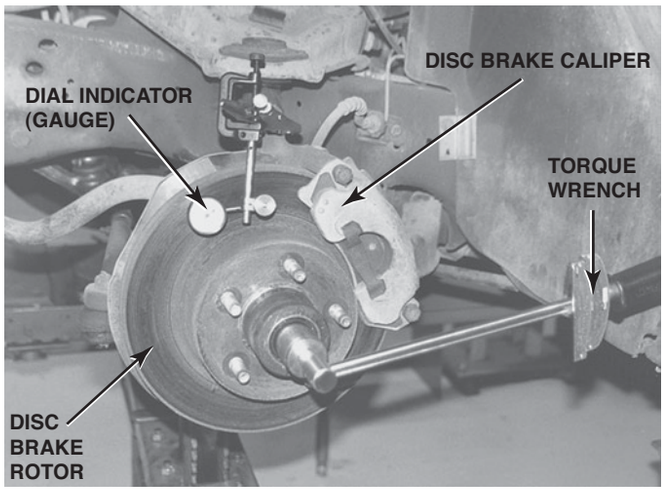


FIGURE 104–27 Before measuring lateral runout with a dial indicator (gauge), remove any wheel bearing end play by tightening the spindle nut to 10 to 20 ft-lb with a torque wrench. This step helps prevent an inaccurate reading. If the vehicle is to be returned to service, be sure to loosen the spindle nut and retighten to specifications (usually, finger tight) to restore proper bearing clearance.

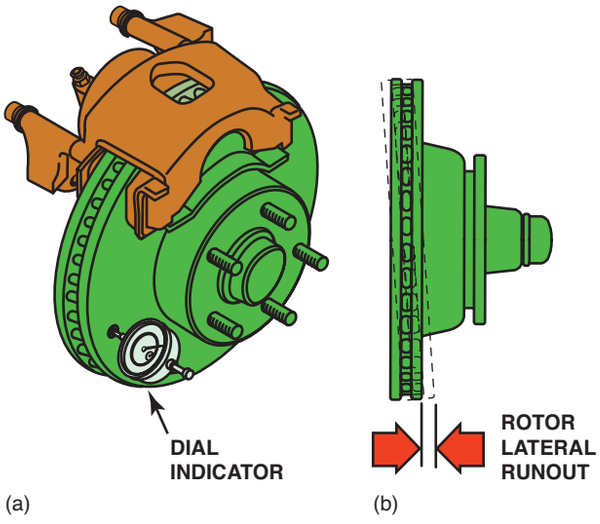


FIGURE 104–28 (a) Rotate the disc brake rotor one complete revolution while observing the dial indicator (gauge). (b) Most vehicle manufacturers specify a maximum runout of about 0.003 in. (0.08 mm).

A small amount of runout provides caliper piston knockback that reduces drag when the brakes are not applied. However, if the amount of runout is too great, excessive brake pedal travel and front-end vibration, felt in the steering wheel, will result. In cases of severe runout, a pulsating brake pedal may also be present.

Lateral runout can be caused by several factors. Overtightened or unevenly tightened lug nuts or bolts are a common source of runout on newer vehicles with downsized brake rotors. Extreme heat or rapid temperature variations also cause runout. Inaccurate machining at the factory or in the field is also a common cause of this distortion. Most maximum values range between 0.002 and 0.005 in. (0.05 and 0.13 mm). Always check service information for the exact specifications for the vehicle being serviced. ● **SEE FIGURES 104–27 AND 104–28.**

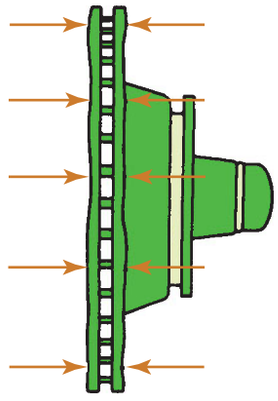


FIGURE 104–29 Brake rotor lack-of-parallelism distortion.

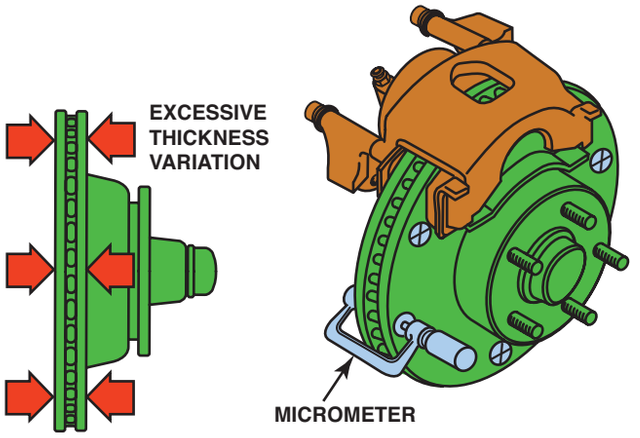


FIGURE 104–30 (a) Disc brake rotor thickness variation (parallelism). (b) The rotor should be measured with a micrometer at four or more equally spaced locations around the rotor.

ROTOR LACK OF PARALLELISM

Lack of **parallelism,** also called **thickness variation (TV),** is a variation in the thickness of the rotor when it is measured at several places around its circumference. ● **SEE FIGURE 104–29.**

A rotor with friction surfaces that are not parallel is the most common disc brake cause of a pulsating brake pedal. A lack of rotor parallelism will cause a pedal pulsation when the brakes are applied at all speeds, and can also cause front-end vibration during braking. ● **SEE FIGURE 104–30.**

Lack of parallelism can be caused by a soft spot in the rotor casting that wears more rapidly than surrounding areas, but the most common cause is rust buildup on the rotor when the vehicle is not driven for an extended period. The part of the friction surface protected by the brake pads does not rust as much as the rest of the rotor, and because the rusted areas wear faster, this results in a thickness variation when the vehicle is driven again.

Because parallelism variation is much more likely to cause a problem than lateral runout, the maximum amount allowed is much smaller than for runout. Most manufacturers specify that the two friction surfaces of a rotor must be parallel within half a thousandth of an inch, 0.0005 in. (0.013 mm), or less.

TECH TIP

Braking Vibration Could Be Due to the Tires

A vibrating condition (roughness) during braking is usually caused by disc brake rotor thickness variation or an out-of-round brake drum. Both conditions should be investigated. However, the tires and/or road conditions can also cause the same vibrations.

Tests performed by vehicle and tire-manufacturing engineers have shown that tires, and tires alone, could be the cause. If no other problem can be isolated, install a different brand of tire on the vehicle and retest. The cause of the tire vibration seems to be due to distortion or movement of the tire tread. A different brand of tires would have a different tread rubber compound, carcass body ply angles, or other factor that can contribute to a vibration during braking.

TECH TIP

Think of a Human Hair

Measurements and specifications do not seem to mean much unless you can visualize the size compared to something with which you are familiar. The diameter of a human hair is from 0.002 to 0.004 in. (2 to 4 thousandths of an inch).

The maximum lateral runout of a rotor is usually within this same dimension. The reason a dial indicator has to be used to measure runout, and a micrometer to measure parallelism, is that the dimensions involved are less than the diameter of a human hair. ● **SEE FIGURE 104–31.**

DISC BRAKE ROTOR THICKNESS

Most rotors have a minimum thickness cast or stamped into the rotor. This thickness is minimum wear thickness. At least 0.015 in. (0.4 mm) must remain after machining to allow for wear. Some vehicle manufacturers, such as General Motors, specify that 0.030 in. [0.8 mm] be left for wear. ● **SEE FIGURE 104–32.**

Whenever machining (resurfacing) a rotor, an equal amount of material must be removed from each side.

WHEN THE ROTORS SHOULD BE MACHINED

According to brake design engineers, a worn rotor has a very smooth friction surface that is ideal for replacement (new) disc brake pads. Often when the rotors are machined, the surface finish is not as

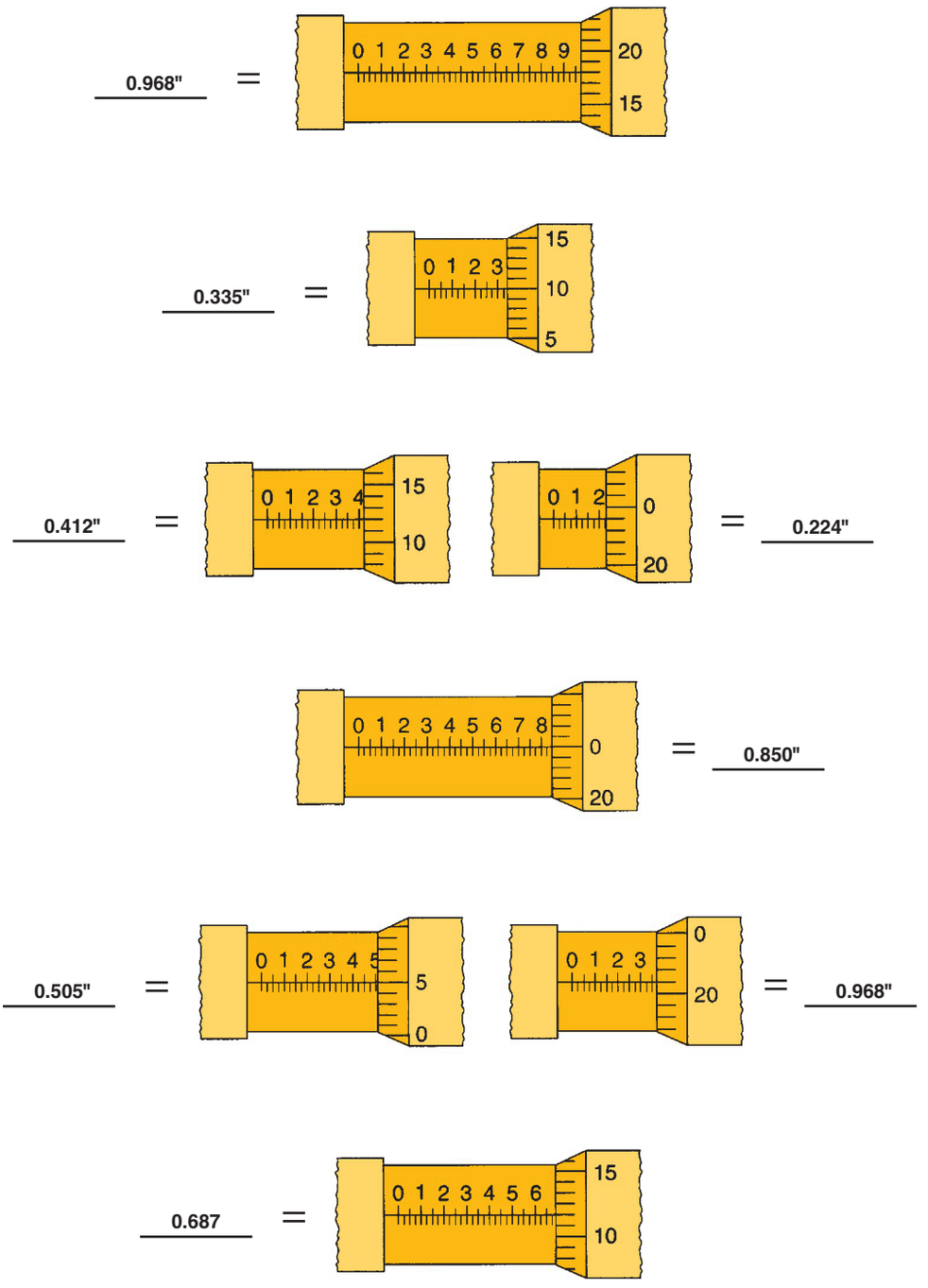


FIGURE 104–31 Sample micrometer readings. Each larger line on the barrel between the numbers represents 0.025″. The number on the thimble is then added to the number showing and the number of lines times 0.025″.

smooth as specified. Therefore, a rotor should be machined only if one of the following conditions exists:

1. Deep grooves deeper than 0.060 in. (1.5 mm). This is the approximate thickness of a nickel! ● **SEE FIGURE 104–33.**
2. Thickness variation exceeding specifications and a brake pedal pulsation complaint.
3. Heavy rust that has corroded the friction surface of the rotor. ● **SEE FIGURES 104–34 AND 104–35.**

Therefore, if there is no complaint of a pulsating brake pedal during braking and the rotor is not deeply grooved or rusted, it should not be machined. New disc brake pads perform best against a smooth surface, and a used disc brake rotor is often smoother than a new rotor.

ROTOR FINISH

The smoothness of the rotor is called rotor finish or surface finish. Surface finish is measured in units called **microinches,** abbreviated **µin.,** where the symbol in front of "in." is the Greek lowercase letter µ (mu). One microinch equals 0.000001 in. (0.025 micrometer [µm]). The finish classification of microinch means the distance between the highest peaks and the deepest valley. The usual method of expressing surface finish is the arithmetic average roughness height, abbreviated **Ra,** which is the average of all peaks and valleys from the mean (average) line. This surface finish is measured using a machine with a diamond stylus, as shown in ● **FIGURE 104–36.**

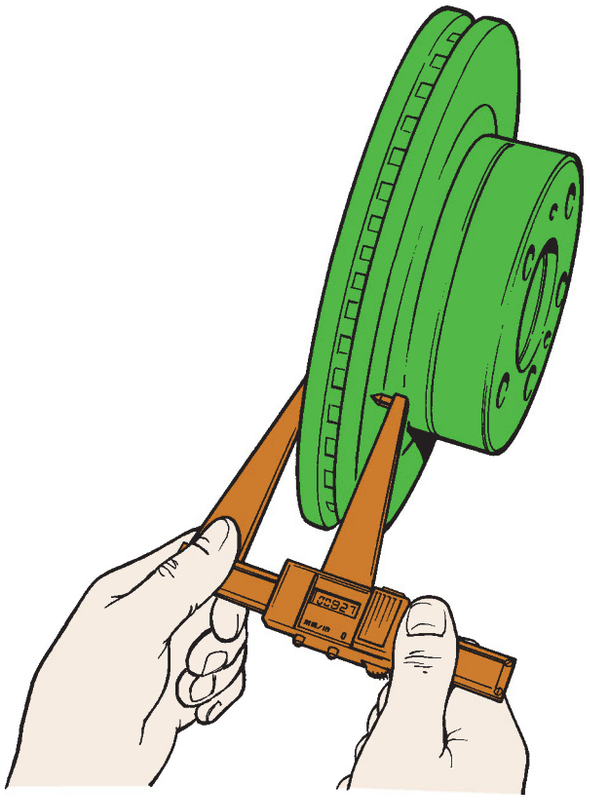


FIGURE 104–32 A digital readout rotor micrometer is an accurate tool to use when measuring a rotor. Both fractional inches and metric millimeters are generally available.

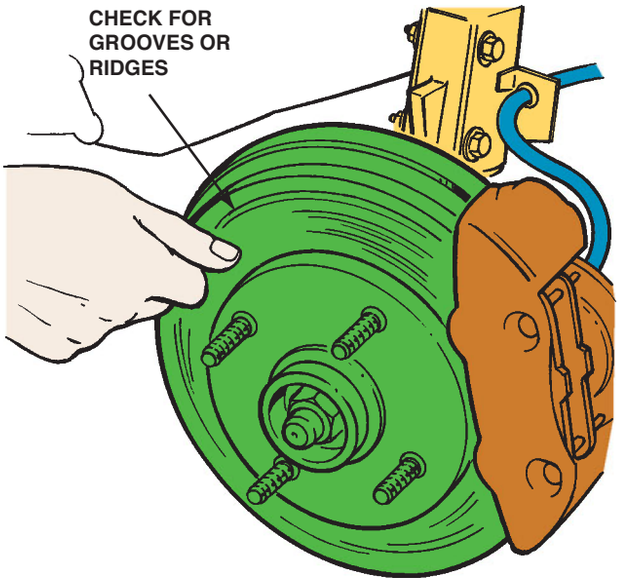


FIGURE 104–33 If a fingernail catches on a groove in the rotor, the rotor should be machined.



FIGURE 104–34 This rusted rotor should be machined.



FIGURE 104–35 Rotors that have deep rust pockets usually cannot be machined.

TECH TIP

The Ballpoint Pen Test

A smooth friction surface on a drum or rotor is necessary for proper brake operation. To quickly determine if the friction surface of a brake drum or rotor is not smooth enough, draw a ballpoint pen across the surface. If the surface is smooth enough, a solid ink line will be observed. If the line drawn by the pen is not solid, then the surface is not smooth enough.

Another classification of surface finish that is becoming obsolete is the *root mean square (RMS).* The RMS method gives a slightly higher number and can be obtained by multiplying Ra × 1.11 = RMS.

Often, a machined rotor will not be as smooth as a new rotor, resulting in a hard-stopping complaint after new brakes have been installed. A rough rotor has less surface area touching the new brake pads, resulting in a hard brake pedal and reduced braking effectiveness. Most new rotors have a surface finish of 45 to 60 µin. Ra.

- The higher the Ra of a rotor, the rougher the surface finish.
- The lower the Ra number, the smoother the surface finish

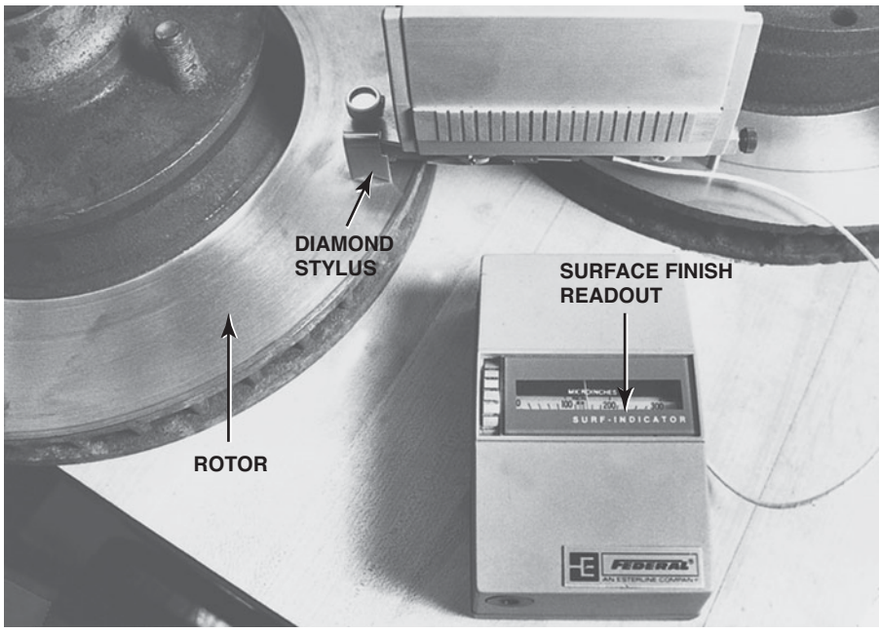


FIGURE 104–36 Electronic surface finish machine. The reading shows about 140 µin. This is much too rough for use but is typical for a rough cut surface.

MACHINING A DISC BRAKE ROTOR

Before machining a rotor, be sure that it can be machined by comparing the minimum thickness specification and the measured thickness of the rotor. Many lathes are capable of removing a large amount of material in one pass, thereby reducing the time necessary to refinish a rotor. These lathes usually use a positive rake tool bit angle. ● **SEE FIGURE 104–37.**

Other lathes that use six-sided reversible tool bits usually use a negative rake tool bit angle. Ammco is an example of a negative rake lathe, whereas Perfect-Hofmann and Accu-turn are examples of positive rake lathes.

CAUTION: Some original equipment and replacement disc brake rotors are close to the minimum allowable thickness when new. Often, these rotors cannot be safely machined at all!

Following is an example of the steps necessary to machine a disc brake rotor. Always follow the instructions for the equipment you are using.

STEP 1 Mount the disc brake rotor to the spindle of the lathe using the cones and adapters recommended. ● **SEE FIGURES 104–38 AND 104–39.**

STEP 2 Install a rotor damper and position the cutting tools close to the rotor surface as shown in ● **FIGURE 104–40.**

NOTE: Failure to install the damper causes vibrations to occur during machining that create a rough surface finish.

STEP 3 Make a scratch cut on the rotor face, as shown in ● **FIGURE 104–41.**

STEP 4 To check that the rotor is mounted correctly, loosen the retaining nut, turn the rotor one-half turn (180°), and retighten the nut. Make another scratch cut.

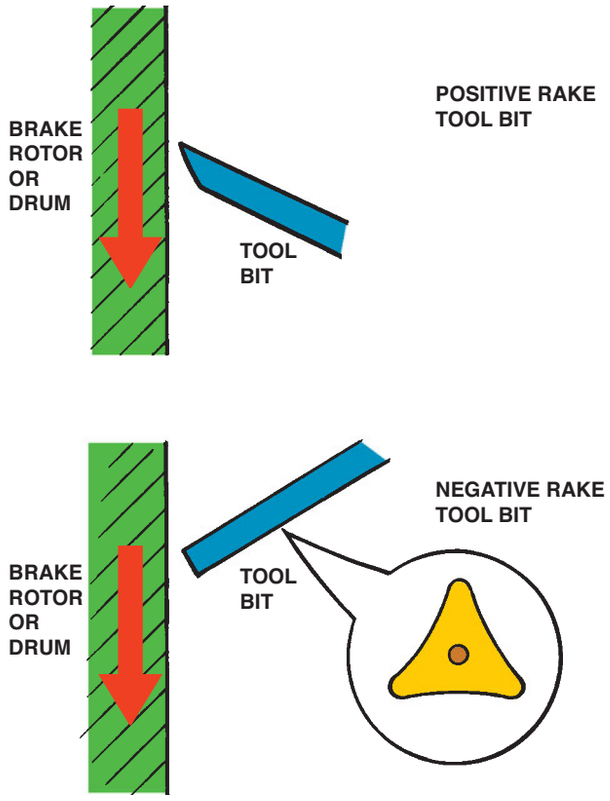


FIGURE 104–37 Most positive rake brake lathes can cut any depth in one pass, thereby saving time. A typical negative rake lathe uses a three-sided turning tool that can be flipped over, thereby giving six cutting edges.

a. The second scratch cut should be side-by-side with the first scratch cut if the rotor is properly installed, as shown in ● **FIGURE 104–42.**

b. If the second scratch cut is on the opposite side (180°) from the first scratch cut, the rotor may not be installed on the lathe correctly.

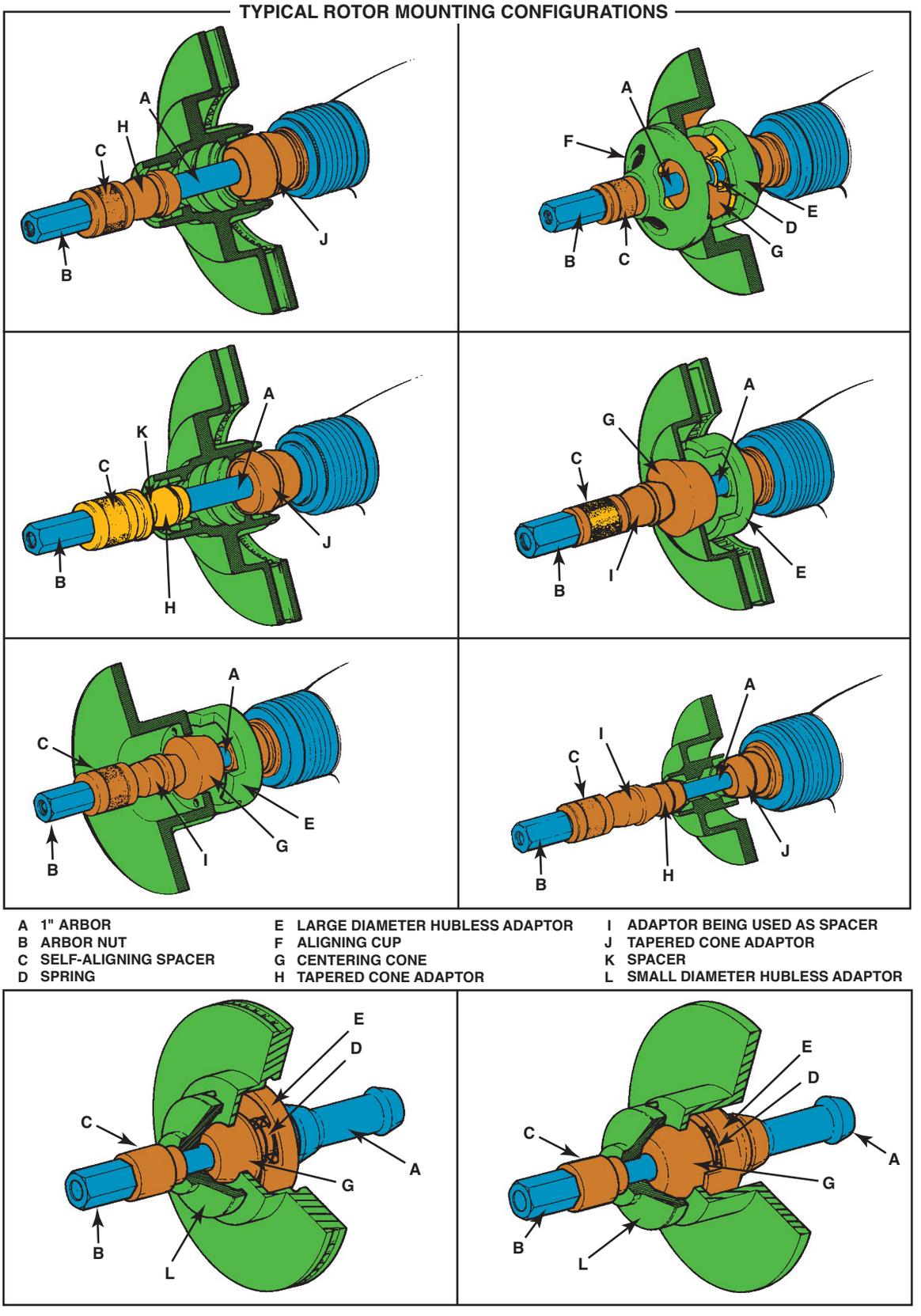
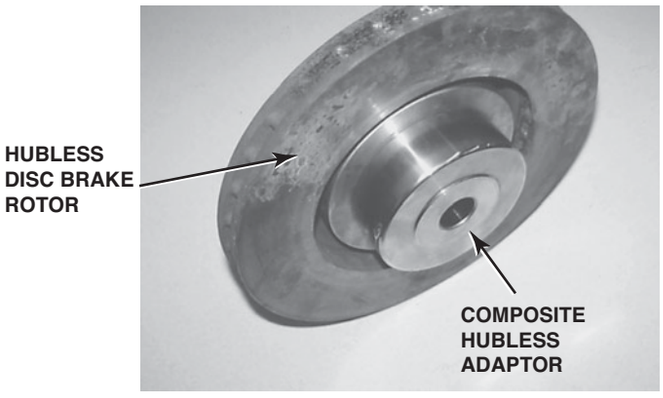


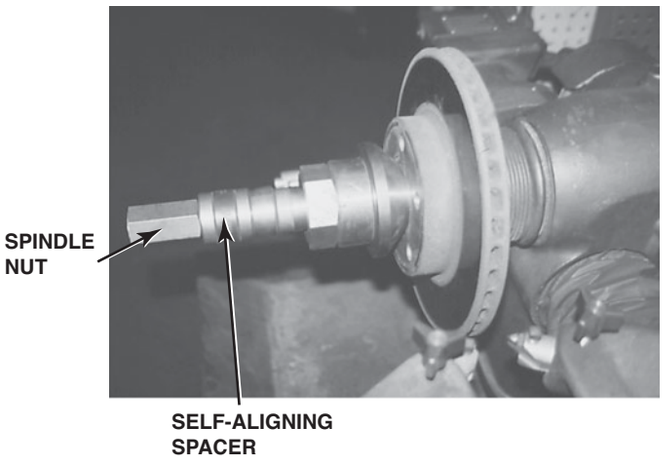
FIGURE 104–38 Recommended adapters and location for machining hubbed and hubless rotors. (*Courtesy of Ammco Tools, Inc.*)

NOTE: The runout as measured with a dial indicator on the brake lathe should be the same as the runout measured on the vehicle. If the runout is not the same, the rotor is not installed on the brake lathe correctly.

STEP 5 After proper installation of the disc brake rotor on the brake lathe, proceed with machining the rotors. For best results do not machine any more material from the rotor than is absolutely necessary. Always follow the recommendations and guidelines as specified by the vehicle manufacturer.



(a)



(b)

FIGURE 104–39 (a) Composite adapter fitted to a rotor. (b) Composite rotor properly mounted on a lathe.

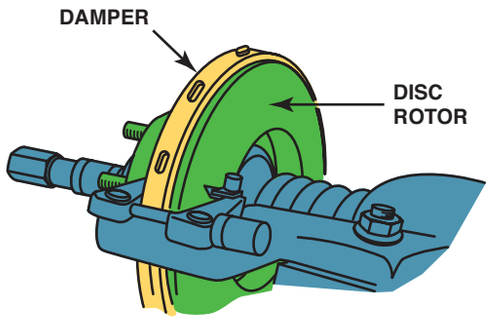


FIGURE 104–40 A damper is necessary to reduce cutting-tool vibrations that can cause a rough surface finish.

ROUGH CUT A rough cut on a lathe involves cutting 0.005 in. per side with a feed of 0.008 in. per revolution and 150 RPM spindle speed. This usually results in a very coarse surface finish of about 150 µin. Ra.

FINISH CUT A finish cut means removing 0.002 in. per side with a feed of 0.002 in. per revolution and 150 RPM spindle speed. Although this cut usually looks smooth, the surface finish is about 90 to 100 µin. Ra. Even a typical finish cut is still not nearly as smooth as a new rotor.

NOTE: Measure the thickness of the rotor after the finish cut and compare with manufacturers' specifications. Be sure to allow for wear. ● SEE CHART 104–1 for a metric/fractional measurement chart.

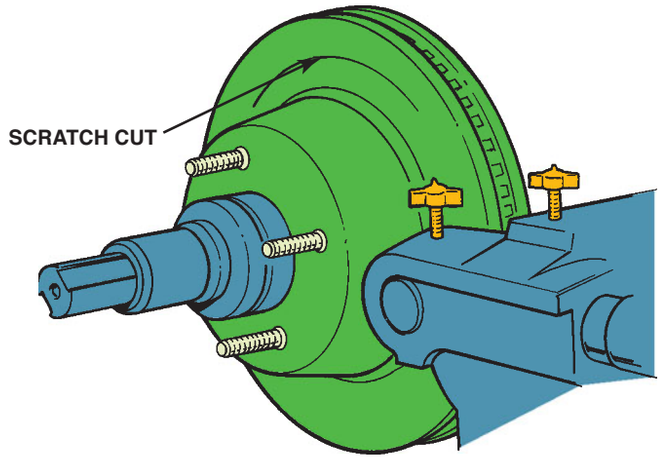


FIGURE 104–41 After installing the rotor on the brake lathe, turn the cutting tool in just enough to make a scratch cut.

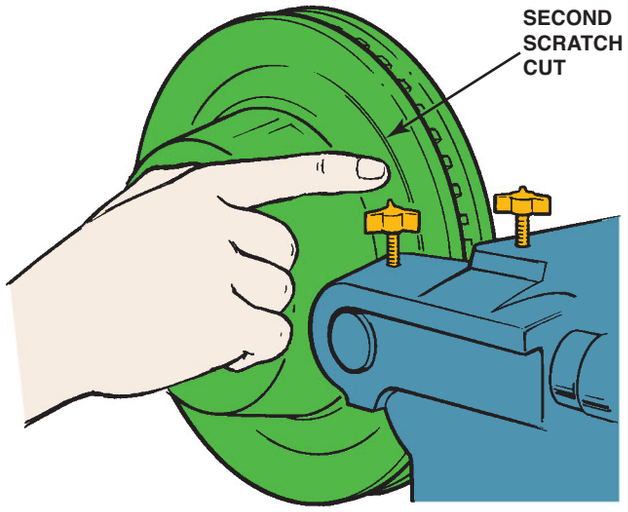


FIGURE 104–42 After making a scratch cut, loosen the retaining nut and rotate the rotor on the spindle of the lathe one-half turn. Tighten the nut and make a second scratch cut. The second scratch cut should be side-by-side with the first scratch if the rotor is installed correctly on the brake lathe.

NONDIRECTIONAL FINISH Most vehicle and brake component manufacturers recommend a nondirectional finish to help prevent the grooves machined into the rotor from acting like record grooves that can force the pads to move outward while the rotor rotates.

CAUTION: Some nondirectional finish tools such as those that use Scotch Brite (a registered trademark) plastic pads often do not make the rotor as smooth as new, even though the finish has been swirled.

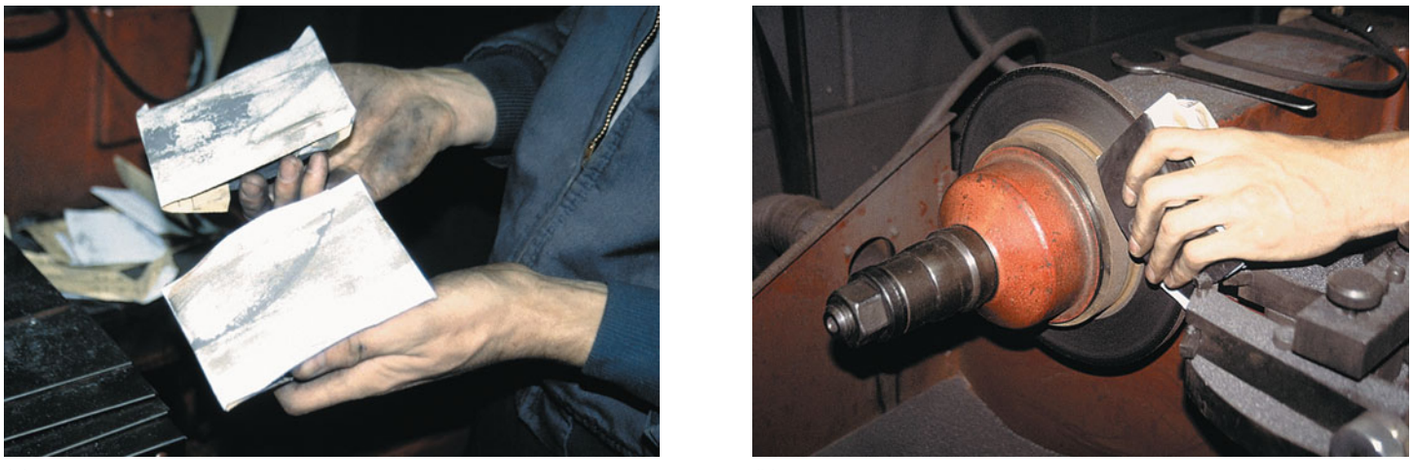
SURFACE FINISHING THE ROTOR The goal of any brake repair or service should be to restore the braking effectiveness to match new vehicle brakes. This means that the rotor finish should be as smooth or smoother than a new rotor for maximum brake pad contact. Research conducted at Delphi has shown that like-new rotor finish can easily be accomplished by using a block and sandpaper. After completing the finish cut, place 150-grit aluminum-oxide sandpaper on a block and apply steady pressure against the rotor surface for 60 seconds on each side of the rotor. ● **SEE FIGURES 104–43 AND 104–44.**

The aluminum oxide is hard enough to remove the highest ridges left by the lathe cutting tool. This results in a surface finish

INCH	DECIMAL INCH	MILLIMETER	INCH	DECIMAL INCH	MILLIMETER
1/64	0.015625	0.396785	33/64	0.515625	13.096875
1/32	0.03125	0.79375	17/32	0.53125	13.49375
3/64	0.046875	1.190625	35/64	0.546875	13.890625
1/16	0.0625	1.5875	9/16	0.5625	14.2875
5/64	0.078125	1.984375	37/64	0.578125	14.684375
3/32	0.09375	2.38125	19/32	0.59375	15.08125
7/64	0.109375	2.778125	39/64	0.609375	15.478125
1/8	0.125	3.175	5/8	0.625	15.875
9/64	0.140625	3.571875	41/64	0.640625	16.271875
5/32	0.15625	3.96875	21/32	0.65625	16.66875
11/64	0.171875	4.365625	43/64	0.671875	17.065625
3/16	0.1875	4.7625	11/16	0.6875	17.4625
13/64	0.203125	5.159375	45/64	0.703125	17.859375
7/32	0.21875	5.55625	23/32	0.71875	18.25625
15/64	0.234375	5.953125	47/64	0.734375	18.653125
1/4	0.25	6.35001	3/4	0.75	19.05
17/64	0.265625	6.746875	49/64	0.765625	19.446875
9/32	0.28125	7.14375	25/32	0.78125	19.84375
19/64	0.296875	7.540625	51/64	0.796875	20.240625
5/16	0.3125	7.9375	13/16	0.8125	20.6375
21/64	0.328125	8.334375	53/64	0.828125	21.034375
11/32	0.34375	8.73125	27/32	0.84375	21.43125
23/64	0.359375	9.128125	55/64	0.859375	21.828125
3/8	0.375	9.525	7/8	0.875	22.225
25/64	0.390625	9.921875	57/64	0.890625	22.621875
13/32	0.40625	10.31875	29/32	0.90625	23.01875
27/64	0.421875	10.715625	59/64	0.921875	23.415625
7/16	0.4375	11.1125	15/16	0.9375	23.8125
29/64	0.453125	11.509375	61/64	0.953125	24.209375
15/32	0.46875	11.90625	31/32	0.96875	24.60625
31/64	0.484375	12.303125	63/64	0.984375	25.003125
1/2	0.50	12.7	1	1.00000	25.4

CHART 104–1

Metric/fractional chart.

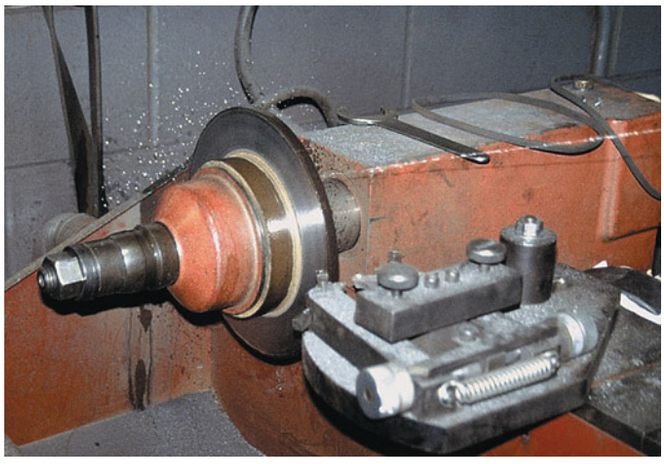


(a) (b)

FIGURE 104–43 (a) This technician uses two sanding blocks each equipped with 150-grit aluminum-oxide sandpaper. (b) With the lathe turned on, the technician presses the two sanding blocks against the surface of the rotor after the rotor has been machined, to achieve a smooth microinch surface finish.



(a)



(b)

FIGURE 104–44 (a) After machining and sanding the rotor, it should be cleaned. In this case brake cleaner from an air pressurized spray can is used. (b) With the lathe turning, the technician stands back away from the rotor and sprays both sides of the rotor to clean it of any remaining grit from the sanding process. This last step ensures a clean, smooth surface for the disc brake pads and a quality brake repair. Sanding each side of the rotor surface for one minute using a sanding block and 150-grit aluminum-oxide sandpaper after a finish cut gives the rotor the proper smoothness and finish.

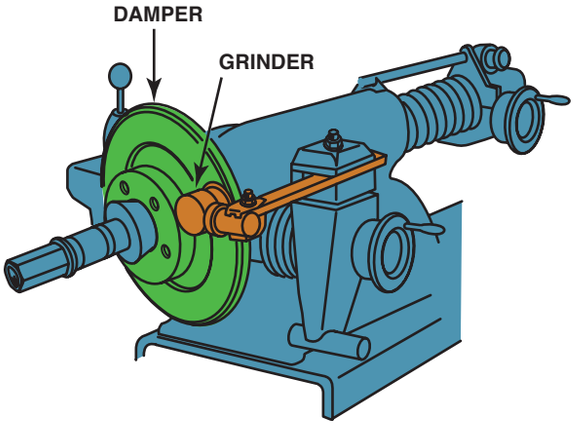


FIGURE 104–45 A grinder with sandpaper can be used to give a smooth nondirectional surface finish to the disc brake rotor.

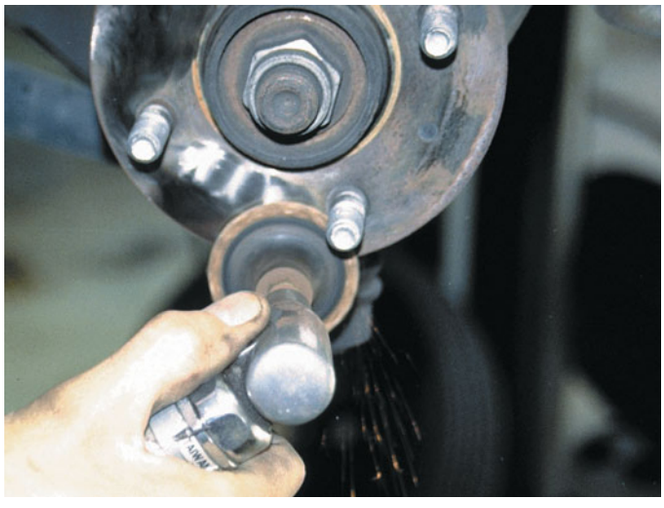


FIGURE 104–47 Rust should always be cleaned from both the rotor and the hub whenever the rotors are machined or replaced. An air-powered die grinder with a sanding disc makes quick work of cleaning this hub.

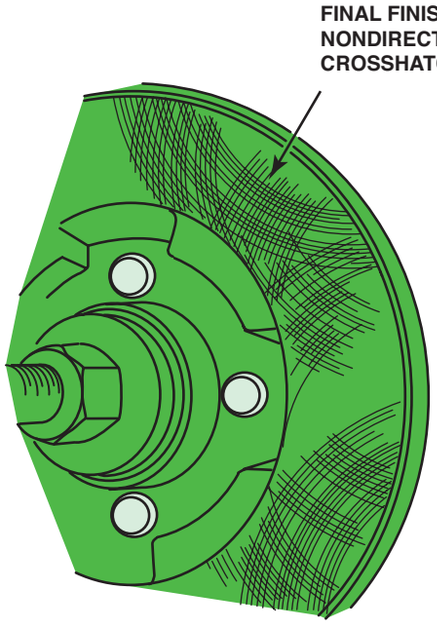


FIGURE 104–46 The correct final surface finish should be smooth and nondirectional.

ranging from 20 to 80 µin. and usually less than 40 µin., which is smoother than a new rotor. ● **SEE FIGURE 104–45.**

NOTE: Many commercial rotor-finish products may also give as smooth a surface finish. ● **SEE FIGURES 104–46.**

Always compare rotor finish to the rotor finish of a new rotor. Microinch finish is often hard to distinguish unless you have a new rotor with which to compare.

BRAKE HUB CLEANING Before installing the disc brake rotor on the vehicle be sure that bearing hub surface is clean and rust free. Using an air-powered die grinder equipped with a sanding disc works well. ● **SEE FIGURE 104–47**

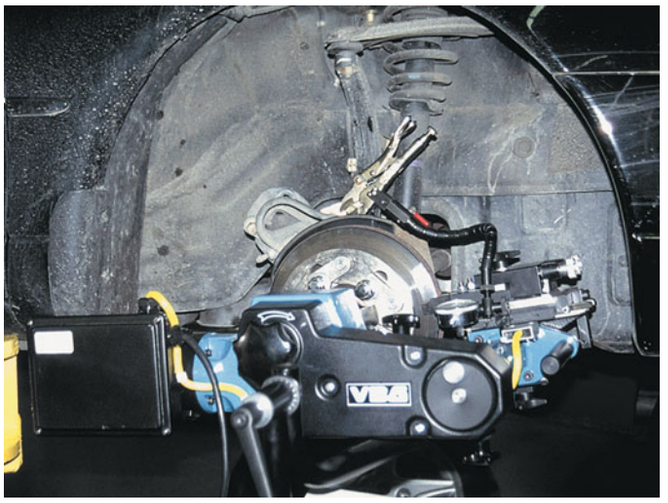


FIGURE 104–48 A typical hub-mount on-the-vehicle lathe. This particular lathe oscillates while machining the rotor, thereby providing a smooth and nondirectional finish at the same time.



FIGURE 104–49 A wheel stud was replaced on the rotor hub assembly when it was discovered to be stripped.

TECH TIP

Turn or Machine?

When asked about what was done to their vehicle, a common response of customers is "They rotated my rotors." Many customers do not understand the terms that are commonly used in the vehicle service industry. Try to use terms that are technically correct and avoid slang when talking to customers. For example, the expression *machined the rotors* indicates an operation, whereas the expression *turned the rotors* may be misinterpreted by some customers as simply meaning using your hand and moving (rotating) the rotor. *Resurfacing, refinishing,* and *reconditioning* are other terms that could be used to describe a drum or rotor machining operation.

TECH TIP

Always Check the Wheel Studs

Before installing the wheel after brake service, check the condition of the wheel studs and lug nuts. Check for stripped threads, rust, or cracks. If necessary, replace the stud. Most studs are replaced by driving them out using a large hammer and then using washers and a lug nut to draw the serrated shoulder of the lug stud into the rotor stud hole. ● **SEE FIGURE 104–49.** Best to always use a torque wrench when installing lug nuts to ensure proper and even torque on all lug nuts. This helps to prevent rotor distortion, which can lead to vibration in the steering and/or pedal pulsation during braking.

ON-THE-VEHICLE ROTOR MACHINING

Many vehicle manufacturers recommend on-the-vehicle machining for rotors if the disc brake rotor must be machined due to deep scoring or pulsating brake pedal complaint. This is especially true of composite rotors or for vehicles such as many Honda vehicles that require major disassembly to remove the rotors.

Caliper-mount, on-the-vehicle lathes require that the disc brake caliper be removed. The cutter attaches to the steering knuckle or caliper support in the same location as the caliper. ● **SEE FIGURE 104–48.** Hub-mount, on-the-vehicle lathes attach to the hub using the lug nuts of the vehicle. To achieve a proper cut, the hub mount must be calibrated for any runout caused by the hub bearings and the outside surface face of the rotor.

NOTE: All on-the-vehicle lathes require that the wheel be removed. For best results, always use a torque wrench when tightening lug nuts or lathe adapters. Unequal torque on the bolts causes stress and distortion that can cause warped rotors and a pulsating brake pedal.

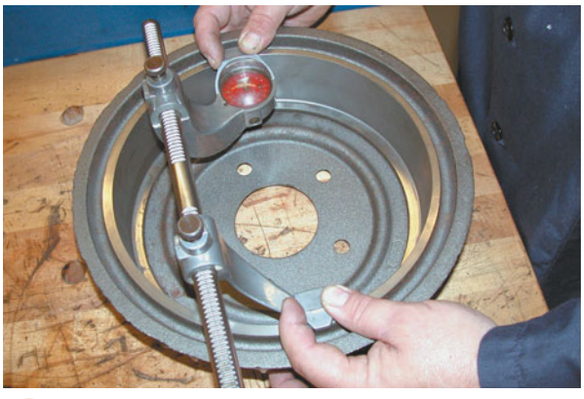
DRUM MACHINING



1 Before starting to machine a brake drum, check the drum for any obvious damage such as heat cracks or hard spots.



2 Lightly tap the drum. It should ring like a bell. If a dull thud is heard, the drum may be cracked and should be discarded.



3 Use a drum micrometer to measure the inside diameter of the drum and compare this measurement to specifications to be sure that the drum can be safely machined.



4 Most brake drums have the maximum inside diameter cast into the drum as shown. Allow 0.030 inch for wear after the machining has been performed.



5 Thoroughly clean the outside and inside of the drum.



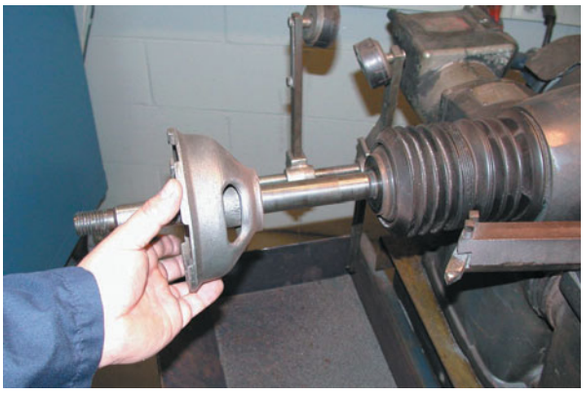
6 Be sure the center hole in the drum is clean and free from any burrs that could prevent the drum from being properly centered on the shaft of the brake lathe.



7 A typical brake lathe used to machine drums.



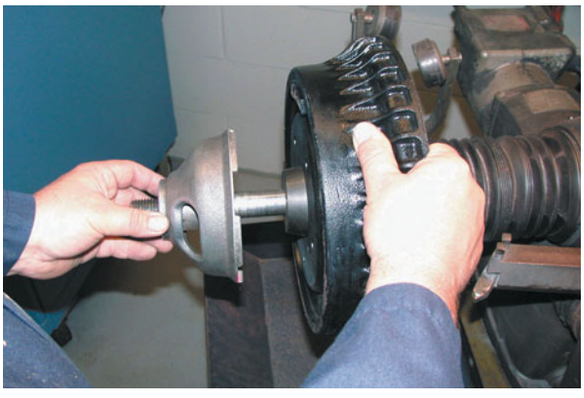
8 Locate a tapered, centering cone that best fits inside the hole of the brake drum.



9 Slide the large face plate over the shaft of the brake lathe.



10 Slide the tapered centering cone onto the shaft with the spring between the face plate and the centering cone.

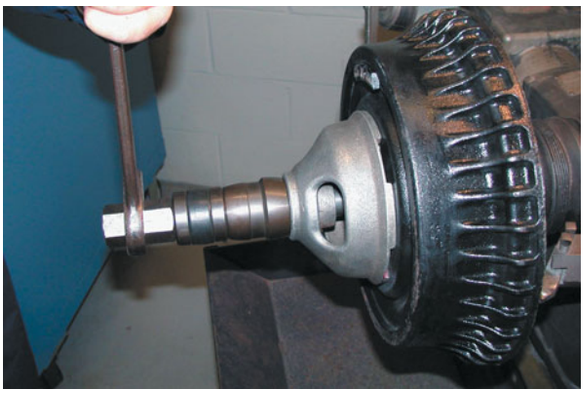


11 Slide the other face plate onto the shaft.



12 Install a bearing collet used as a spacer, then the self-aligning spacer (SAS) and left-hand-thread spindle nut.

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13 Tighten the spindle nut.



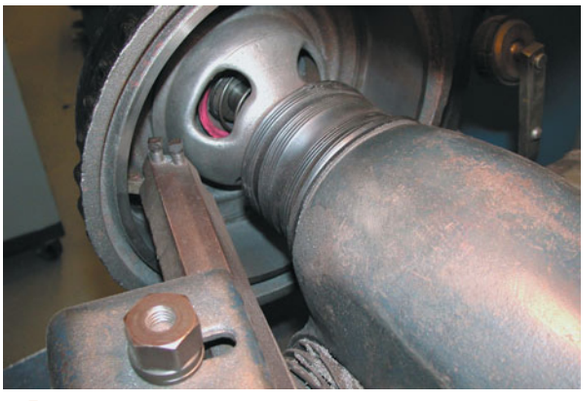
14 Loosen the turning bar retainer.



15 Carefully check the cutting bits and either rotate the bit to a new cutting point or replace it with a new part as necessary.



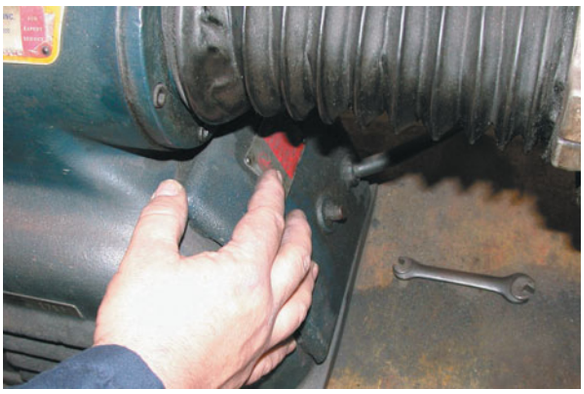
16 Turn the spindle control knob until the spindle is as short as possible (i.e., the drum as close to the machine as possible) to help reduce vibration as much as possible.



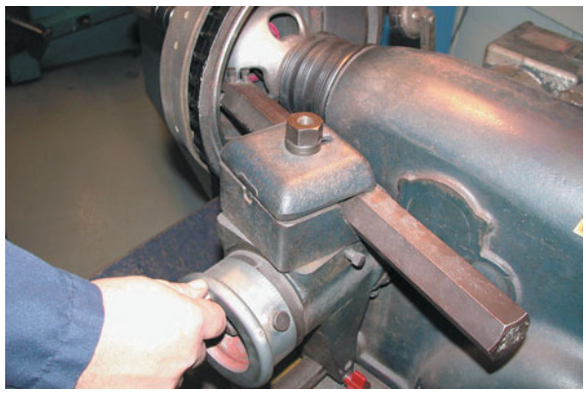
17 Position the cutting bar so that the cutting bit is located at the back surface of the drum.



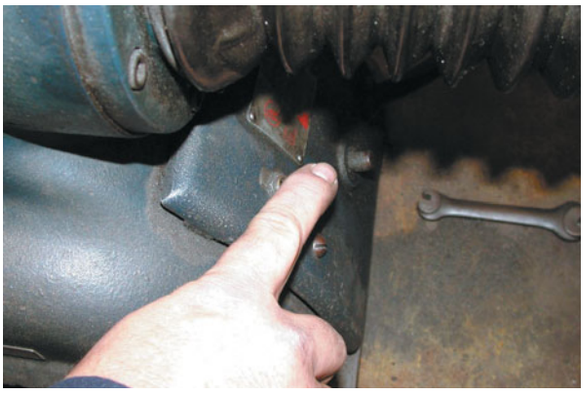
18 Install the silencer band (vibration dampener strap).



19 Be sure the tool bit and clothing are away from the drum and turn the brake lathe on.



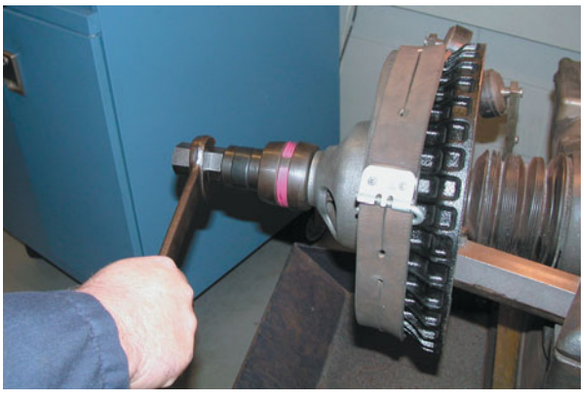
20 Center the bit in the center of the brake surface of the drum and rotate the control knob that moves the bit into contact with the drum friction surface. This should produce a light scratch cut.



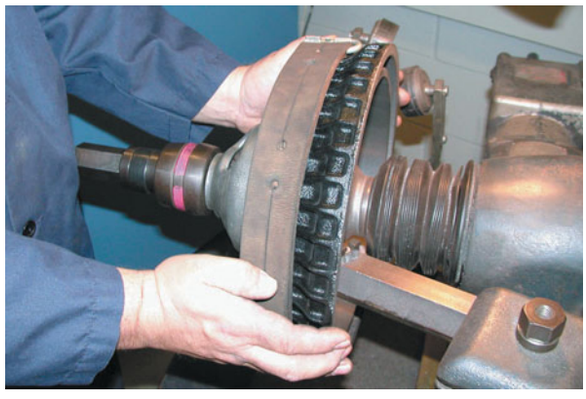
21 Turn the lathe off.



22 Observe the scratch cut.

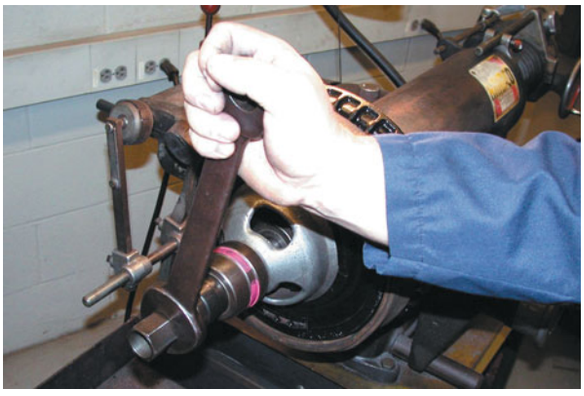


23 Loosen the spindle nut.

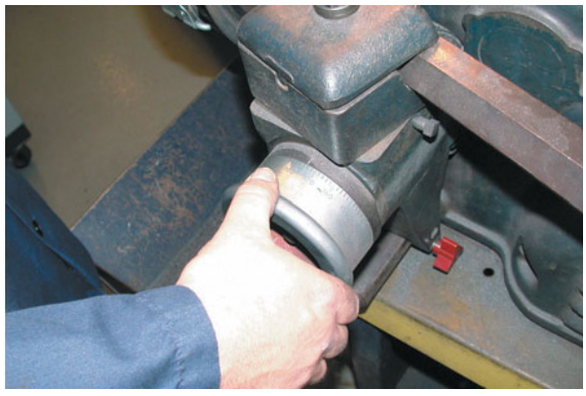


24 Rotate the drum 180° (one-half turn) on the spindle.

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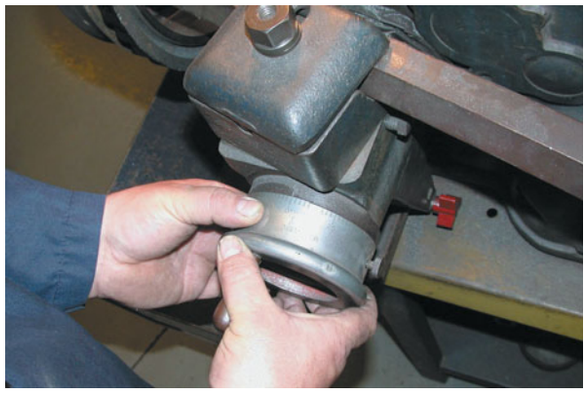
25 Tighten the spindle nut.



26 Turn the lathe on, rotate the control knob, and run the cutter into the drum for another scratch cut.



27 Observe the scratch cut. If the second scratch cut is in the same place as the first scratch cut or extends all the way around the drum, the drum is correctly mounted on the lathe.



28 Adjust the depth gauge to zero when the cutter just touches the drum.



29 Run the cutter all the way to the back surface of the drum.



30 Adjust the depth of the cut and lock it in position by turning the lock knob. Most vehicle manufacturers recommend a rough cut depth should be 0.005–0.010 in. and a finish cut of 0.002 in.



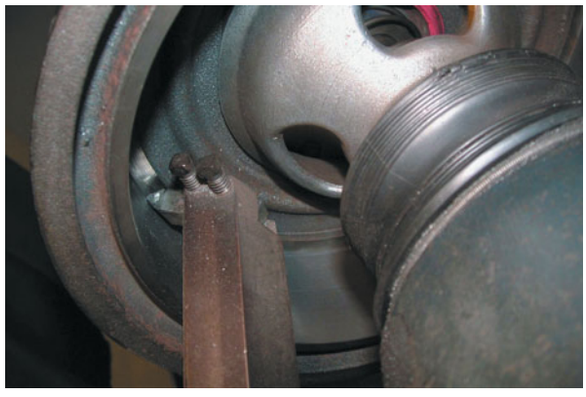
31 Select a fast-feed rate if performing a rough cut (0.006–0.016 in. per revolution) or 0.002 in. per revolution for a finish cut.



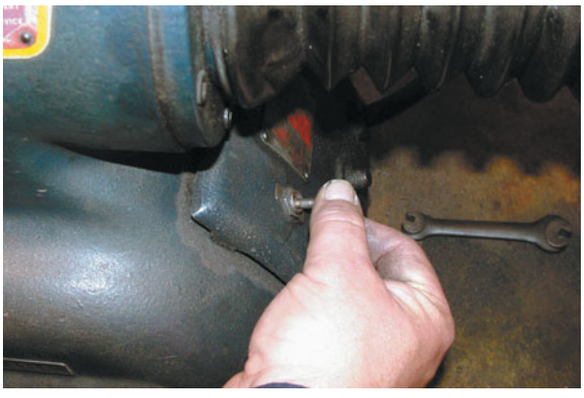
32 Turn the lock knob to keep the feed adjustment from changing.



33 Engage the automatic feed.



34 The drum will automatically move as the tool remains stationary to make the cut.



35 Turn the lathe off.

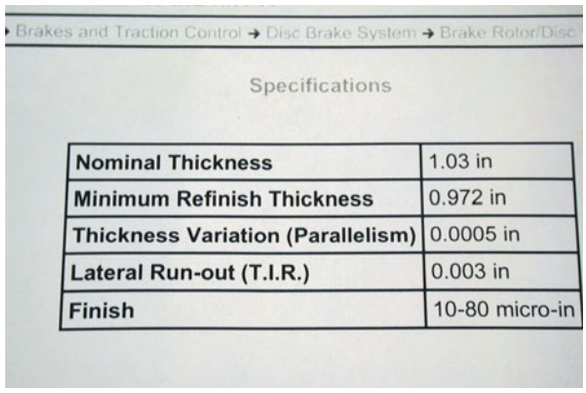


36 If additional material must be removed, proceed with the finish cut. Clean thoroughly before installing on a vehicle.

ROTOR MACHINING



1 Before machining any rotor, use a micrometer and measure the thickness of the rotor.



2 Check the specifications for the minimum allowable thickness.



3 Visually check the rotor for evidence of heat cracks or hard spots that would require replacement (rather than machining) of the rotor.



4 After removing the grease seal and bearings, remove the grease from the bearing races.



5 Clean and inspect the brake lathe spindle for damage or burrs that could affect its accuracy.



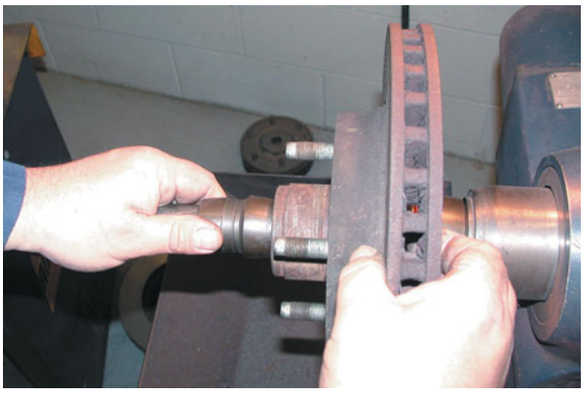
6 Select a tapered cone adapter that fits the inner bearing race.



7 Slide the cone adapter onto the brake lathe spindle.



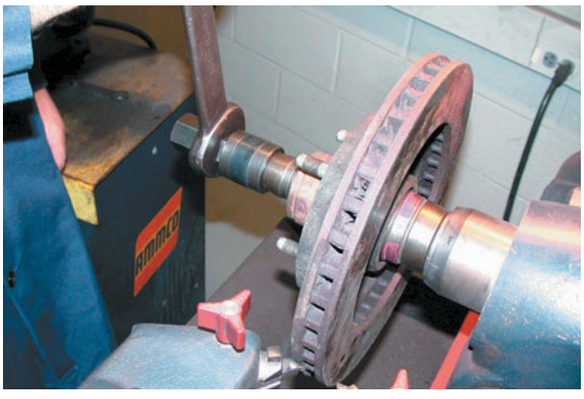
8 Select the proper size cone adapter for the smaller outer wheel bearing race.



9 Place the rotor onto the large cone adapter and then slide the small cone adapter into the outer wheel bearing race.



10 Install the self-aligning spacer (SAS) and spindle nut.



11 Tighten the spindle nut (usually left-hand threads).

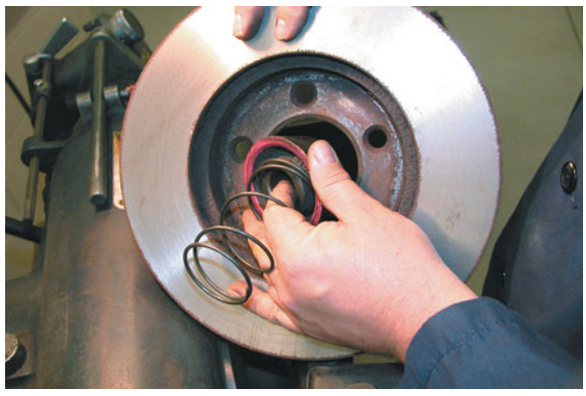


12 If a hubless rotor is being machined, be sure to thoroughly clean the inside surface.

CONTINUED ▶



13 Also remove all rust from the other side of the hubless rotor.



14 Select the proper centering cone for the hole in the center of the hub.



15 Select the proper size cone-shaped hubless adapter and the tapered centering cone with a spring in between.



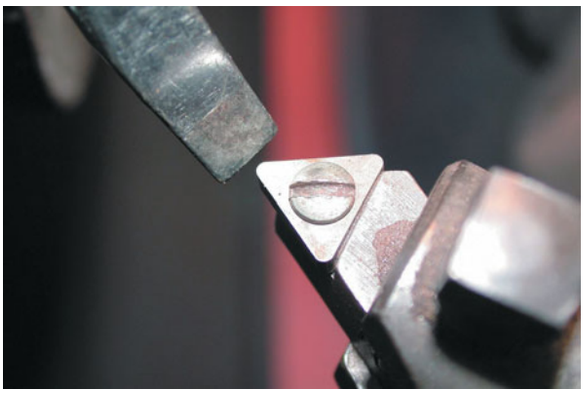
16 After sliding the rotor over the centering cone, install the matching hubless adapter.



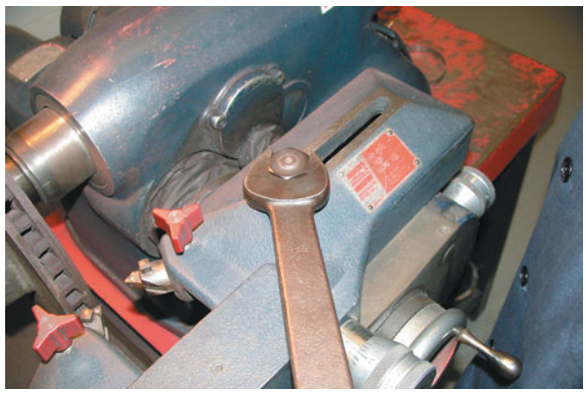
17 Install the self-aligning spacer (SAS) and spindle nut.



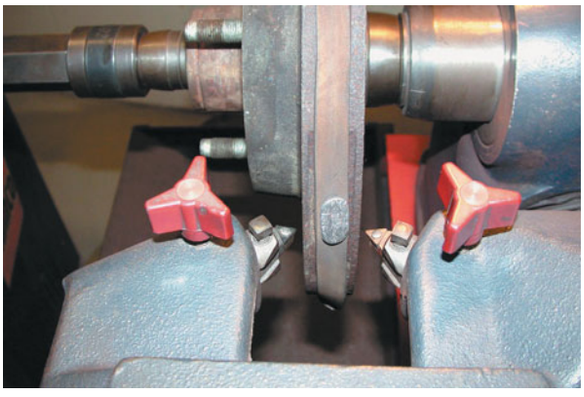
18 After the rotor has been secured to the brake lathe spindle, install the noise silencer band (dampener).



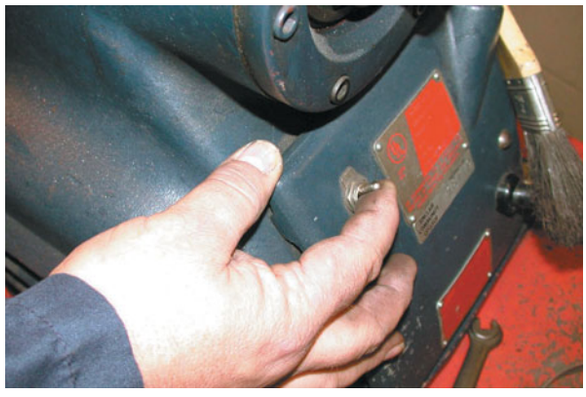
19 Carefully inspect the cutting bits and replace, if necessary.



20 Loosen the tool holder arm.



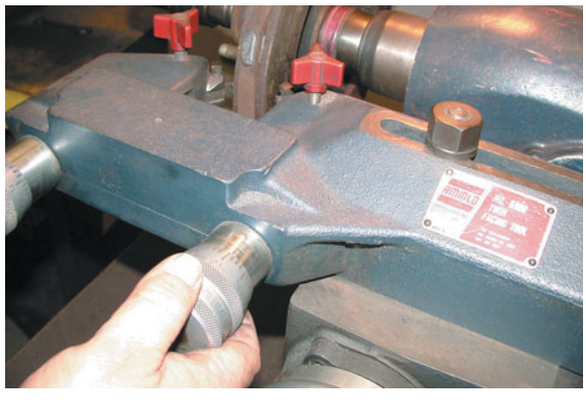
21 Adjust the twin cutter arm until the rotor is centered between the two cutting bits.



22 Turn the lathe on.



23 Move the cutter arm toward the center of the rotor, placing the cutting bits in about the center of the friction surface.



24 Turn one cutting bit into the surface of the rotor to make a scratch cut. This step checks the lathe setup for accuracy.

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25 Turn the lathe off.



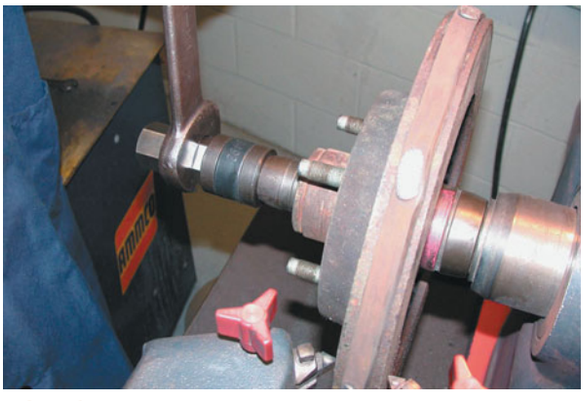
26 Observe the first scratch cut.



27 Loosen the spindle retaining nut.



28 Rotate the rotor 180° (one-half turn) on the spindle of the brake lathe.



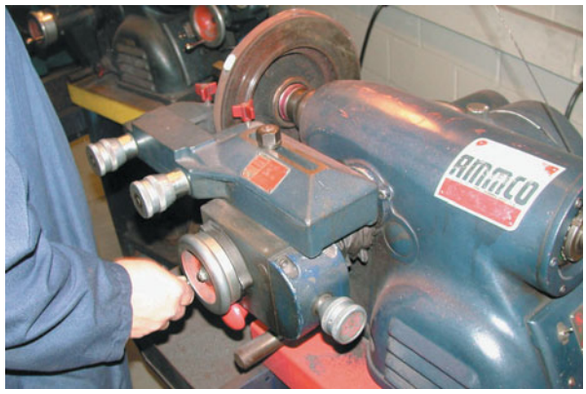
29 Tighten the spindle nut.



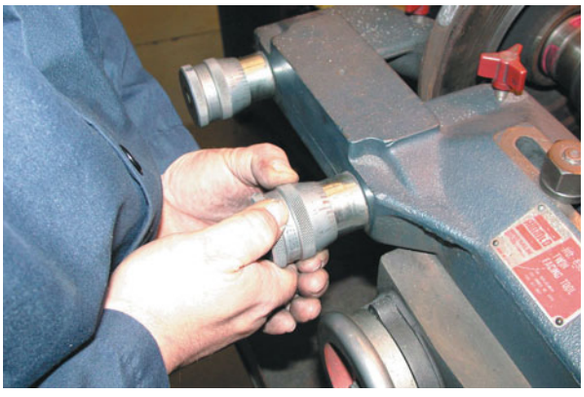
30 Turn the lathe back on and turn the cutting bit slightly into the rotor until a second scratch cut is made.



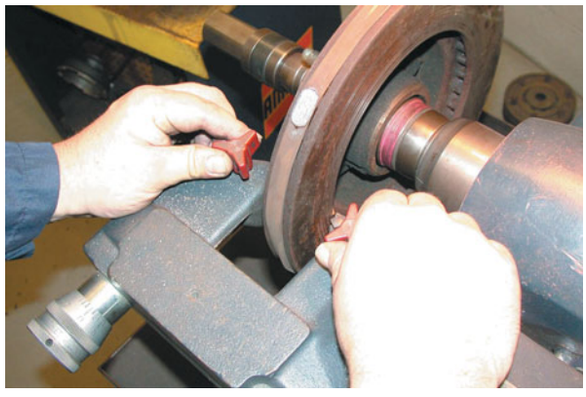
31 If the second scratch cut is in the same location as the first scratch cut or extends all around the surface of the rotor, then the rotor is properly installed on the lathe.



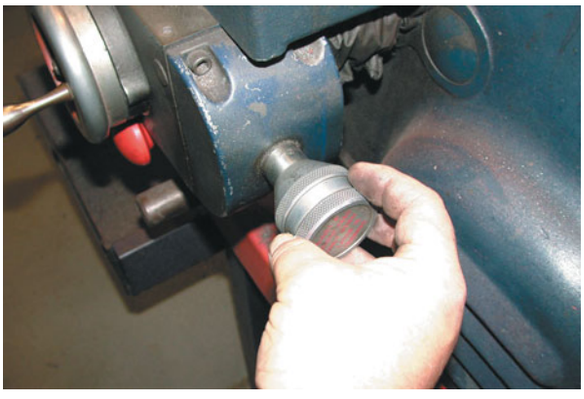
32 Start the machining process by moving the twin cutters to about the center of the rotor friction surface.



33 Turn the cutting bits inward until they touch the rotor and zero the depth adjustment.



34 Adjust the twin cutters, then dial in the amount of depth (0.005–0.010 in. per side for a rough cut or 0.002 in. for a finish cut) and lock the adjustment so that vibration will not change the setting.

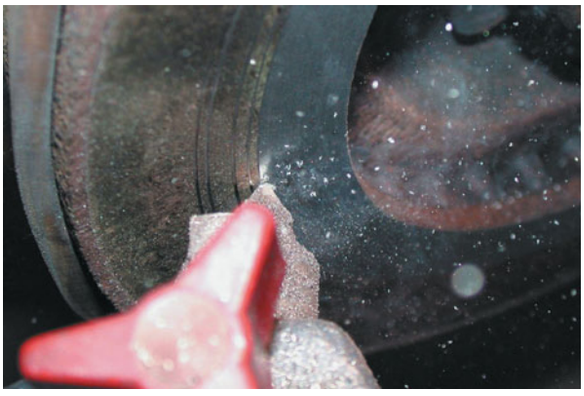


35 Turn the feed control knob until the desired feed rate is achieved for the first or rough cut (0.006–0.010 in. per revolution) or finish cut (0.002 in. per revolution).



36 Engage the automatic feed.

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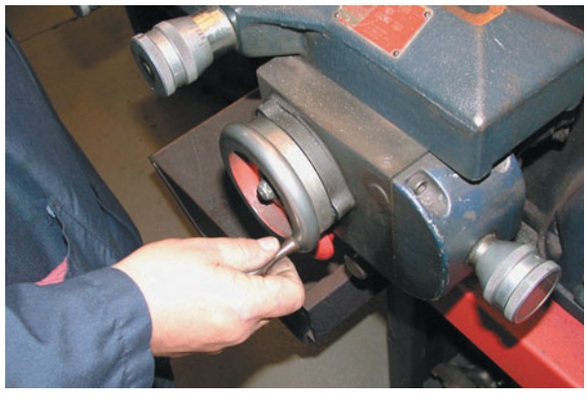
37 Observe the machining operation.



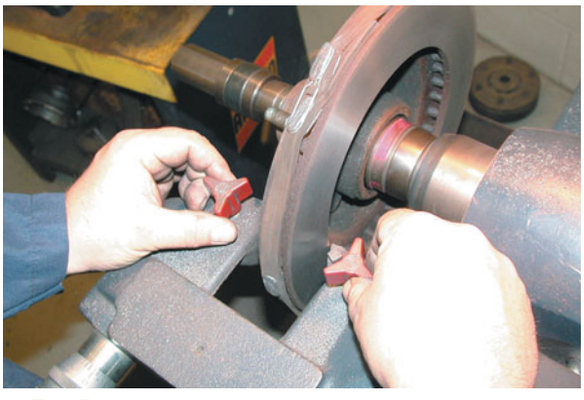
38 After the cutting bits have cleared the edge of the rotor, turn the lathe off and measure the thickness of the rotor.



39 Readjust the feed control to a slow rate (0.002 in. per revolution or less) for the finish cut.



40 Reposition the cutting bits for the finish cut.



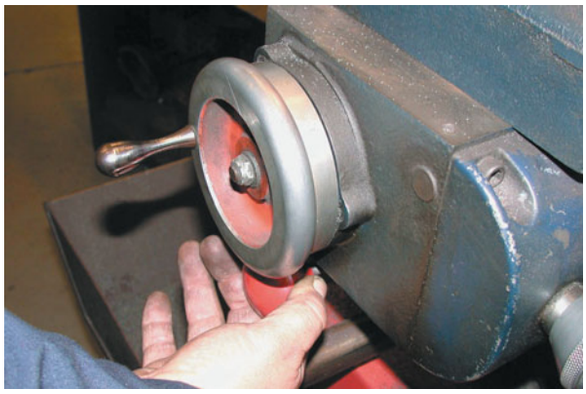
41 Loosen the adjustment locks.



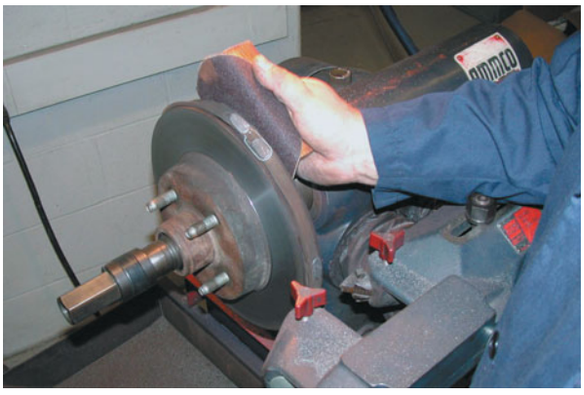
42 Turn the depth of the cut for the finish cut (0.002 in. maximum).



43 Lock the adjustment.



44 Engage the automatic feed.



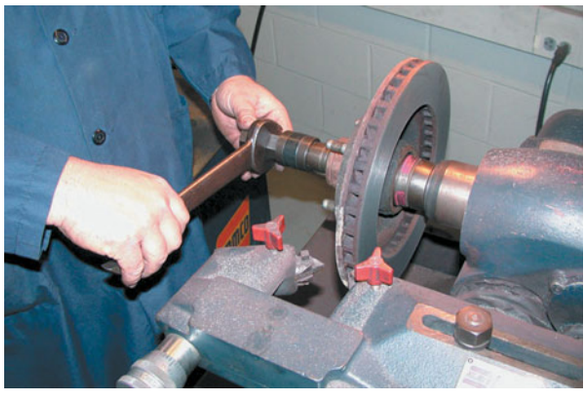
45 Use 150-grit aluminum-oxide sandpaper on a block of wood for 60 seconds per side or a grinder to give a nondirectional and smooth surface to both sides of the rotor.



46 After the sanding or grinding operation, thoroughly clean the machined surface of the rotor to remove any and all particles of grit that could affect the operation and life of the disc brake pads.



47 Remove the silencer band.



48 Loosen the spindle retaining nut and remove the rotor.

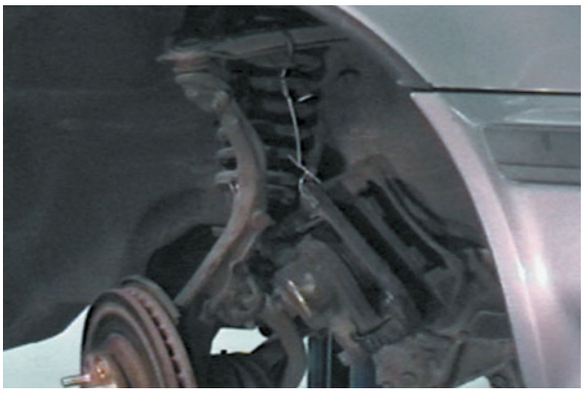
ON-THE-VEHICLE LATHE



1 Prepare to machine a disc brake rotor using an on-the-vehicle lathe by properly positioning the vehicle in the stall and hoisting the vehicle to a good working height.



2 Mark the lug nut closest to the valve stem so that the wheel can be reinstalled in the same location. Remove the wheels and place them out of the way.



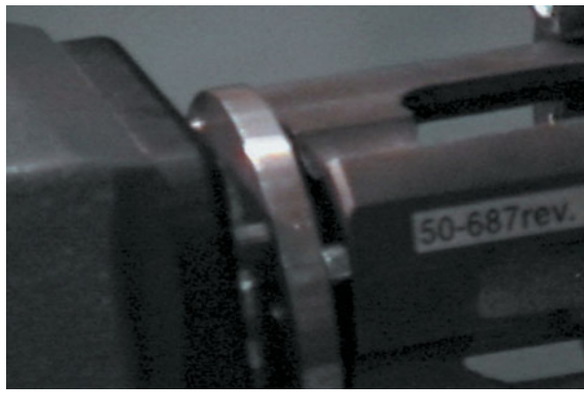
3 Remove the disc brake caliper on caliper mount type lathes and use a wire to support the caliper out of the way of the rotor.



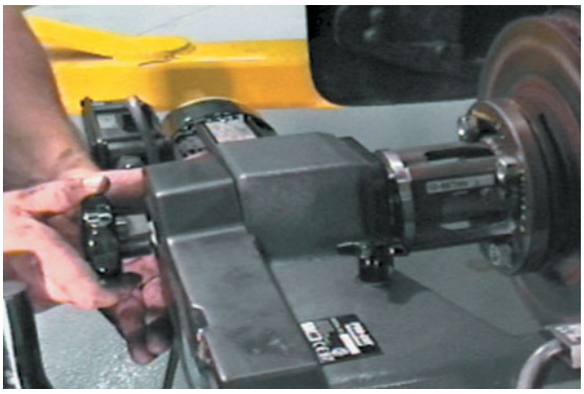
4 Measure the rotor thickness and compare it with factory specifications before machining. If a discard thickness is specified, be sure to allow an additional 0.015 in. for wear.



5 Install the hub adapter onto the hub and secure it using the wheel lug nuts. Never use an impact wrench to install the lug nuts.



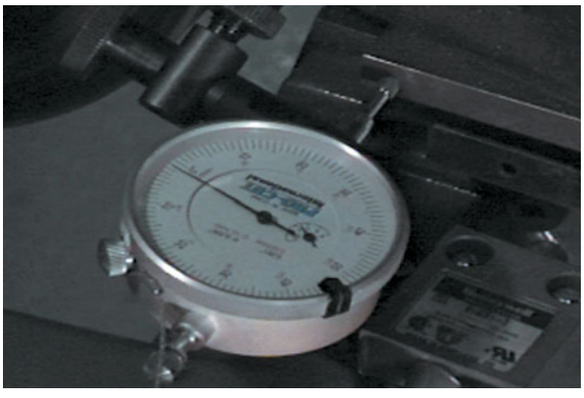
6 Engage the drive unit by aligning the hole in the drive plate with the raised button on the adapter.



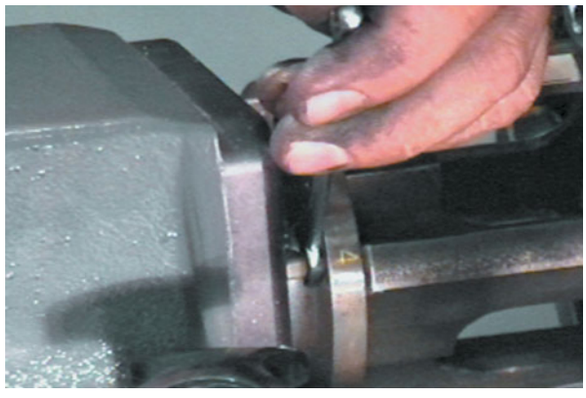
7 Use the thumb wheel to tighten the drive unit to the adapter.



8 Attach a dial indicator to a secure part on the vehicle and position the dial indicator on a flat portion of the lathe to measure the lathe runout.



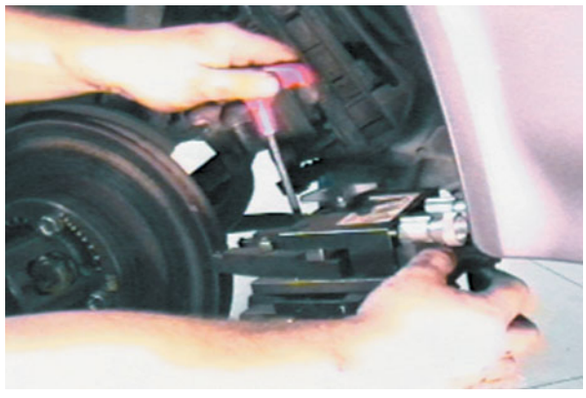
9 Rotate the wheel or turn the lathe motor on and measure the amount of runout. Newer models are self-adjusting.



10 Use a wrench to adjust the runout using the four numbers stamped on the edge of the drive flange as a guide.

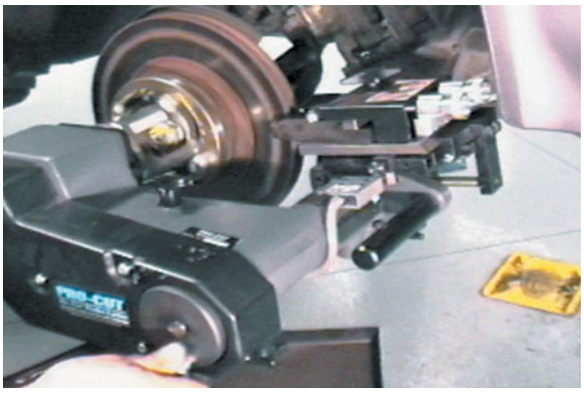


11 After the hub runout is adjusted to 0.005 in. or less, remove the dial indicator from the vehicle.

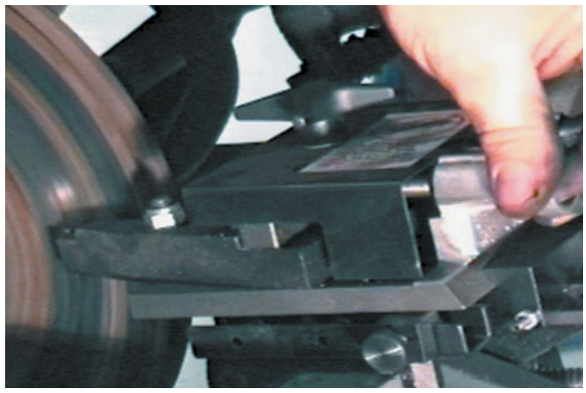


12 Using a T-handle Allen wrench, adjust the cutter arms until they are centered on the disc brake rotor.

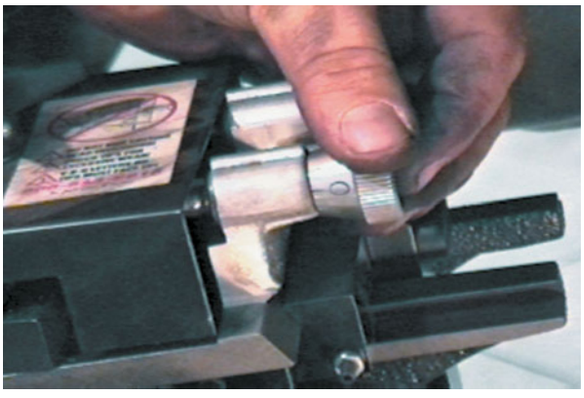
CONTINUED ▶



13 Move the cutters to the center of the rotor.



14 Adjust the cutter depth until each cutter barely touches the rotor.



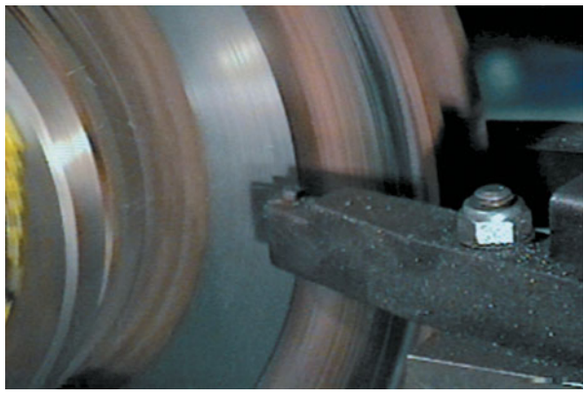
15 Position the cutters to the inside edge of the rotor surface and adjust the cutters to the desired depth of cut.



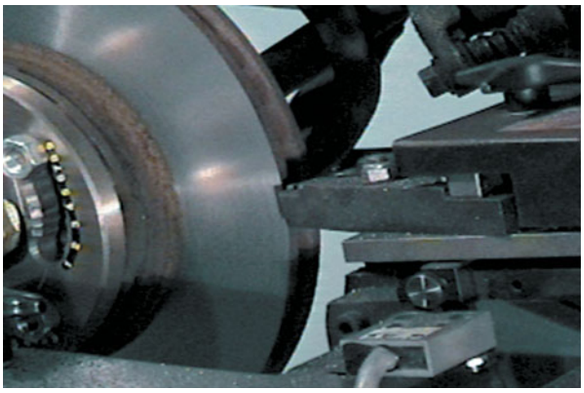
16 Adjust the automatic shut-off so the lathe will turn itself off at the end of the cut.



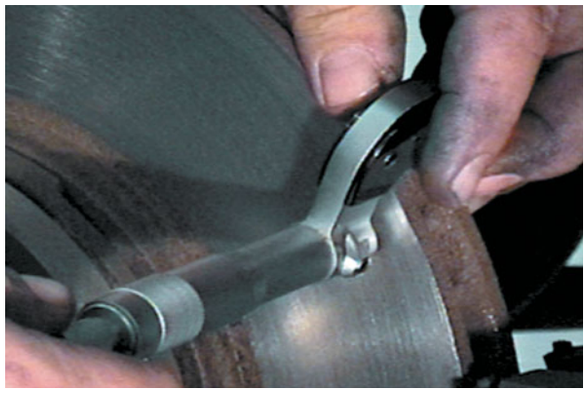
17 Turn the lathe on by depressing the start button.



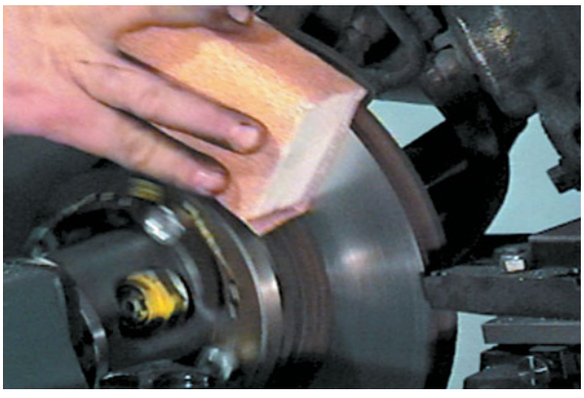
18 Monitor the machining operations as the lathe automatically moves the cutters from the center toward the outside edge of the rotor.



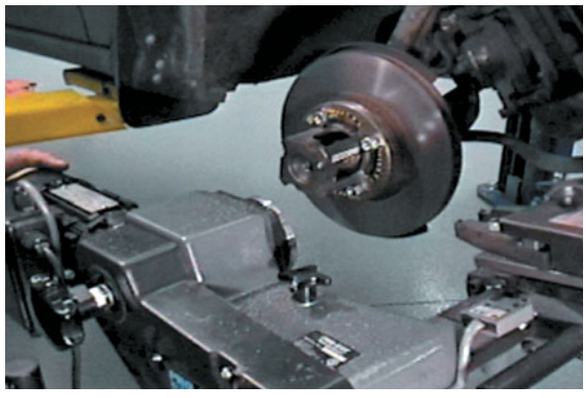
19 After the lathe reaches the outside edge of the rotor, the drive motor should stop.



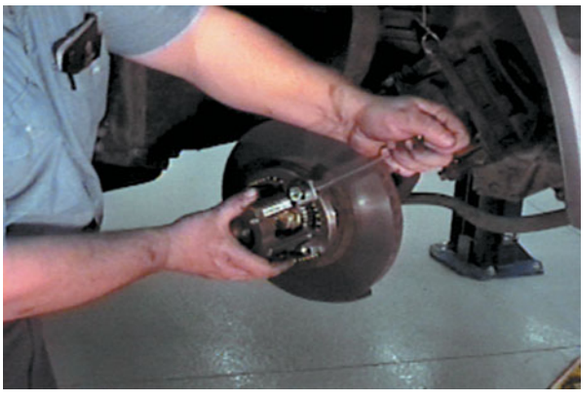
20 Measure the thickness of the rotor after machining to be certain that the rotor thickness is within service limits.



21 The technician is using 150-grit aluminum-oxide sandpaper and a wood block for 60 seconds on each side of the rotor to provide a smooth surface finish.



22 After completing the machining and resurfacing of the rotor unclamp the drive unit from the hub adapter and clean the rotor.



23 After the drive unit has been removed, remove the lug nuts holding the adapter to the rotor hub.



24 After removing the hub adapter, the caliper with new brake pads and hardware can be reinstalled.

CONTINUED ▶



25 Be sure to torque the caliper retaining bolts to factory specifications.



26 Install the wheel and wheel cover. On this vehicle, the wheel cover must be installed before the lug nuts because the lug nuts hold the wheel cover on the wheel.



27 Always use a torque wrench or a torque-limiting adapter with an air impact wrench as shown here when tightening lug nuts.



28 Be sure to clean the wheel covers of any grease or fingerprints before returning the vehicle to the customer.



29 Pump the brake pedal several times to restore proper brake pedal height. Check and add brake fluid as necessary before moving the vehicle.



30 Carefully back out of the stall and test-drive the vehicle to be assured of proper brake operation before returning the vehicle to the customer.

REVIEW QUESTIONS

1. Explain the difference between "machine to" specifications and "discard."
2. List the steps for machining a brake drum.
3. Describe how to measure a disc brake rotor for lateral runout and thickness variation.
4. List the steps for machining a disc brake rotor.
5. Describe what is necessary to achieve "like-new" disc brake rotor finish.

CHAPTER QUIZ

1. Technician A says that aluminum brake drums use cast iron friction surfaces. Technician B says that up to 0.030 in. (0.8 mm) should be left after machining a drum to allow for wear. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
2. Technician A says that hard spots in a brake drum should be removed using a carbide-tip machining tool. Technician B says that the drum should be replaced if hard spots are discovered. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
3. Technician A says that brake drums on the same axle should be close to the same inside diameter for best brake balance. Technician B says that a brake drum may be cracked if it rings like a bell when tapped with a light steel hammer. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
4. A hubless brake drum cannot be machined because it cannot be held in a lathe.
   a. True **b.** False
5. The major reason for brake pedal pulsation during braking is due to excessive rotor thickness variation.
   a. True **b.** False
6. Rotor finish is measured in _____.
   a. Millimeters **c.** Microinches
   b. Inches **d.** Centimeters
7. The lower the Ra of a rotor, the _____ the surface.
   a. Smoother **c.** Higher
   b. Rougher **d.** Lower
8. A disc brake rotor is being installed on a lathe for machining. During the setup a scratch test is performed. The scratch extended all the way around the rotor. Technician A says that the rotor should be loosened, rotated 180°, and retightened. Technician B says that the rotor is not warped. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
9. Typical maximum rotor runout specifications are _____.
   a. 0.0003 to 0.0005 in. (0.008 to 0.013 mm)
   b. 0.003 to 0.005 in. (0.08 to 0.13 mm)
   c. 0.030 to 0.050 in. (0.8 to 1.3 mm)
   d. 0.300 to 0.500 in. (8.0 to 13 mm)
10. Typical maximum rotor thickness variation (parallelism) specifications are _____.
    a. 0.0003 to 0.0005 in. (0.008 to 0.013 mm)
    b. 0.003 to 0.005 in. (0.08 to 0.13 mm)
    c. 0.030 to 0.050 in (0.8 to 1.3 mm)
    d. 0.300 to 0.500 in. (8.0 to 13 mm)

chapter 105

POWER BRAKE UNIT OPERATION, DIAGNOSIS, AND SERVICE

OBJECTIVES: **After studying Chapter 105, the reader will be able to:** • Prepare for the Brakes (A5) ASE certification test content area "D" (Power Assist Units Diagnosis and Repair). • List the parts of a vacuum brake booster. • Describe how a vacuum brake booster operates. • Explain how to test a vacuum brake booster. • Describe how a hydraulic brake booster operates.

KEY TERMS: Atmospheric pressure 1196 • Brake assist system (BAS) 1201 • Dual-diaphragm vacuum booster 1201 • in. Hg (inches of mercury) 1196 • mm Hg (millimeters of mercury) 1196 • Power chamber 1197 • Pressure differential 1196 • Supplemental brake assist (SBA) 1203 • Tandem-diaphragm vacuum booster 1201 • Vacuum 1196

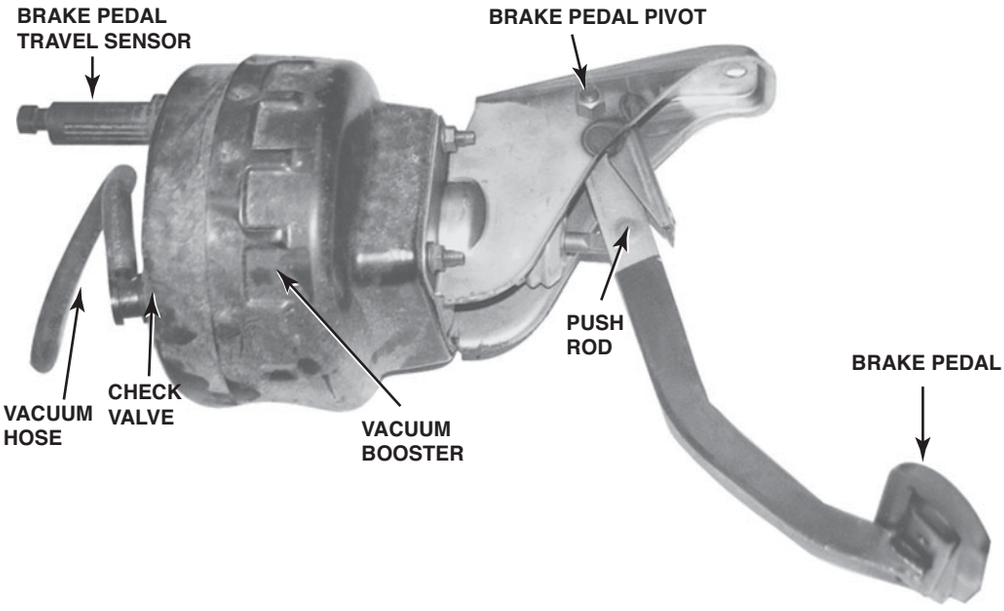


FIGURE 105–1 Typical vacuum brake booster assembly. The vacuum hose attaches to the intake manifold of the engine. The brake pedal travel sensor is an input sensor for the antilock braking system.

THE NEED FOR POWER BRAKE ASSIST

To double the stopping power of a disc brake, the driver must double the force on the brake pedal. This is the reason that most vehicles equipped with disc brakes are power assisted, even on small, lightweight vehicles. The use of semimetallic brake pads also requires greater force. The most commonly used power-assisted units are vacuum operated.

On vehicles equipped with a power brake booster, the brake pedal ratio is decreased and the master cylinder bore size is increased. The combined effect of these changes is to reduce pedal effort, while greatly increasing pedal reserve. ● **SEE FIGURE 105–1.**

Power boosters do not alter the hydraulic system and they still allow braking even if the booster fails or its power supply is cut off. All boosters have a power reserve that provides assist for at least one hard stop, and sometimes several light brake applications, even after power is lost. However, because power brake systems are designed with the added force of the booster taken into account, the amount of brake pedal pressure required to slow or stop a vehicle is much higher than in a nonboosted system once the reserve is used up. For this reason, some vehicles with power brakes have a brake pedal that is wide enough to allow two-foot braking should the booster fail. ● **SEE FIGURE 105–2.**

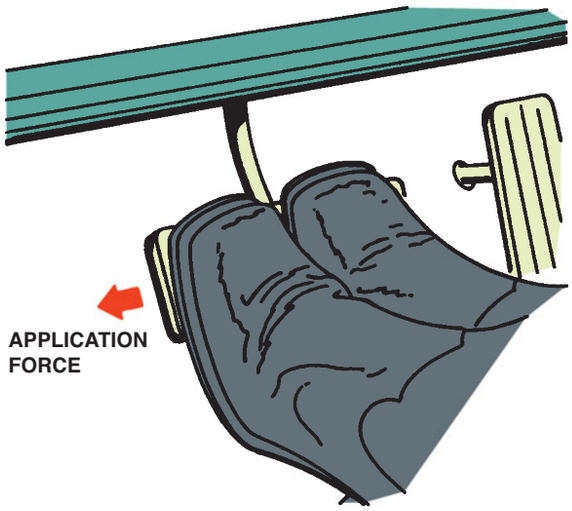


FIGURE 105–2 A wide brake pedal allows two-foot braking if power assist is lost.

PRINCIPLES OF VACUUM

Most vacuum-powered brake boosters get their vacuum supply from the engine intake manifold. An engine is essentially a big air pump because the pistons move up and down in the cylinders to pump in air and fuel, and pump out exhaust. They do this by creating differences in air pressure.

As a piston moves downward on an intake stroke with the intake valve open, it creates a larger area inside the cylinder for air to fill. This lowers the air pressure within the cylinder, and the higher-pressure air outside the engine flows in through the intake manifold in an attempt to fill the low-pressure area. Although it may seem as though the low pressure is pulling air into the engine, it is really the higher pressure outside that forces air in. The difference in pressure between two areas is called a **pressure differential.**

Because throttle valves and manifold shape restrict intake airflow, high-pressure air from outside the engine is almost never able to move into the cylinders fast enough to fill the space created. As a result, gasoline-powered internal-combustion engines normally operate with a low-pressure area, or partial vacuum, in the intake manifold. The term **vacuum** is used to refer to any pressure lower than **atmospheric pressure.** Atmospheric pressure varies with altitude, but is approximately 14.7 pounds per square inch (PSI) at sea level. ● **SEE FIGURE 105–3.**

MEASURING VACUUM Vacuum is measured in **inches of mercury (in. Hg)** or in **millimeters of mercury (mm Hg),** a figure that indicates how far a column of mercury in a tube will rise when

a vacuum is applied at one end, and atmospheric pressure at the other. Vacuum is a measurement of the pressure differential between the lower pressure inside the tube, and the higher pressure outside it.

A perfect vacuum is about 30 in. Hg (762 mm Hg). However, a perfect vacuum occurs only in space, and is never achieved in an engine's intake manifold. Manifold vacuum varies with throttle position. The lowest manifold vacuum (highest pressure) occurs when the throttle is wide open with the engine under load. The highest manifold vacuum (lowest pressure) may be as much as 24 in. Hg (610 mm Hg) when the vehicle is rolling rapidly downhill in gear with the throttle closed. Manifold vacuum at idle typically falls between 15 and 20 in. Hg (381 and 508 mm Hg), and most vacuum brake boosters are designed to operate with vacuum levels in this range.

BOOSTER VACUUM SUPPLY Vacuum boosters get their vacuum supply from the engine intake manifold. Diesel engines, however, run unthrottled (engine speed is controlled strictly by the amount of fuel injected) and have little or no intake manifold vacuum. If a vehicle with a diesel engine is equipped with a vacuum-powered brake booster, it must also be fitted with an auxiliary vacuum pump.

Some small gasoline-powered and diesel engines use a belt-driven add-on pump. ● **SEE FIGURE 105–4.**

Some vehicles use an electric vacuum pump. An electrically powered vacuum pump is turned on and off by a pressure switch on the booster. This means they operate only when needed, and thus reduce power drain on the engine. ● **SEE FIGURE 105–5.**

VACUUM BOOSTER THEORY

Vacuum boosters use the principle of pressure differential to increase brake application force. The typical vacuum booster has a **power chamber** separated into two smaller chambers by a flexible

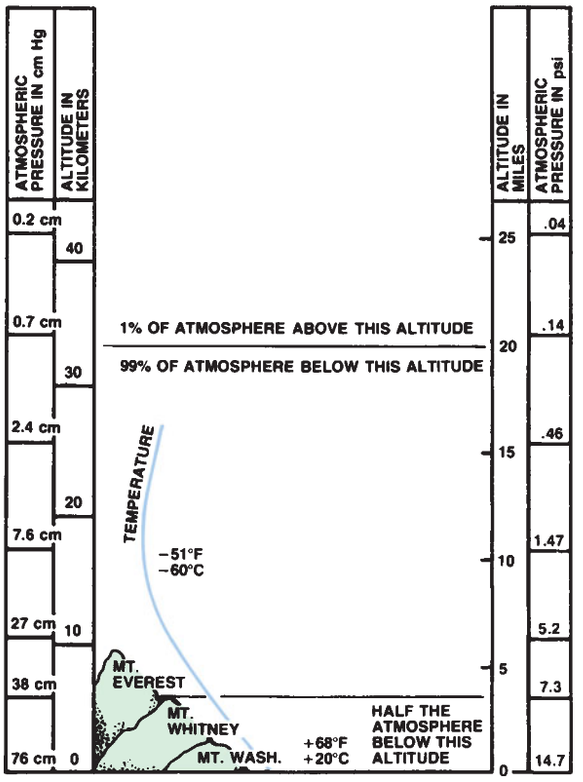


FIGURE 105–3 Atmospheric pressure varies with altitude.

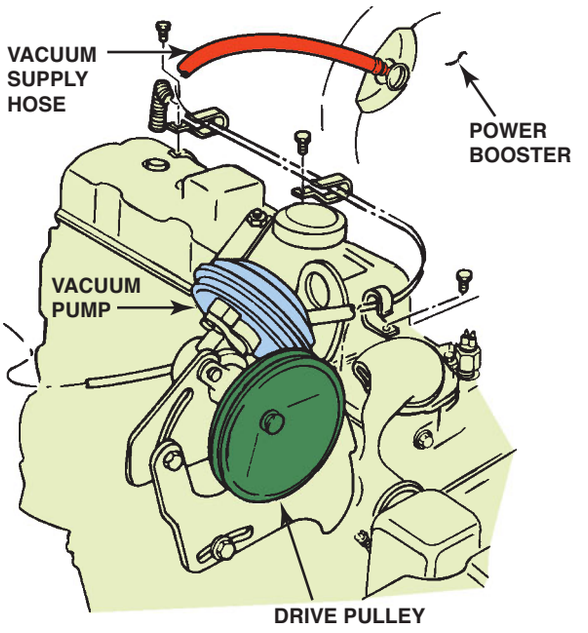


FIGURE 105–4 A belt-driven auxiliary vacuum pump.

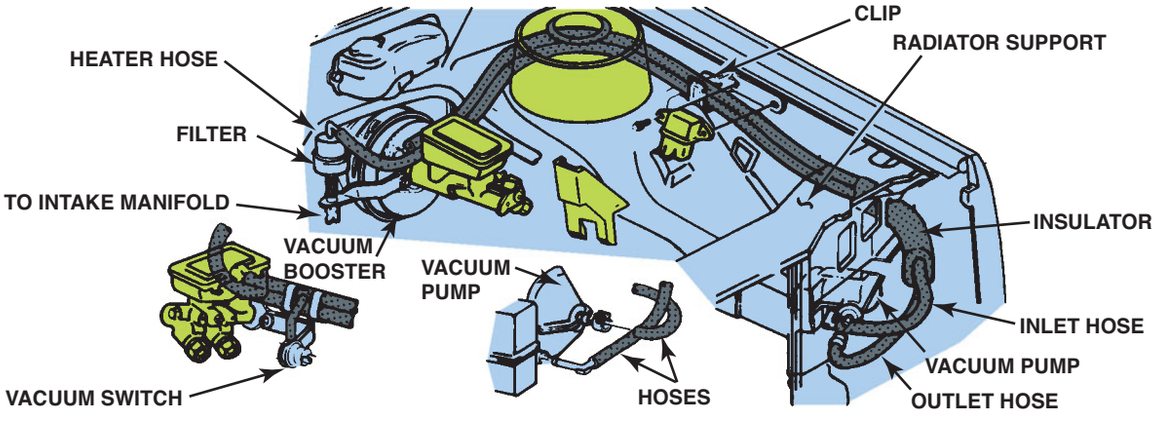


FIGURE 105–5 An electrically powered vacuum pump.

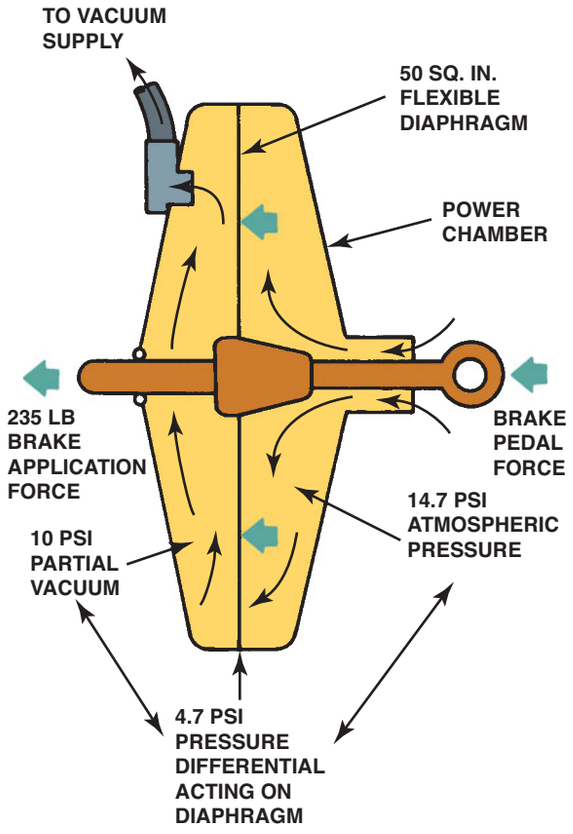


FIGURE 105–6 Vacuum brake boosters operate on the principle of pressure differential.

diaphragm. When air pressure is greater on one side of the diaphragm than the other, a pressure differential is created. In an attempt to equalize pressure in the two chambers, the higher pressure exerts a force that moves the diaphragm toward the lower-pressure area. Rods attached to the diaphragm transmit this force, plus the force the driver exerts on the brake pedal, to the master cylinder.

The amount of force created in this manner is proportional to the difference in pressure between the two sides. In other words, the greater the pressure differential, the greater the force. To calculate the force, the pressure differential is multiplied by the diaphragm surface area. For example, if a power booster diaphragm has atmospheric pressure (14.7 PSI) on one side, and a typical intake manifold vacuum of 20 in. Hg (10 PSI of absolute pressure), the pressure differential acting on the diaphragm would be as follows.

14.7 PSI − 10 PSI = 4.7 PSI

If we once again multiply this times the area of the diaphragm, the result is as follows.

4.7 PSI × 50 sq. in. = 235 pounds of force

Vacuum booster diaphragms are sized to fit specific applications and provide the necessary application force. Most vacuum boosters are capable of providing hundreds of pounds of application force. ● **SEE FIGURE 105–6.**

CHARCOAL FILTER

The vacuum hose leading from the engine to the power booster should run downward without any low places in the hose. If a dip or sag occurs in the vacuum hose, condensed fuel vapors and/or moisture can accumulate that can block or restrict the vacuum to the booster. Many manufacturers use a small charcoal filter in the vacuum line between the engine and booster, as shown in ● **FIGURE 105–7.**



FIGURE 105–7 The charcoal filter traps gasoline vapors that are present in the intake manifold and prevents them from getting into the vacuum chamber of the booster.

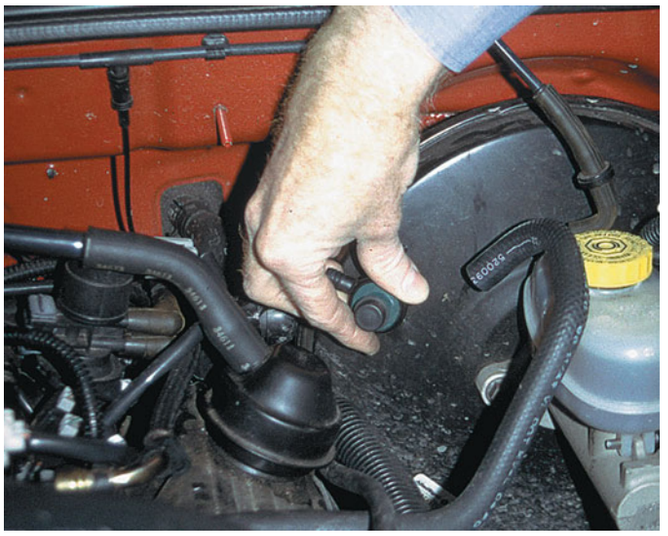
TECH TIP

Check the Vacuum, Then the Brakes

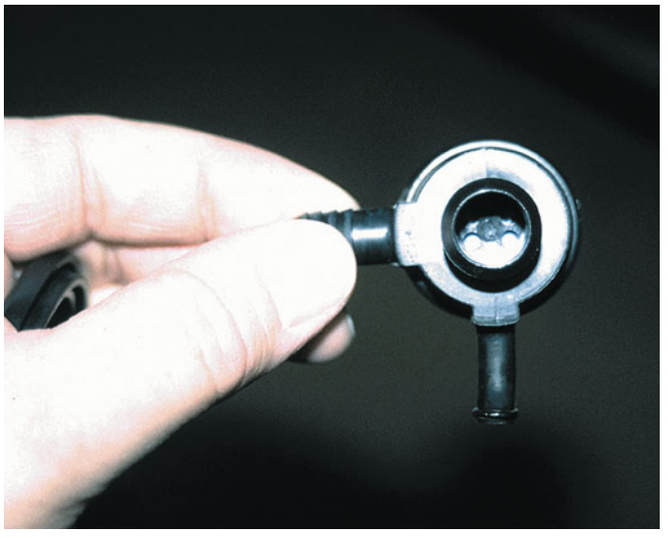
A customer complained of a very rough idle and an occasional pulsating brake pedal. The customer was certain that the engine required serious work since there were over 100,000 miles on the vehicle. During the troubleshooting procedure, a spray cleaner was used to find any vacuum (air) leaks. A large hole was found melted through a large vacuum hose next to the vacuum hose feeding the vacuum-operated power brake booster.

After repairing the vacuum leak, the vehicle was test driven again to help diagnose the cause of the pulsating brake pedal. The engine idled very smoothly after the vacuum leak was repaired and the brake pulsation was also cured. The vacuum leak resulted in lower-than-normal vacuum being applied to the vacuum booster. During braking, when engine vacuum is normally higher (deceleration), the vacuum booster would assist, then not assist when the vacuum was lost. This on-and-off supply of vacuum to the vacuum booster was noticed by the driver as a brake pulsation. Always check the vacuum at the booster whenever diagnosing any brake problems. Most vehicle manufacturers specify a minimum of 15 in. Hg of vacuum at the booster. The booster should be able to provide at least two or three stops even with no vacuum. The booster should also be checked to see if it can hold a vacuum after several hours. A good vacuum booster, for example, should be able to provide a power assist after sitting all night without starting the engine.

The charcoal filter attracts and holds gasoline vapors and keeps fumes from entering the vacuum booster. Without this filter, gasoline fumes can enter the vacuum booster, where they can deteriorate the rubber diaphragm and other rubber components of the booster.



(a)



(b)

FIGURE 105–8 (a) Many vacuum brake booster check valves are located where the vacuum hose from the engine (vacuum source) attaches to the vacuum booster. (b) This one-way valve prevents the loss of vacuum when the engine is off. The diaphragm inside allows air to flow in one direction only.

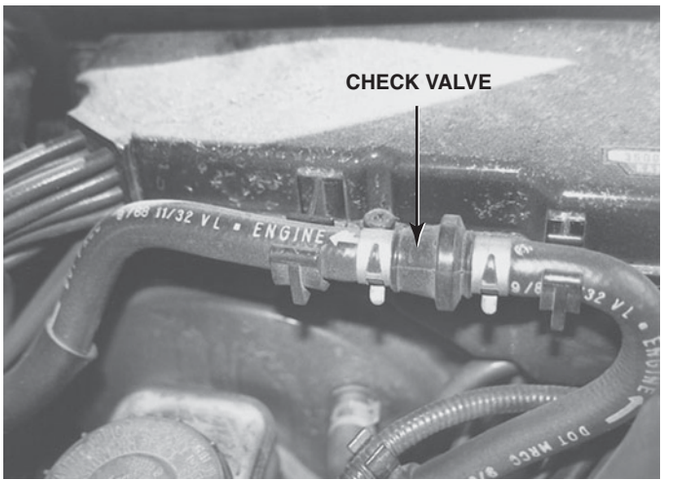


FIGURE 105–9 Not all check valves are located at the vacuum line to the booster housing connection. This vehicle uses an inline check valve located between the intake manifold of the engine and the vacuum brake booster.

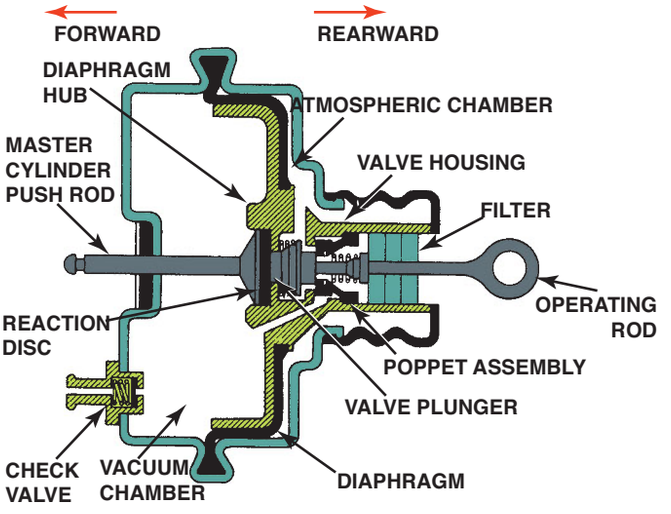


FIGURE 105–10 Cross-sectional view of a typical vacuum brake booster assembly.

VACUUM CHECK VALVE

All vacuum boosters use a one-way vacuum check valve. This valve allows air to flow in only one direction—from the booster toward the engine. This valve prevents loss of vacuum when the engine stops. Without this check valve, the vacuum stored in the vacuum booster would simply be lost through the hose and intake manifold of the engine. ● **SEE FIGURES 105–8 AND 105–9.**

CAUTION: Sometimes an engine backfire can destroy or blow the vacuum check valve out of the booster housing. If this occurs, all power assist will be lost and a much greater-than-normal force must be exerted on the brake pedal to stop the vehicle. Be sure to repair the cause of the backfire before replacing the damaged or missing check valve. Normal causes of backfire include an excessively lean air–fuel ratio or incorrect firing order or ignition timing.

VACUUM BRAKE BOOSTER OPERATION

A vacuum power-brake booster contains a rubber diaphragm(s) connected to the brake pedal at one end and to the master cylinder at the other end. When the brakes are off or released, there is equal vacuum on both sides of the diaphragm.

The vacuum power unit contains the power-piston assembly, which houses the control valve and reaction mechanism, and the power-piston return spring. The control valve is composed of the air valve (valve plunger), the floating control-valve assembly, and the pushrod. The reaction mechanism consists of a hydraulic piston reaction plate and a series of reaction levers. An air filter, air silencer, and filter retainer are assembled around the valve operating rod, filling the cavity inside the hub of the power piston. The pushrod that operates the air valve projects out of the end. ● **SEE FIGURE 105–10.**

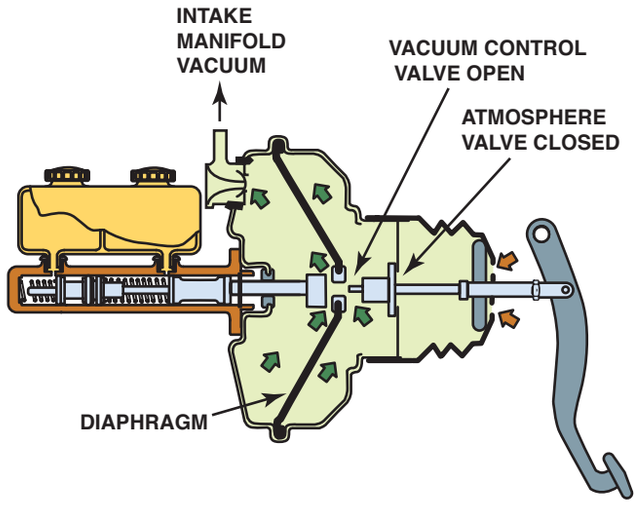


FIGURE 105–11 In the release position (brake pedal up), the vacuum is directed to both sides of the diaphragm.

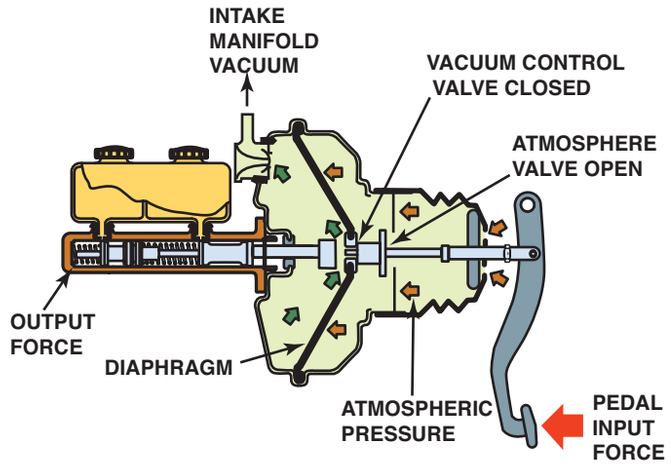


FIGURE 105–12 Simplified diagram of a vacuum brake booster in the apply position. Notice that the atmospheric valve is open and air pressure is being applied to the diaphragm.

RELEASED-POSITION OPERATION At the released position (brake pedal up), the air valve is seated on the floating control valve, which shuts off the air. The floating control valve is held away from the valve seat in the power-piston insert. Vacuum from the engine is present in the space on both sides of the power piston. Any air in the system is drawn through a small passage in the power piston, over the seat in the power-piston insert, and through a passage in the power-piston insert. There is a vacuum on both sides of the power piston, and it is held against the rear of the housing by the power-piston return spring. At rest, the hydraulic reaction plate is held against the reaction retainer. The air-valve spring holds the reaction lever against the hydraulic reaction plate and holds the air valve against its stop in the tube of the power piston. The floating control-valve assembly is held against the air-valve seat by the floating control-valve spring. ● **SEE FIGURE 105–11.**

APPLIED-POSITION OPERATION As the brake pedal is depressed, the floating control valve is moved toward its seat in the power piston, away from the rear of the booster. The smaller air valve spring causes the air valve to stretch out toward the retreating floating control valve until it bottoms out on the lip of the power piston's vacuum passage. This closes off the vacuum supply to the rear section of the housing. Since the floating control valve travels farther than the sealing end of the air valve, atmospheric air is allowed to enter between the air valve and the floating control valve pressurizing the rear section of the housing. At this point, the rear section of the housing is pressurized and the front section is under vacuum. Atmospheric pressure can then force the power piston forward.

NOTE: This movement of air into the rear chamber of the brake booster may be heard inside the vehicle as a hissing noise. The loudness of this airflow varies from vehicle to vehicle and should be considered normal.

As the power piston travels forward, the pushrod pushes against the hydraulic reaction plate in the master cylinder, pushing the master cylinder primary and secondary pistons forward. As back-pressure builds up on the end of the master cylinder piston, the floating control valve is pushed back off of its seat in the power piston, applying back-pressure to the brake pedal. The power piston return spring also generates some brake pedal force. All in all, approximately 30% of the brake load is applied back to the brake pedal. This gives the driver a feel that is proportional to the degree of brake application. ● **SEE FIGURE 105–12.**

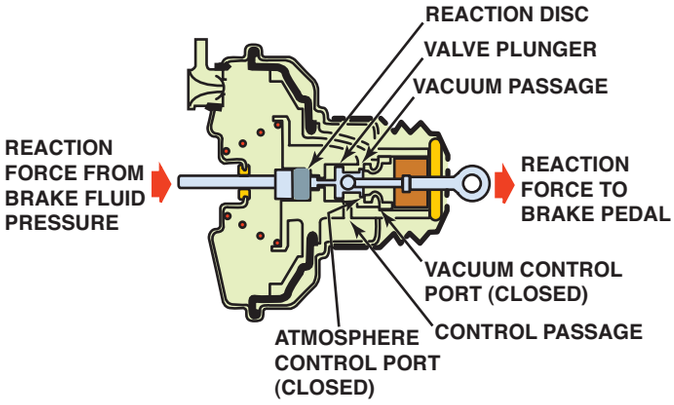


FIGURE 105–13 Cross section of a vacuum brake booster in the hold position with both vacuum and atmospheric valves closed. Note that the reaction force from the brake fluid pressure is transferred back to the driver as a reaction force to the brake pedal.

HOLD-POSITION OPERATION When the desired brake pedal force is reached and there is balance between the opposing forces of the brake pedal and the master cylinder, the power piston moves forward "around" the floating control valve and reaction disc until the air valve sealing end "catches up" with the floating control valve. At this point, the air valve is once again sealed against the floating control valve and is no longer blocking the vacuum passage in the power piston. The floating control valve is again held away from its seat. Vacuum once again is present on both sides of the diaphragm and power piston. The status of the booster is almost exactly as it was in the released state except that the positions of the power piston and subsequently the master cylinder pistons are farther forward. Brake pedal force is keeping the power piston in its position. If additional braking is required (brake pedal pushed farther), the floating control valve moves away from the air valve permitting the power of atmospheric pressure to push the power piston and master cylinder pistons forward. If the pedal is released, since vacuum is then present on both sides of the diaphragm, the power piston return spring moves the power piston to its released state. ● **SEE FIGURE 105–13.**

VACUUM-FAILURE MODE In case of vacuum source interruption, the brake operates as a standard brake as follows. As the pedal is pushed down, the operating rod forces the floating control

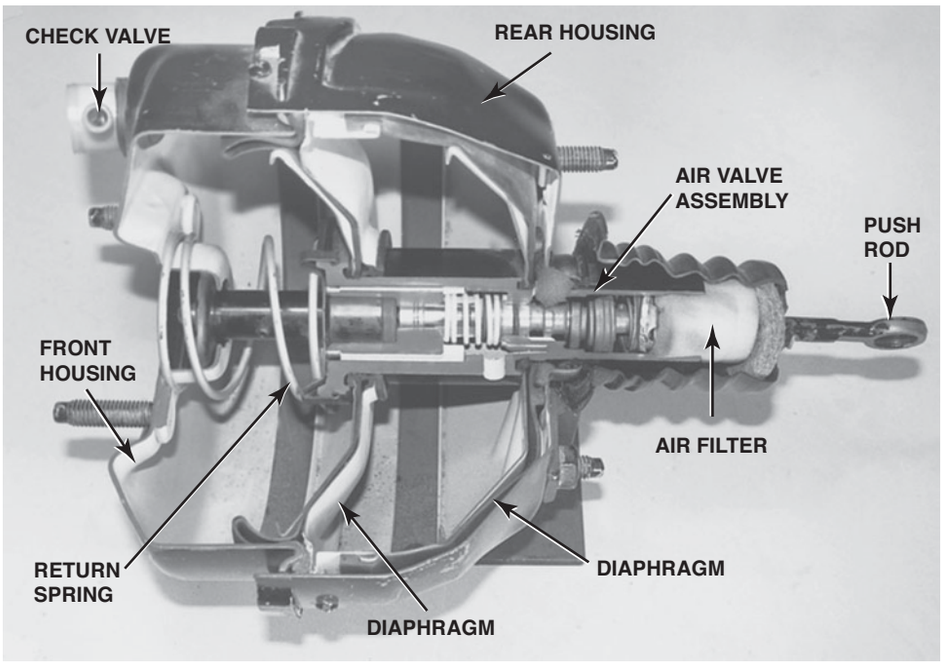


FIGURE 105–14 Cutaway showing a dual-diaphragm (tandem) vacuum brake booster.

TECH TIP

A Low, Soft Brake Pedal Is Not a Power Booster Problem

Some service technicians tend to blame the power brake booster if the vehicle has a low, soft brake pedal. A defective power brake booster causes a hard brake pedal, not a soft brake pedal. A soft or spongy brake pedal is usually caused by air being trapped somewhere in the hydraulic system.

Many times, the technician has bled the system and, therefore, thinks that the system is free of any trapped air. According to remanufacturers of master cylinders and power brake boosters, most of the returned parts under warranty are not defective. Incorrect or improper bleeding procedures account for much of the problem.

valve against the power piston and reaction disc. This force is then applied to the pushrod and subsequently the hydraulic reaction plate fastened to the master cylinder piston rod, which applies pressure in the master cylinder. For safety in the event of a stalled engine and a loss of vacuum, a power brake booster should have adequate storage of vacuum for several power-assisted stops.

DUAL- (TANDEM-) DIAPHRAGM VACUUM BOOSTERS

To provide power assist, air pressure must work against a rubber diaphragm. The larger the area of the diaphragm, the more force can be exerted. The usual method of increasing the area of the vacuum diaphragm was to increase the diameter of the vacuum booster. However, a larger vacuum booster took up too much room under the hood of many vehicles. Instead of increasing the diameter, vacuum booster manufacturers used two smaller-diameter diaphragms and placed one in front of the other. These designs increased the total area without increasing the physical diameter of the booster. This style is called a **dual-diaphragm** or **tandem-diaphragm** vacuum booster. ● **SEE FIGURE 105–14.**

BRAKE ASSIST SYSTEM

Some vehicles are equipped with a **brake assist system (BAS)** that applies the brakes with maximum force if the system detects that the driver is making a panic stop. Tests performed by brake engineers have indicated that it is normal for a person to first apply the brakes rapidly during a panic situation. However, it was also found that the driver would tend to reduce the force applied to the brake pedal. As a result, the vehicle did not brake with the maximum effort.

OPERATION The brake assist system opens an air valve on the rear part of the vacuum booster assembly. As a result, more air at atmospheric pressure can flow into the rear chamber of the vacuum booster, thereby increasing the force applied to the master cylinder. The BAS function works with the electronic stability control (ESC) system to ensure maximum braking efficiency during evasive or emergency situations.

If the speed of the brake pedal application exceeds a predetermined limit as determined by the brake pedal travel sensor, the ABS controller energizes the BAS solenoid valve. When the solenoid valve opens, additional air at atmospheric pressure enters the driver's side of the booster. The additional pressure applies the brakes faster and with more force. The BAS solenoid is deenergized when the brake pedal is released and normal braking returns. ● **SEE FIGURES 105–15 AND 105–16.**

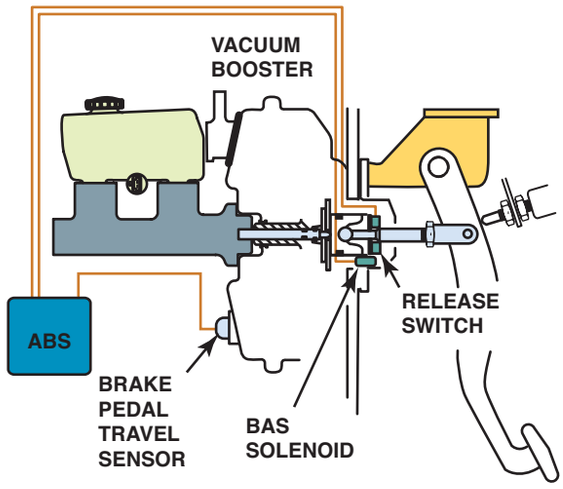


FIGURE 105–15 A typical brake assist system uses a brake pedal travel sensor and a BAS solenoid to apply the brakes during a panic condition.

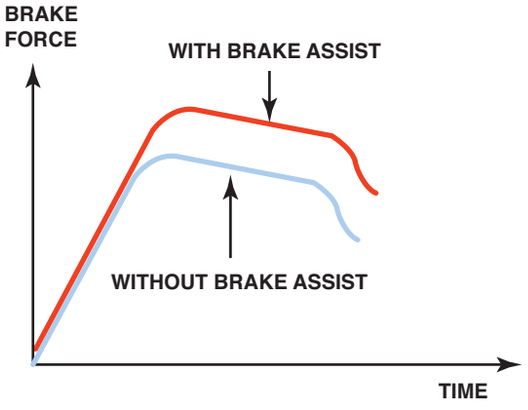


FIGURE 105–16 When the brake assist function operates, the brake force is much higher than normal.

VACUUM BOOSTER OPERATION TEST

With the engine "off," apply the brakes several times to deplete the vacuum. With your foot on the brake pedal, start the engine. The brake pedal *should* drop. If the brake pedal does *not* drop, check for proper vacuum source to the booster. There should be at least 15 in. Hg of vacuum at the booster for proper operation. If there is proper vacuum, repair or replacement of the power booster is required.

VACUUM BOOSTER LEAK TEST

To test if the vacuum booster can hold a vacuum perform the following steps:

STEP 1 Operate the engine to build up a vacuum in the booster, then turn the engine off.

STEP 2 Wait one minute.

STEP 3 Depress the brake pedal several times. There should be two or more power-assisted brake applications.

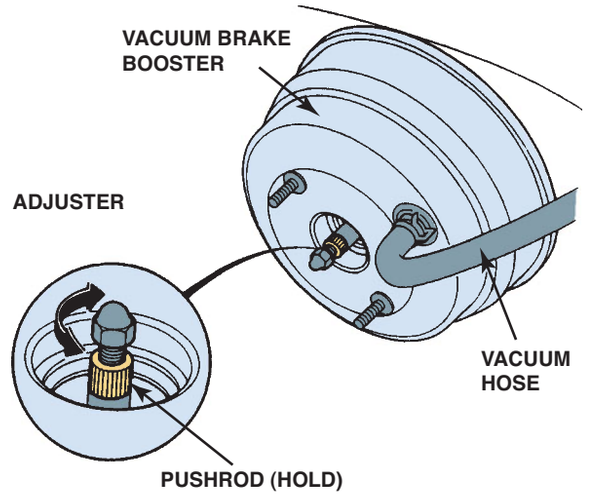


FIGURE 105–17 Typical adjustable pushrod. This adjustment is critical for the proper operation of the braking system. If the pushrod is too long, the brakes may be partially applied during driving. If the rod is too short, the brake pedal may have to be depressed farther down before the brakes start to work.

If applications are not power assisted, either the vacuum check valve or the booster is leaking. To test the check valve, remove the valve from the booster and blow through the check valve. If air passes through, the valve is defective and must be replaced. If the check valve is okay, the vacuum booster is leaking and should be repaired or replaced based on the manufacturer's recommendations.

HYDRAULIC SYSTEM LEAK TEST

An internal or external hydraulic leak can also cause a brake system problem. To test if the hydraulic system (and not the booster) is leaking, depress and release the brake pedal (service brakes) several times. This should deplete any residual power assist. On some ABS units, this may require depressing the brake pedal 20 or more times!

After depleting the power-assist unit, depress and then hold the brake pedal depressed with medium force (20 to 35 lb or 88 to 154 N). The brake pedal should *not* fall away. If the pedal falls, the hydraulic brake system is leaking. Check for external leakage at wheel cylinders, calipers, hydraulic lines, and hoses. If there is no external leak, there may be an internal leak inside the master cylinder. Repair or replace components as needed to correct the leakage.

PUSHROD CLEARANCE ADJUSTMENT

Whenever the vacuum brake booster or the master cylinder is replaced, the pushrod length should be checked. The length of the pushrod must match correctly with the master cylinder. ● **SEE FIGURE 105–17.**

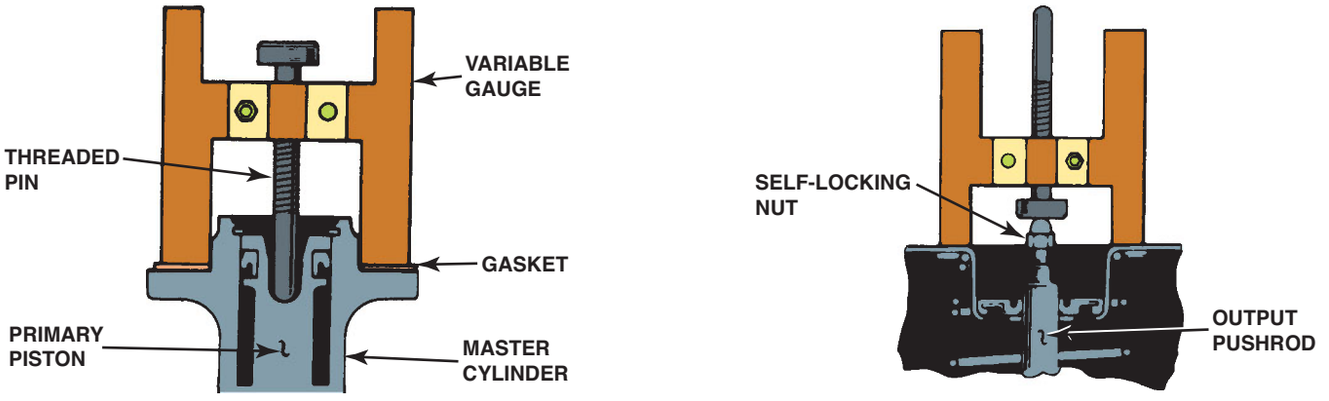


FIGURE 105–18 Typical vacuum brake booster pushrod gauging tool. (a) The tool is first placed against the mounting flange of the master cylinder and the depth of the piston determined. (b) The gauge is then turned upside down and used to gauge the pushrod length. Some vacuum brake boosters do not use adjustable pushrods. If found to be the incorrect length, a replacement pushrod of the correct length should be installed.

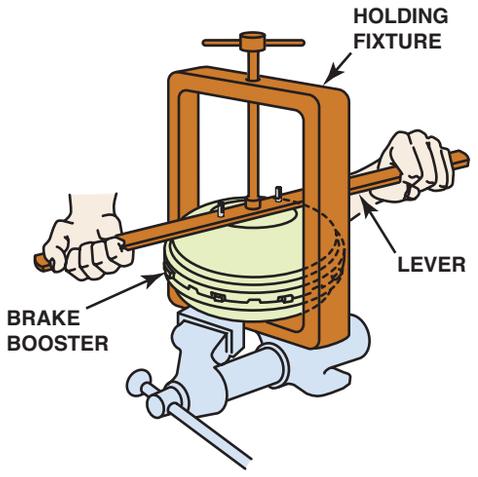


FIGURE 105–19 A holding fixture and a long tool being used to rotate the two halves of a typical vacuum brake booster.

If the pushrod is too long and the master cylinder is installed, the rod may be applying a force on the primary piston of the master cylinder even though the brake pedal is not applied. This can cause the brakes to overheat, causing the brake fluid to boil. If the brake fluid boils, a total loss of braking force can occur. Obviously, this pushrod clearance check and adjustment is very important. A gauge is often used to measure the position of the master cylinder piston, and then the other end of the gauge is used to determine the proper pushrod clearance. ● **SEE FIGURE 105–18.**

VACUUM BOOSTER DISASSEMBLY AND SERVICE

Some vehicle manufacturers recommend that the vacuum brake booster be replaced as an assembly if tested to be leaking or defective. Some vehicle manufacturers recommend that the vacuum brake booster be disassembled and overhauled if defective. A special holding fixture should be used before rotating (unlocking) the front and rear housing because the return spring is strong. ● **SEE FIGURE 105–19.**

Disassemble the vacuum brake booster according to the manufacturer's recommended procedures for the specific unit being serviced. ● **SEE FIGURE 105–20.**

A rebuilding kit is available that includes all necessary parts and the proper silicone grease. The manufacturer warns that all parts included in the kit be replaced. Always follow the manufacturer's recommendations.

? FREQUENTLY ASKED QUESTION

What Is Supplemental Brake Assist?

Supplemental brake assist, SBA, is a motor-driven vacuum pump that can supplement engine vacuum to the vacuum brake booster. This unit is used on some General Motors vehicles. When a vehicle is driven under a heavy load, engine vacuum is low. To meet the brake standards, some vehicles are equipped with the brake assist system that consists of the following components:

- A pressure sensor that is used to measure the vacuum in the vacuum booster.
- An intake manifold check valve that is used to prevent vacuum from escaping the vacuum boost.
- A motor-driven vacuum pump.

The vacuum pump motor will start and run if the pressure sensor detects the vacuum in the booster is below 7 in. Hg and will shut off after the vacuum level increases to 9 in. Hg.

HYDRO-BOOST HYDRAULIC BRAKE BOOSTER

Hydro-Boost is a hydraulically operated power-assist unit built by Bendix. The Hydro-Boost system uses the pressurized hydraulic fluid from the vehicle's power steering pump as a power source rather

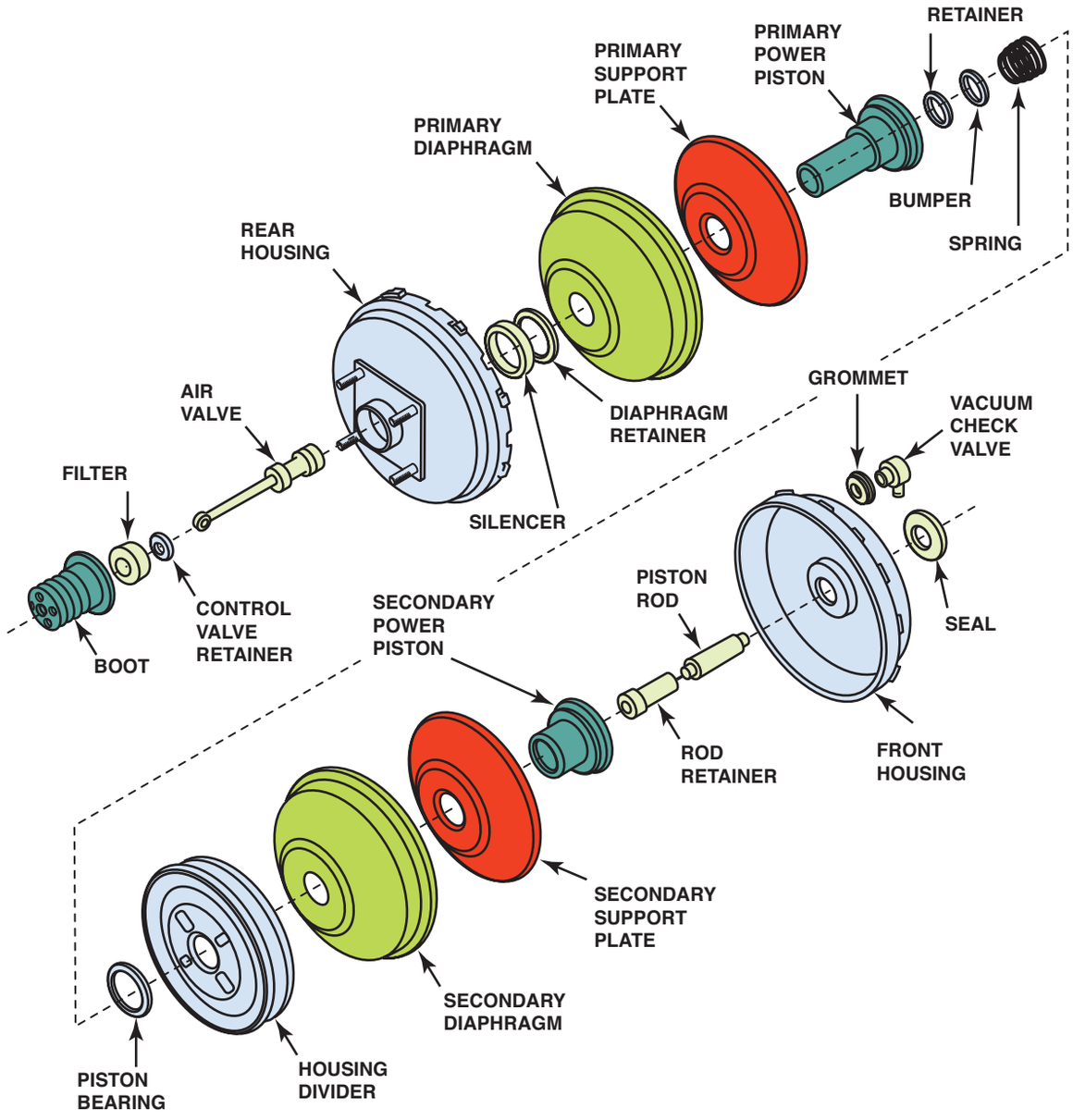


FIGURE 105–20 Exploded view of a typical dual-diaphragm vacuum brake booster assembly.

than using engine vacuum as is used with vacuum boosters. ● **SEE FIGURES 105–21 AND 105–22.**

The Hydro-Boost unit is used on vehicles that lack enough engine vacuum, such as turbocharged or diesel engine vehicles. During operation, diesel engines do not produce vacuum in the intake manifold. As a result, diesel engines must use accessory engine-driven vacuum pumps to operate vacuum accessories. Turbocharged and supercharged engines do not create engine vacuum during periods of acceleration. Even though vacuum is available when the engine is decelerating, some vehicle manufacturers elect to install a Hydro-Boost system rather than equip the vehicle with an accessory engine-driven vacuum pump.

OPERATION Fluid pressure from the power steering pump enters the unit and is directed by a spool valve. ● **SEE FIGURE 105–23.** When the brake pedal is depressed, the lever and primary valve are moved. The valve closes off the return port, causing pressure to build in the boost pressure chamber. The hydraulic pressure pushes on the

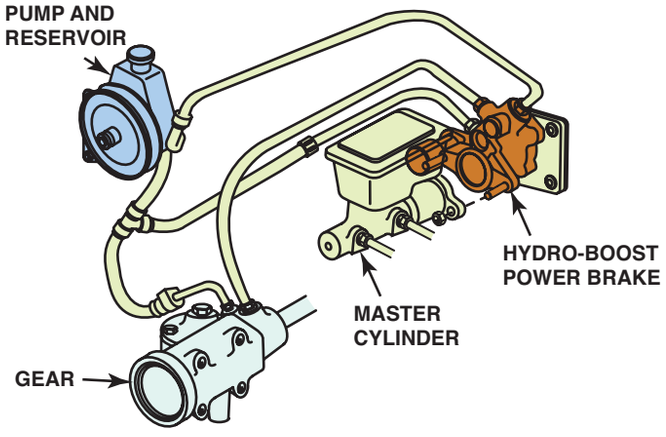


FIGURE 105–21 Hydro-Boost unit attaches between the bulkhead and the master cylinder and is powered by the power steering pump.

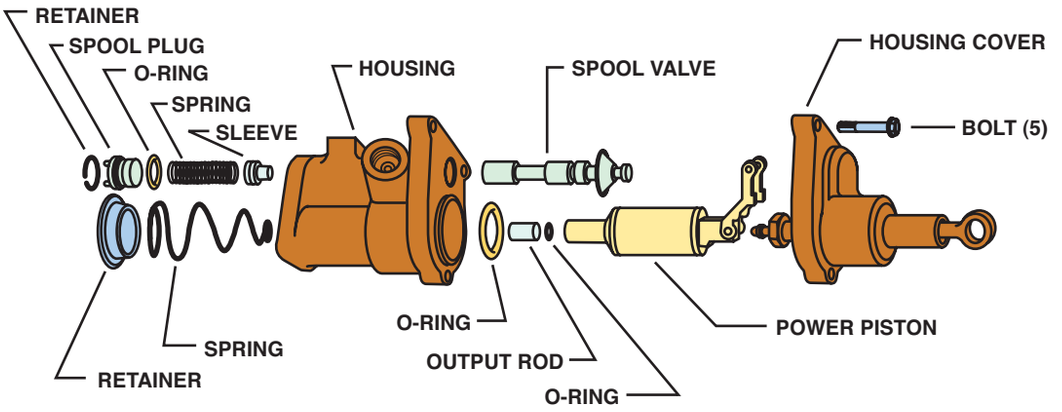


FIGURE 105–22 Exploded view of the Hydro-Boost unit.

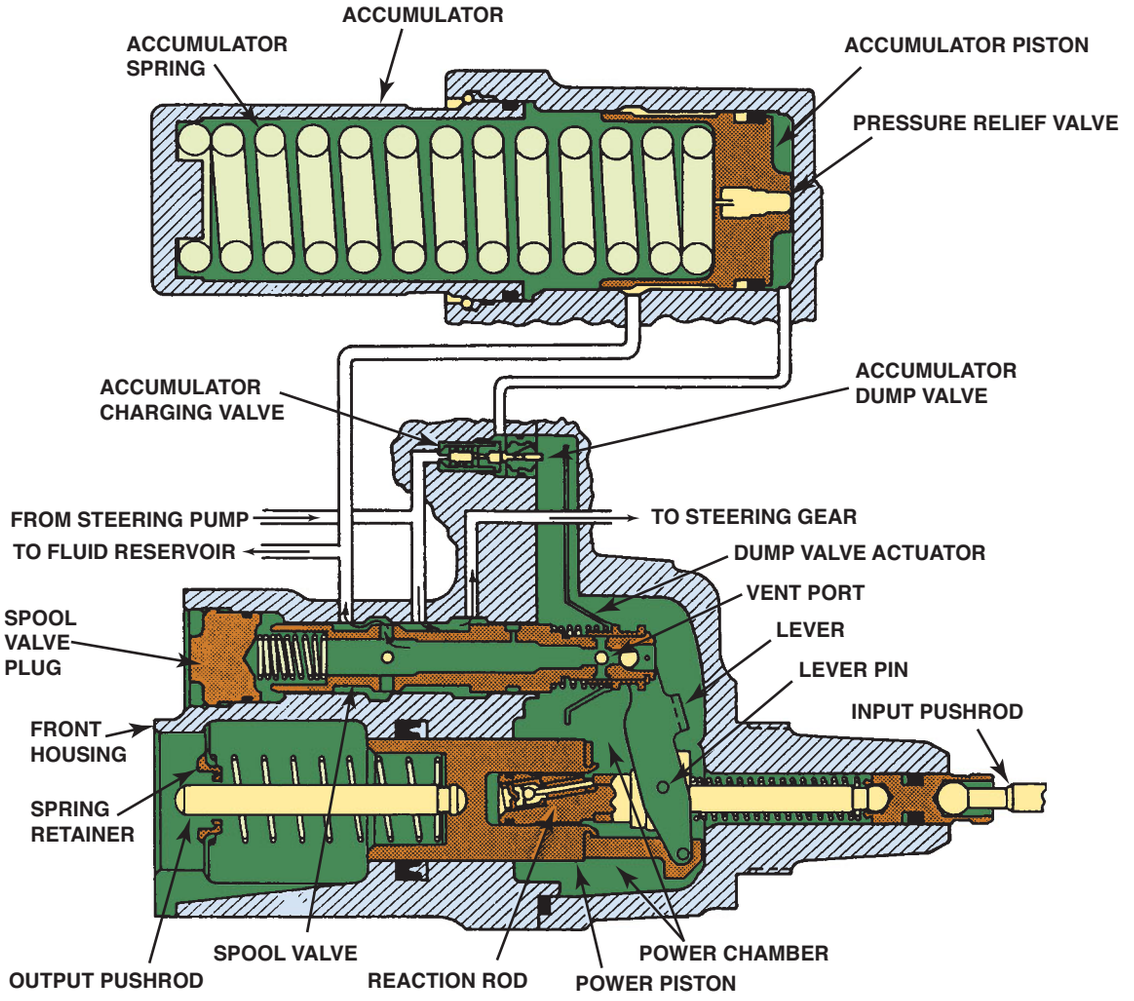


FIGURE 105–23 A Hydro-Boost hydraulic booster in the unapplied position.

power piston, which then applies force to the output rod that connects to the master cylinder piston. In the event of a power steering pump failure, power assist is still available for several brake applications. ● **SEE FIGURE 105–24.**

During operation, hydraulic fluid under pressure from the power steering pump pressurizes an accumulator. ● **SEE FIGURE 105–25.** While some units use a spring inside the accumulator, most Hydro-Boost units use nitrogen gas. The fluid trapped in the accumulator under pressure is used to provide power-assisted stops in the event of a hydraulic system failure.

DIAGNOSIS The power source for Hydro-Boost units comes from the power steering pump. The first step of troubleshooting is to perform a thorough visual inspection, including the following:

1. Checking for proper power steering fluid level
2. Checking for leaks from the unit or power steering pump
3. Checking the condition and tightness of the power steering drive belt
4. Checking for proper operation of the base brake system

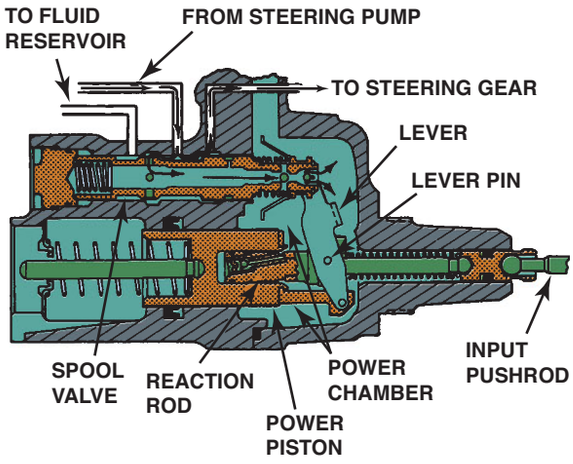


FIGURE 105–24 A Hydro-Boost hydraulic booster as the brakes are applied.

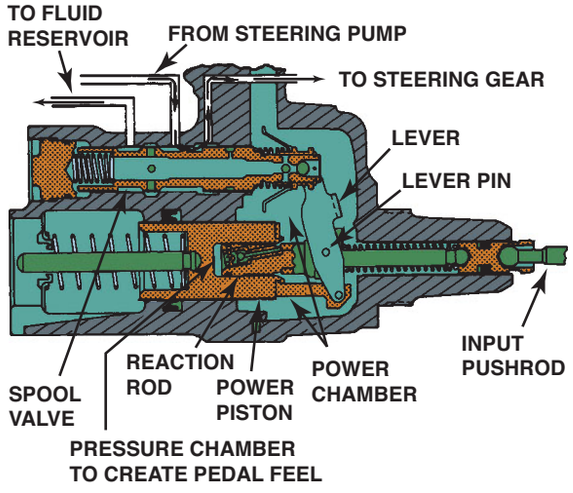


FIGURE 105–25 A Hydro-Boost hydraulic booster in the holding position.

After checking all of the visual components, check for proper pressure and volume from the power steering pump using a power steering pump tester, as shown in ● **FIGURES 105–26 AND 105–27.**

The pump should be capable of producing a minimum of 2 gallons (7.5 liters) with a maximum pressure of 150 PSI (1,000 kPa) with the steering in the straight-ahead position. With the engine "off," the accumulator should be able to supply a minimum of two power-assisted brake applications.

HYDRO-BOOST FUNCTION TEST With the engine off, apply the brake pedal several times until the accumulator is depleted completely. Depress the service brake pedal and start the engine. The pedal should fall and then push back against the driver's foot.

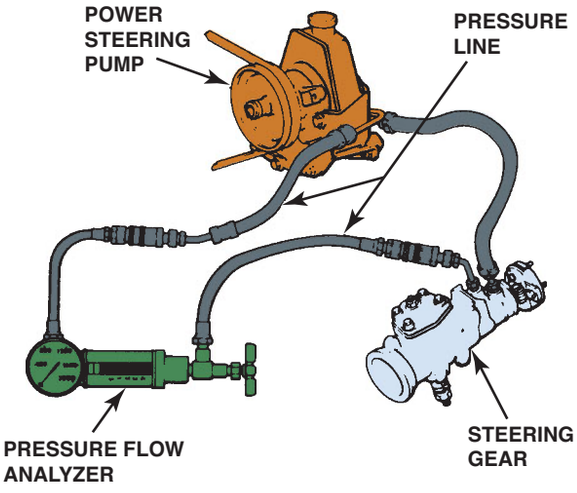


FIGURE 105–27 Pressure and flow analyzer installation to check the power steering pump output.

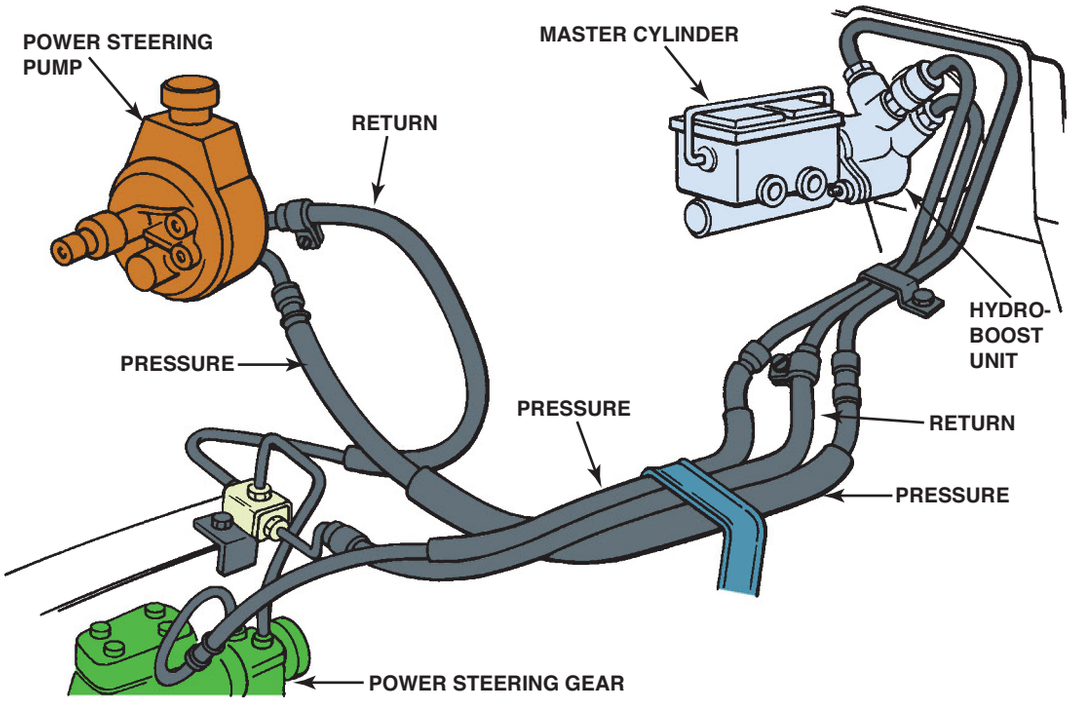


FIGURE 105–26 A typical Hydro-Boost hydraulic line arrangement showing the pump, steering gear, and brake booster assembly.

TECH TIP

The Hydro-Boost Accumulator Test

The accumulator stores hydraulic fluid under pressure to provide a reserve in the event of a failure of the power steering system. The accumulator is designed to provide three or more power-assisted stops with the engine off. **SEE FIGURE 105–28.**

If the accumulator fails, it does not hold pressure. To easily check whether the accumulator has lost its charge, simply grasp the accumulator with your hand and try to twist or move it. The accumulator should have so much pressure on it that it should not move or wiggle. If the accumulator moves, it has lost its ability to hold pressure and the Hydro-Boost unit should be replaced.



FIGURE 105–28 The accumulator should be able to hold pressure and feel tight when hand force is used to try to move it.

HYDRO-BOOST SYMPTOM-BASED GUIDE

EXCESSIVE BRAKE PEDAL EFFORT Possible causes for this include the following:

1. Loose or broken power steering pump belt
2. No fluid in the power steering reservoir
3. Leaks in the power steering, booster, or accumulator hoses
4. Leaks at tube fittings, power steering, booster, or accumulator connections
5. External leakage at the accumulator
6. Faulty booster piston seal, causing leakage at the booster flange vent
7. Faulty booster cover seal with leakage between the housing and cover
8. Faulty booster spool plug seal

SLOW BRAKE PEDAL RETURN Possible causes for this include the following:

1. Excessive seal friction in the booster
2. Faulty spool action
3. Broken piston return spring
4. Restriction in the return line from the booster to the pump reservoir
5. Broken spool return spring

GRABBY BRAKES Possible causes for this include the following:

1. Broken spool return spring
2. Faulty spool action caused by contamination in the system

BOOSTER CHATTERS—PEDAL VIBRATES Possible causes for this include the following:

1. Power steering pump belt slipping
2. Low fluid level in the power steering pump reservoir
3. Faulty spool operation caused by contamination in the system

REVIEW QUESTIONS

1. Describe the purpose and function of the one-way check valve used on vacuum brake booster units.
2. Explain how vacuum is used to assist in applying the brakes.
3. Describe how to perform a vacuum booster leak test and hydraulic system leak test.
4. Explain how a Hydro-Boost system functions.

CHAPTER QUIZ

1. Two technicians are discussing vacuum brake boosters. Technician A says that a low, soft brake pedal is an indication of a defective booster. Technician B says that there should be at least two power-assisted brake applications after the engine stops running. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. Technician A says that to check the operation of a vacuum brake booster, the brake pedal should be depressed until the assist is depleted and then start the engine. Technician B says that the brake pedal should drop when the engine starts, if the booster is okay. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

3. Brake pedal feedback to the driver is provided by the _____.
   a. Vacuum check-valve operation
   b. Reaction system
   c. Charcoal filter unit
   d. Vacuum diaphragm

4. The proper operation of a vacuum brake booster requires that the engine be capable of supplying at least _____.
   a. 15 in. Hg vacuum
   b. 17 in. Hg vacuum
   c. 19 in. Hg vacuum
   d. 21 in. Hg vacuum

5. The purpose of the charcoal filter in the vacuum hose between the engine and the vacuum brake booster is to _____.
   a. Filter the air entering the engine
   b. Trap gasoline vapors to keep them from entering the booster
   c. Act as a one-way check valve to help keep a vacuum reserve in the booster
   d. Direct the vacuum

6. A defective vacuum brake booster will cause a _____.
   a. Hard brake pedal
   b. Soft (spongy) brake pedal
   c. Low brake pedal
   d. Slight hiss noise when the brake pedal is depressed

7. An accumulator such as that used on hydraulic brake boosters _____.
   a. Reduces brake pedal noise
   b. Provides higher force being fed back to the driver's foot
   c. Provides a reserve in the event of a failure
   d. Works against engine vacuum

8. The first step in diagnosing a Hydro-Boost problem is _____.
   a. A pressure test of the pump
   b. A volume test of the pump
   c. To tighten the power steering drive belt
   d. A thorough visual inspection

9. A brake pedal feels spongy when depressed. Technician A says that a defective hydraulic brake booster could be the cause. Technician B says that a defective vacuum brake booster could be the cause. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

10. If the engine stops running, the Hydro-Boost will not be able to provide any power assist for the brakes.
   a. True
   b. False

chapter 106

ABS COMPONENTS AND OPERATION

OBJECTIVES: **After studying Chapter 106, the reader will be able to:** • Prepare for the Brakes (A5) ASE certification test content area "F" (Antilock Brake System Diagnosis and Repair). • Explain the reason for ABS. • Describe the purpose and function of the ABS components, such as wheel speed sensors, electrohydraulic unit, and electronic controller. • Discuss how the ABS components control wheel slippage.

KEY TERMS: Accumulator 1215 • Active sensor 1213 • Air gap 1213 • Antilock braking systems (ABS) 1208 • Channel 1211 • Control module 1210 • Flash codes 1214 • Integral ABS 1211 • Isolation solenoid 1214 • Nonintegral ABS 1211 • Pressure decay stage 1215 • Pressure dump stage 1215 • Pressure holding stage 1215 • Pressure increase stage 1215 • Pressure reduction stage 1215 • Pressure release stage 1215 • Rear Antilock Braking System (RABS) 1211 • Rear Wheel Antilock (RWAL) 1211 • Release solenoid 1215 • Select low principle 1211 • Solenoid valves 1210 • Tire pressure monitoring system (TPMS) 1217 • Tire slip 1209 • Tone ring 1212 • Traction 1208 • Wheel speed sensors (WSS) 1212

ANTILOCK BRAKING SYSTEM

OVERVIEW

Antilock braking systems (ABS) help prevent the wheels from locking during sudden braking, especially on slippery surfaces. This helps the driver maintain control.

Antilock brakes increase safety because they eliminate lockup and minimize the danger of skidding, allowing the vehicle to stop in a straight line. ABS also allows the driver to maintain steering control during heavy braking so the vehicle can be steered to avoid an obstacle or another vehicle.

ABS can improve braking when road conditions are less than ideal, as when making a sudden panic stop or when braking on a wet or slick road. ABS does this by monitoring the relative speed of the wheels to one another. It uses this information to modulate brake pressure as needed to control slippage and maintain traction when the brakes are applied.

ABS AND TIRE TRACTION

Preventing brake lockup is important because of the adverse effect a locked wheel has on tire **traction.** The brakes slow the rotation of the wheels, but it is friction between the tire and road that stops the vehicle and allows it to be

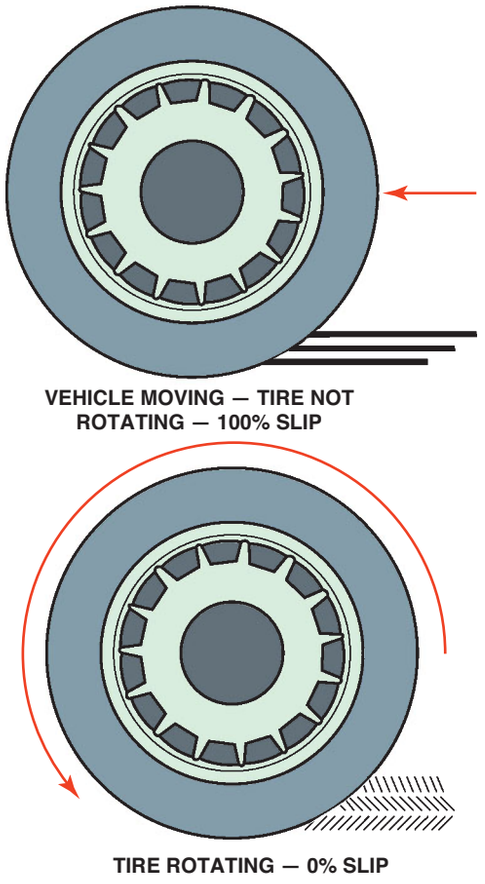


FIGURE 106–1 Maximum braking traction occurs when tire slip is between 10% and 20%. A rotating tire has 0% slip and a locked-up wheel has 100% slip.

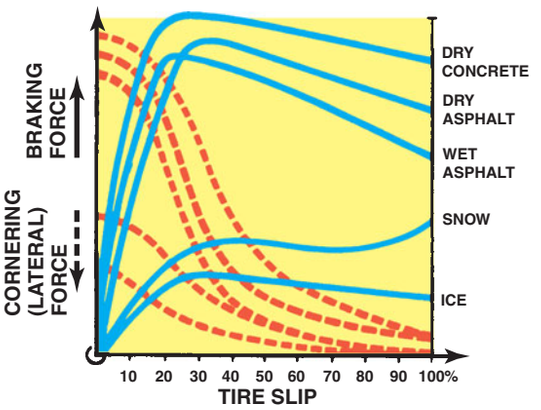


FIGURE 106–2 Traction is determined by pavement conditions and tire slip.

steered. If tire traction is reduced, stopping distances increase, and the directional stability of the vehicle suffers.

Traction is defined in terms of **tire slip,** which is the difference between the actual speed and the rate at which the tire tread moves across the road. A free-rolling wheel has nearly zero tire slip, while a locked wheel has 100% tire slip. ● **SEE FIGURE 106–1.**

When the brakes are applied, the rotational speed of the wheel drops, and tire slip increases because the tread moves across the road slower than the actual vehicle speed. This slip creates friction that converts kinetic energy into braking and cornering force.

TIRE SLIP AND BRAKING DISTANCE

On dry or wet pavement, maximum braking traction occurs when tire slip is held between approximately 15% and 30%. ● **SEE FIGURE 106–2.**

On snow- or ice-covered pavement, the optimum slip range is 20% to 50%. In each case, if tire slip increases beyond these levels, the amount of traction decreases. A skidding tire with 100% slip provides 20% to 30% less braking traction on dry pavement, and this is generally true on slippery roads as well. In nearly all cases, the shortest stopping distances are obtained when the brakes are applied with just enough force to keep the tire slip in the range where traction is greatest.

NOTE: All antilock braking systems stop controlling the wheel brakes when the vehicle speed drops to about 5 MPH (8 km/h). The wheel speed sensors are often not accurate that these low speeds and loss of vehicle control at this low speed is unlikely.

TECH TIP

Tire "Chirp" Noise during Hard Braking Is Normal

Sometimes customers state that they do not think that their antilock braking system (ABS) is working correctly because they heard the tires making noise (chirping sound) during hard braking. This is normal as the tires slip about 20% during an ABS stop.

TIRE SLIP AND VEHICLE STABILITY

A tire's contact patch with the road can provide only a certain amount of traction. When a vehicle is stopped in a straight line, nearly all of the available traction can be used to provide braking force. Only a small amount of traction is required to generate lateral force that keeps the vehicle traveling in a straight line. However, if a vehicle has to stop and turn at the same time, the available traction must be *divided* to provide both cornering (lateral) and braking force.

No tire can provide full cornering power and full braking power at the same time. When a brake is locked and the tire has 100% slip, all of the available traction is used for braking, and none is left for steering. As a result, a skidding tire follows the path of least resistance. This means that if the rear brakes lock, the back end of the vehicle will tend to swing around toward the front causing a spin. If the front brakes lock, steering control will be lost and the vehicle will slide forward in a straight line until the brakes are released to again make traction available for steering.

ABS AND BASE BRAKES

An antilock braking system is only an "add-on" to the existing base brake system. ABS only comes into play when traction conditions are marginal or during sudden panic stops when the tires lose traction and begin to slip excessively. The rest of the time ABS has no effect on normal driving, handling, or braking.

NOTE: All vehicles sold in the United States for the 2012 model year and newer are required to be equipped with electronic stability system. These systems require that the vehicle be equipped with antilock braking system (ABS) as standard equipment.

ABS also makes no difference in the maintenance, inspection, service, or repair of conventional brake system components. A vehicle with ABS brakes uses the same brake linings, calipers, wheel cylinders,

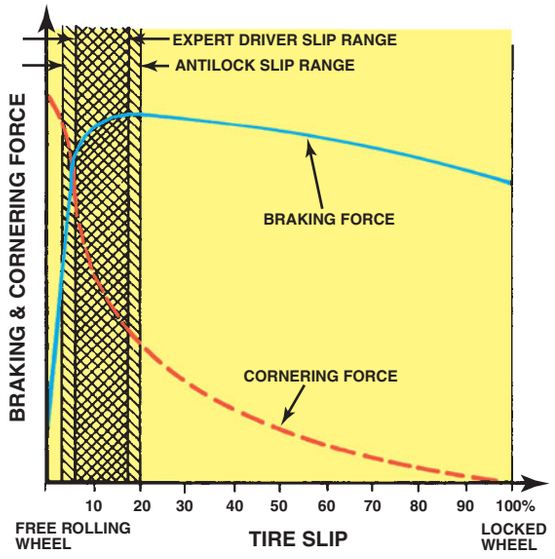


FIGURE 106–3 A good driver can control tire slip more accurately than an ABS if the vehicle is traveling on a smooth, dry road surface.

and other system components as a vehicle without ABS brakes. The only exception being the master cylinder on certain applications.

All ABS systems are also designed to be as "fail-safe" as possible. Should a failure occur that affects the operation of the ABS system, the system will deactivate itself and the vehicle will revert to normal braking. Therefore, an ABS failure will not prevent the vehicle from stopping.

ABS LIMITATIONS There are two situations in which an antilock brake system will *not* provide the shortest stopping distances. The first involves straight stops made on smooth, dry pavement by an *expert* driver. Under these conditions, a skilled driver can hold the tires consistently closer to the ideal slip rate than the ABS can. ● **SEE FIGURE 106–3.**

This is possible because current antilock braking systems may allow the amount of tire slip to drop as low as 5%, which is somewhat below the point where maximum tire traction is achieved. However, for the average driver, or under less than ideal conditions, antilock brakes will almost always stop the vehicle in a shorter distance.

The other situation in which antilock brakes will not provide the shortest stops is when braking on loose gravel or dirt, or in deep, fluffy snow. Under these conditions, a locked wheel will stop the vehicle faster because loose debris builds up and forms a wedge in front of the tire that helps stop the vehicle. ● **SEE FIGURE 106–4.**

An antilock braking system will prevent this wedge from forming, so some vehicles with antilock brakes have a switch on the instrument panel that allows the system to be deactivated when driving on these kinds of road surfaces.

ABS AND THE LAWS OF PHYSICS No ABS can overcome the laws of physics. The weight and speed of a moving vehicle give it a great deal of kinetic energy, and only so much of that energy can be converted into braking or cornering force at any given time. The limiting factor in this conversion is the traction between the tires and road.

Although a vehicle with four-wheel antilock brakes will stop in very nearly the shortest possible distance, this will still not prevent an accident if the brakes are applied too late to bring the vehicle to a complete stop before impact. However, because steering control is retained with four-wheel antilock brakes, it may be possible to drive the vehicle around a potential accident while in the process of braking.

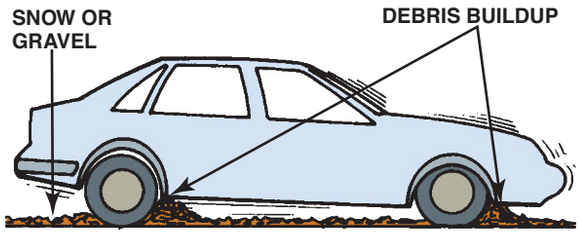


FIGURE 106–4 A wedge of gravel or snow in the front of a locked wheel can help stop a vehicle faster than would occur if the wheel brakes were pulsed on and off by an antilock braking system.

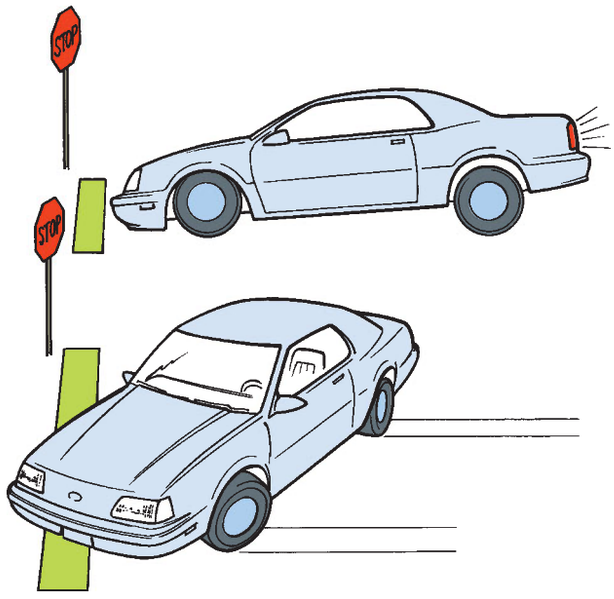


FIGURE 106–5 Being able to steer and control the vehicle during rapid braking is one major advantage of an antilock braking system.

Another situation where antilock brakes cannot defy the laws of physics occurs when a vehicle enters a corner traveling faster than it is physically possible to negotiate the turn. In this situation, antilock brakes will not prevent the vehicle from leaving the road. However, they will allow the vehicle to be slowed and steered in the process, thus lessening the severity of the eventual impact. ● **SEE FIGURE 106–5.**

ABS OPERATION

WHEEL SPEED SENSOR INPUT All ABS systems control tire slip by monitoring the relative deceleration rates of the wheels during braking. Wheel speed is monitored by one or more wheel speed sensors. If one wheel starts to slow at a faster rate than the others, or at a faster rate than that which is programmed in the antilock **control module,** it indicates a wheel is starting to slip and is in danger of losing traction and locking. The ABS responds by momentarily reducing hydraulic pressure to the brake on the affected wheel or wheels. This allows the wheel to speed up momentarily so it can regain traction. As traction is regained, brake pressure is reapplied to again slow the wheel. The cycle is repeated over and over until the vehicle stops or until the driver eases pressure on the brake pedal.

CONTROL VALVES Electrically operated **solenoid valves** (or motor-driven valves in the case of Delphi ABS-VI applications) are

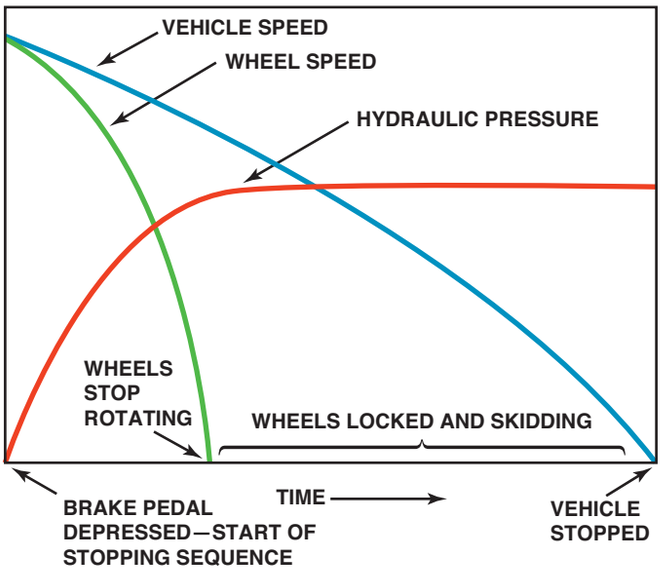


FIGURE 106–6 A typical stop on a slippery road surface without antilock brakes. Notice that the wheels stopped rotating and skidded until the vehicle finally came to a stop.

used to hold, release, and reapply hydraulic pressure to the brakes. This produces a pulsating effect, which can be felt in the brake pedal during hard braking. The rapid modulation of brake pressure in a given brake circuit reduces the braking load on the affected wheel and allows it to regain traction to prevent lockup. The effect is much the same as pumping the brakes, except that the ABS system does it automatically for each brake circuit, and at speeds that would be humanly impossible—up to 20 times per second depending on the system (some cycle faster than others). ● **SEE FIGURE 106–6.**

Once the rate of deceleration for the affected wheel catches up with the others, normal braking function and pressure resume, and antilock reverts to a passive mode.

SYSTEM CONFIGURATIONS

All ABS systems keep track of wheel deceleration rates with wheel speed sensors. The various ABS systems use a different number of sensors, depending on how the system is configured. These include four-channel, three-channel, and single-channel systems. ● **SEE FIGURE 106–7.**

FOUR-CHANNEL ABS SYSTEMS On some applications, each wheel is equipped with its own speed sensor. This type of arrangement is called a "four-wheel, four-channel" system since each wheel speed sensor provides input for a separate hydraulic control circuit or "channel" for that wheel.

The term **channel** always refers to the number of separate or individually controlled ABS hydraulic circuits in an ABS system, not the number of wheel speed sensor electrical circuits.

NOTE: For vehicle stability systems to function, there has to be four wheel speed sensors and four channels so the hydraulic control unit can pulse individual wheel brakes to help achieve vehicle stability.

THREE-CHANNEL ABS SYSTEMS Some four-wheel ABS systems have a separate wheel speed sensor for each front wheel

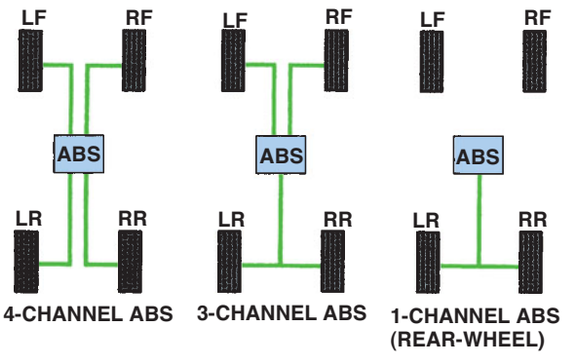


FIGURE 106–7 ABS configuration includes four-channel, three-channel, and single-channel.

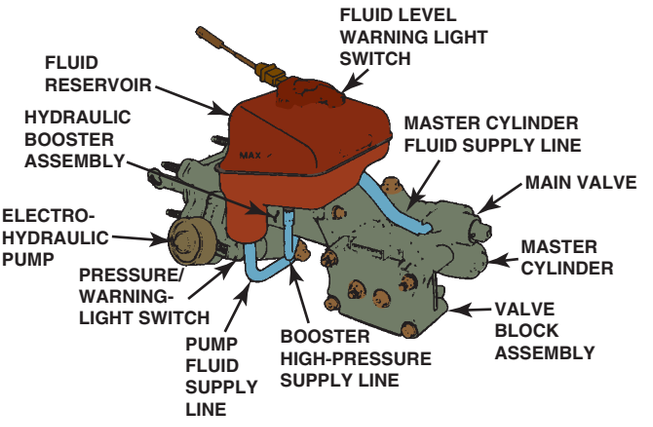


FIGURE 106–8 A typical integral ABS unit that combines the function of the master cylinder, brake booster, and antilock braking system in one assembly.

but use a common speed sensor for both rear wheels. These are called "three-channel" systems. The rear wheel speed sensor is mounted in either the differential or the transmission. The sensor reads the combined or average speed of both rear wheels. This type of setup saves the cost for an additional sensor and reduces the complexity of the system by allowing both rear wheels to be controlled simultaneously. This is known as the **select low principle.** Three-channel systems are the most common type of ABS setup used on rear-wheel-drive applications.

SINGLE-CHANNEL ABS SYSTEMS The single-channel rear-wheel-only ABS system is used on many rear-wheel-drive pickups and vans. Ford's version is called **Rear Antilock Braking System (RABS),** while General Motors and Chrysler call theirs **Rear Wheel Antilock (RWAL).** The front wheels have no speed sensors, and only a single speed sensor mounted in the differential or transmission is used for both rear wheels. Rear-wheel antilock systems are typically used on applications where vehicle loading can affect rear wheel traction, which is why it is used on pickup trucks and vans. ABS was first used in pickup trucks because when the truck brakes, the weight transfer that occurs when the stop unloads the rear of the truck especially if the bed of truck is empty.

INTEGRAL AND NONINTEGRAL Another distinction between ABS systems is whether they are **integral** or **nonintegral ABS.** Integral systems combine the brake master cylinder and ABS hydraulic modulator, electric pump, and accumulator into one assembly. ● **SEE FIGURE 106–8.**

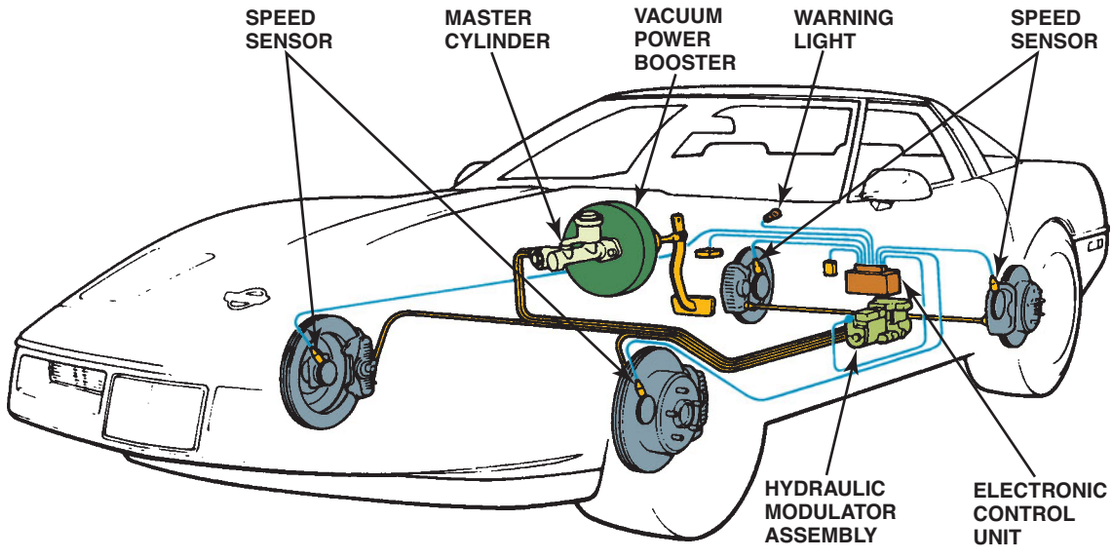


FIGURE 106–9 A typical nonintegral-type (remote) ABS.

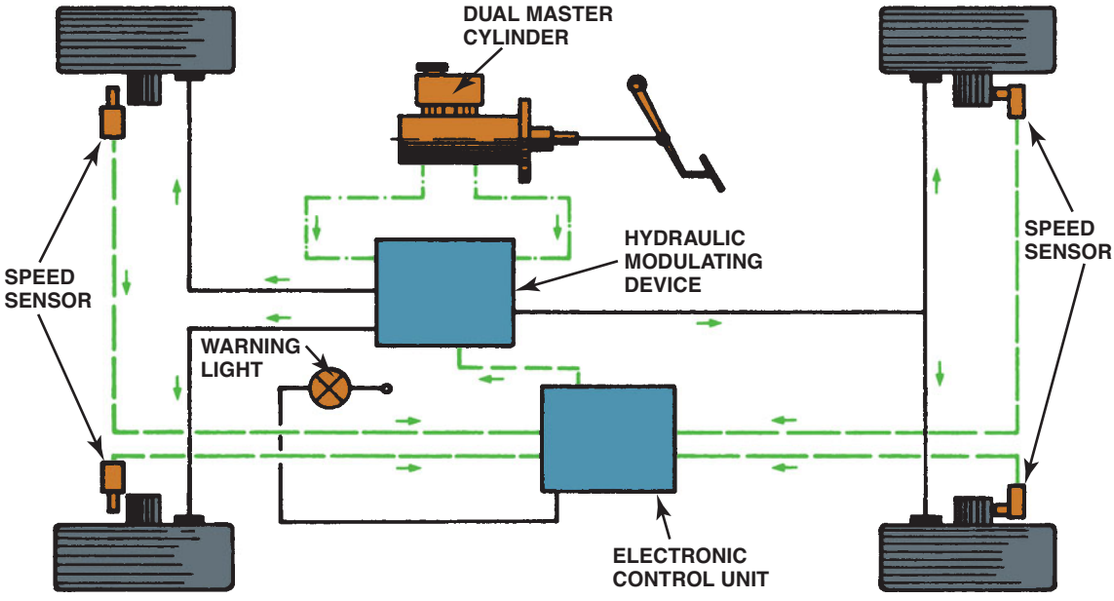


FIGURE 106–10 A schematic drawing of a typical antilock braking system.

Integral systems do not have a vacuum booster for power assist and rely instead on pressure generated by the electric pump for this purpose. Most of the older ABS applications are integral systems. Integral ABS systems include the Bendix 10 and Bendix 9 (Jeep) ABS systems, Bosch 3, Delco Moraine Powermaster III, and Teves Mark 2.

Nonintegral ABS systems, which are sometimes referred to as "add-on" systems, have become the most common type of ABS system because of their lower cost and simplicity. ● **SEE FIGURE 106–9.**

Nonintegral ABS systems have a conventional brake master cylinder and vacuum power booster with a separate hydraulic modulator unit. Some also have an electric pump for ABS braking (to reapply pressure during the ABS hold-release-reapply cycle), but do not use the pumps for normal power assist.

Nonintegral (add-on) systems include Bendix 3, Bendix 6, Bendix ABX-4, Bendix Mecatronic, Bosch 2, Bosch 2S Micro, Bosch 2U, Bosch 2E, Bosch 5, Delco Moraine ABS-VI, Kelsey-Hayes RABS/RWAL, 4WAL, EBC-5 and EBC-10, Sumitomo ABS, Teves Mark 4 ABS and MK20, and Toyota rear-wheel ABS.

ABS COMPONENTS

Basic components that are common to all antilock brake systems include the following.

- Wheel speed sensors
- Electronic control unit
- ABS warning lamp
- Hydraulic modulator assembly with electrically operated solenoid valves (or motor-driven valves in the case of Delphi ABS-VI)

● **SEE FIGURE 106–10.**

WHEEL SPEED SENSORS

Most **wheel speed sensors,** abbreviated **WSS,** consist of a magnetic pickup and a toothed sensor ring (usually called a **tone ring**). The sensor may be mounted in the steering knuckle, wheel hub, brake backing plate, transmission tailshaft, or differential housing. ● **SEE FIGURE 106–11.**

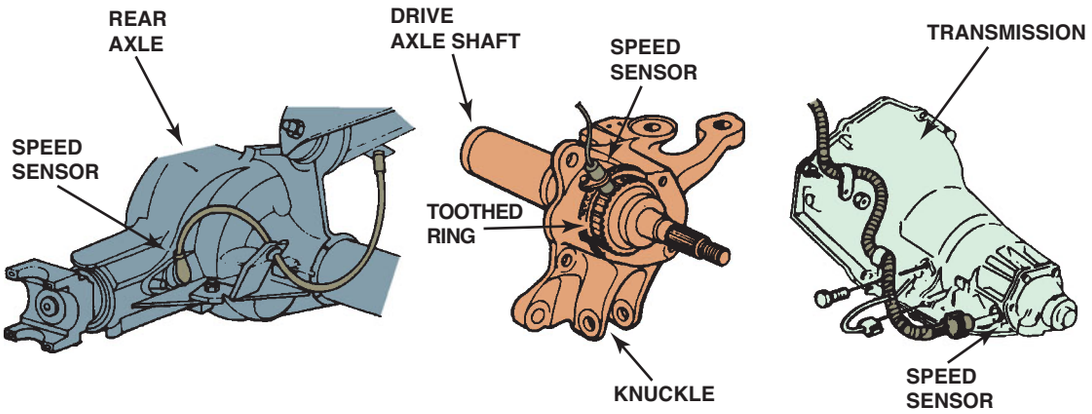


FIGURE 106–11 Wheel speed sensors for the rear wheels may be located on the rear axle, on the transmission, or on the individual wheel knuckle.

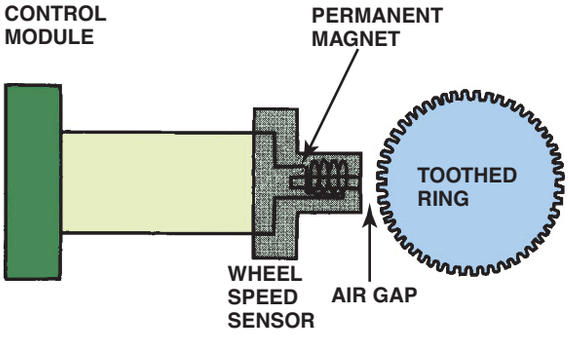


FIGURE 106–12 A schematic of a typical wheel speed sensor. The toothed ring is also called a *tone ring.*

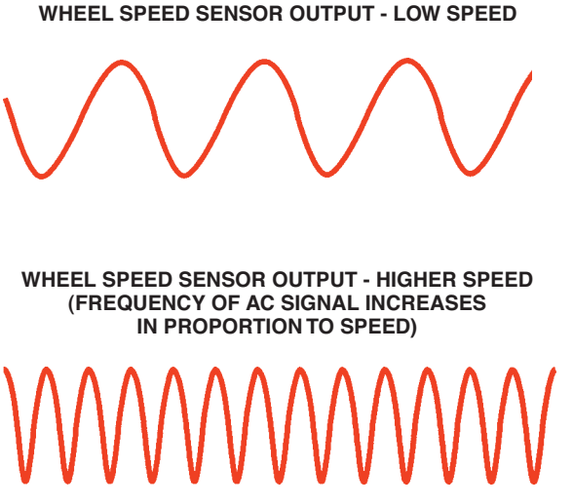


FIGURE 106–13 Wheel speed sensors produce an alternating current (AC) signal with a frequency that varies in proportion to wheel speed.

On some applications, the sensor is an integral part of the wheel bearing and hub assembly. The sensor rings may be mounted on the axle hub behind the brake rotors, on the brake rotors or drums, on the outside of the outboard constant velocity joints on a front-wheel-drive vehicle, on the transmission tailshaft, or inside the differential on the pinion gear shaft.

SENSOR OPERATION. The sensor pickup has a magnetic core surrounded by coil windings. ● **SEE FIGURE 106–12.**

As the wheel turns, teeth on the sensor ring move through the pickup's magnetic field. This reverses the polarity of the magnetic field and induces an alternating current (AC) voltage in the sensor windings. The number of voltage pulses per second induced in the pickup changes frequency. ● **SEE FIGURE 106–13.**

The frequency of the signal is therefore proportional to wheel speed. The higher the frequency, the faster the wheel is turning.

The signals are sent to the ABS control module (or an intermediate module in some General Motors rear-wheel ABS applications), where the AC signal is converted into a digital signal for processing. The control module then monitors wheel speed by counting the pulses from each of the wheel speed sensors. If the frequency signal from one wheel starts to change abruptly with respect to the others, it tells the module that wheel is starting to lose traction. The module then applies antilock braking if needed to maintain traction.

SENSOR AIR GAP. The distance or **air gap** between the end of the sensor and its ring is critical. A close gap is necessary to produce a strong, reliable signal. But metal-to-metal contact between the sensor and its ring must be avoided since this would damage both. The air gap must not be too wide or a weak or erratic signal (or no signal) may result. The air gap on some wheel speed sensors is adjustable, and is specified by the vehicle manufacturer.

SENSOR APPLICATIONS AND PRECAUTIONS. Wheel speed sensor readings are affected by the size of the wheels and tires on the vehicle. A tire with a larger overall diameter will give a slower speed reading than one with a smaller diameter. Because the ABS system is calibrated to a specific tire size, vehicle manufacturers warn against changing tire sizes. A different tire size or aspect ratio could have an effect on the operation of the ABS system.

Wheel speed sensors are also magnetic, which means they can attract metallic particles. These particles can accumulate on the end of the sensor and reduce its ability to produce an accurate signal. Removing the sensor and cleaning the tip may be necessary if the sensor is producing a poor signal.

DIGITAL WHEEL SPEED SENSORS. A conventional wheel speed sensor uses a permanent magnet with a surrounding coil of wire to produce an AC voltage signal that is proportional to wheel speed. The major problem with this type of sensor is that the voltage output and frequency are very low at slow speeds and therefore, cannot produce accurate wheel speed for ABS and traction control.

A digital wheel speed sensor, also called an **active sensor,** uses either a Hall-effect or a variable-reluctance circuit to produce a square waveform where the frequency is proportional to the wheel speed. A digital wheel speed sensor can also detect direction and can therefore be used by the controller for hill holding. The accuracy of these digital sensors also makes correlation to global positioning

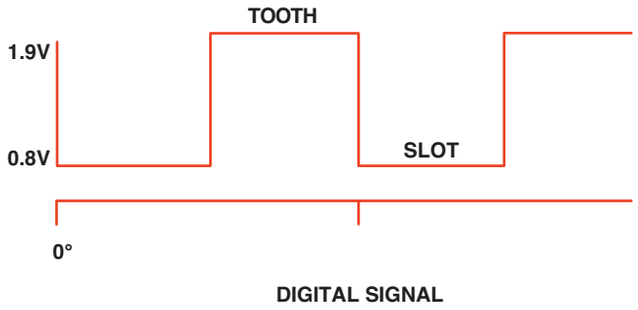


FIGURE 106–14 A digital wheel speed sensor produces a square wave output signal.

used in navigational systems more accurate, especially when the vehicle is being driven at slow speeds.

NOTE: While all GPS navigation systems use satellites for global positioning, the vehicle uses other sensors to keep track of minor changes in speed and vehicle direction.

The typical digital or Hall effect wheel speed sensor uses three wires:

1. A reference voltage from the controller which can be 5, 8 or 12 volts depending on the system
2. Signal wire that sends a digital on-off signal to the controller whose frequency is proportional to the vehicle speed.
3. A ground

The sensor voltage toggles between about 0.8V and 1.9V. ● **SEE FIGURE 106–14.**

ABS CONTROL MODULE

CONTROL MODULE TERMS The ABS electronic control module, which may be referred to as an "electronic brake control module" (EBCM), "electronic brake module" (EBM), or "controller antilock brakes" (CAB) module, is a digital microprocessor that uses inputs from its various sensors to regulate hydraulic pressure during braking to prevent wheel lockup. The module may be located on the hydraulic modulator assembly (as it is on many of the newer compact ABS systems), or it may be located elsewhere in the vehicle, such as the trunk, passenger compartment, or under the hood.

MODULE INPUTS The key inputs for the ABS control module come from the wheel speed sensors and the brake pedal switch. ● **SEE FIGURE 106–15.**

The brake pedal switch signals the control module when the brakes are being applied, which causes it to go from a "standby" mode to an active mode. At the same time, the wheel speed sensors provide information about what is happening to the wheels while the brakes are being applied.

NOTE: A fault with the brake switch will not prevent ABS operation. The brake switch allows the controller to react faster to an ABS event.

MODULE OPERATION If the control module detects a difference in the deceleration rate between one or more wheels when braking, or if the overall rate of deceleration is too fast and exceeds the limits programmed into the control module, it triggers the ABS control module to momentarily take over. The control module cycles the solenoid valves in the modulator assembly to pulsate hydraulic pressure in the affected brake circuit (or circuits) until sensor information indicates that the deceleration rates have returned to normal and braking is under control. Normal braking resumes. When the brake pedal is released or when the vehicle comes to a stop, the control module returns to a standby mode until it is again needed.

ABS WARNING LAMP Every ABS system has an amber indicator lamp on the instrument panel that warns the driver when a problem occurs within the ABS system. The lamp comes on when the ignition is turned on for a bulb check, then goes out after the engine starts. If the warning light remains on or comes on while driving, it usually indicates a fault in the ABS system that will require further diagnosis. On most applications, the ABS system disables if the ABS warning light comes on and remains on. This should have no effect on normal braking, unless the red brake warning lamp is also on. The ABS warning light is also used for diagnostic purposes when retrieving **flash codes** (trouble codes) from the ABS module.

HYDRAULIC MODULATOR ASSEMBLY

PURPOSE AND FUNCTION The modulator valve body is part of the master cylinder assembly in nonintegral antilock systems but separate in nonintegral systems. It contains solenoid valves for each brake unit (in Delphi ABS-VI applications, however, motor-driven valves are used instead of solenoids). The exact number of valves per circuit depends on the ABS system and the application. Some use a pair of on-off solenoid valves for each brake circuit while others use a single valve that can operate in more than one position.

ABS SOLENOID A solenoid consists of a wire coil with a movable core and a return spring. When current from the ABS control module energizes the coil, it pulls on the movable core. Depending on how the solenoid is constructed, this may open or close a valve that is attached to the movable core. When the control current is shut off, the solenoid snaps back to its normal or rest position.

Some solenoids are designed to do more than just switch on or off to open or close a valve. Some pull a valve to an intermediate position when a certain level of current is applied to the coil, then pull the valve to a third position when additional current is provided. ● **SEE FIGURE 106–16.**

This design allows a single solenoid to perform the same functions as two or even three single-position solenoids.

The solenoids in the hydraulic modulator assembly are used to open and close passageways between the master cylinder and the individual brake circuits. By opening or closing the modulator valves to which they're attached, brake pressure within any given circuit can be held, released, and reapplied to prevent lockup during hard braking.

ABS CONTROL PRESSURE STAGES The standard ABS control strategy that is used is a three-step cycle:

- The first step is to hold or isolate the pressure in a given brake circuit by closing an **isolation solenoid** in the modulator assembly. This solenoid is normally electrically and

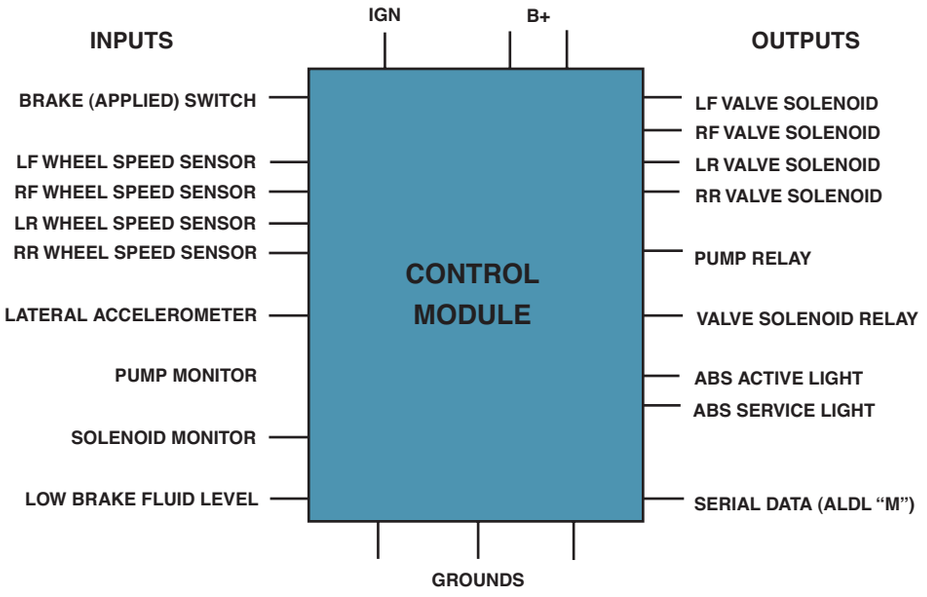


FIGURE 106–15 Typical inputs and outputs for brake control modules.

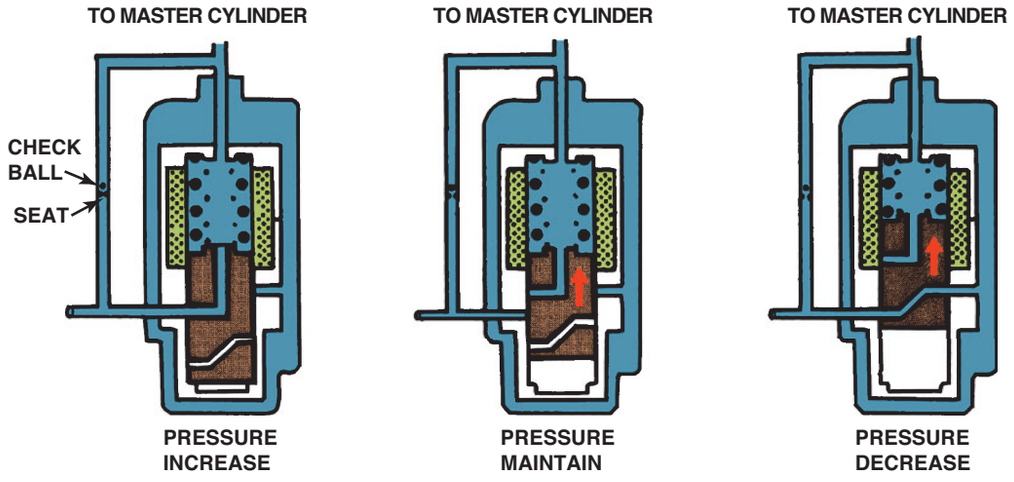


FIGURE 106–16 An ABS three-way solenoid can increase, maintain, or decrease brake pressure to a given brake circuit.

hydraulically open. ● **SEE FIGURE 106–17.** When the solenoid is electrically closed, it becomes hydraulically closed, which blocks off the line and prevents any further pressure from the master cylinder reaching the brake. This is called the **pressure holding stage.**

- If the wheel speed sensor continues to indicate the wheel is slowing too quickly and is starting to lock, the same solenoid or a second **release solenoid** is energized to open a vent port that releases pressure from the brake circuit. ● **SEE FIGURE 106–18.** The fluid is usually routed into a spring-loaded or pressurized storage reservoir (called an **accumulator**) so it can be reused as needed. Releasing pressure in the brake circuit allows the brake to loosen its grip so the wheel can speed up and regain traction. This is called **pressure reduction, pressure release, pressure decay,** or **pressure dump stage.** The pressure reduction solenoid is normally hydraulically closed and electrically opened.
- The release and/or isolation solenoid(s) are then closed and/or the additional solenoid energized so pressure can be reapplied to the brake from the master cylinder or accumulator to reapply the brake. ● **SEE FIGURE 106–19.** This is called the **pressure increase stage.** During the pressure increase stages, the isolation solenoid is electrically and hydraulically opened. The pressure reduction solenoid is electrically opened and hydraulically closed.

The hold-release-reapply cycle repeats as many times as needed until the vehicle either comes to a halt or the driver releases the brake pedal. The speed at which this occurs depends on the particular ABS system that is on the vehicle, but can range from a few times per second up to dozens of times per second.

PUMP MOTOR AND ACCUMULATOR

A high-pressure electric pump is used in some ABS systems to generate power assist for normal braking as well as the reapplication of brake pressure during ABS braking. ● **SEE FIGURE 106–20.** In some systems, it is used only for the reapplication of pressure during ABS braking.

The pump motor is energized by a relay, which is switched on and off by the ABS control module. The fluid pressure generated by the pump is stored in the accumulator. Some ABS systems have more than one accumulator. The accumulator on ABS systems, where the hydraulic modulator is part of the master cylinder assembly, consists of a pressure storage chamber filled with nitrogen gas.

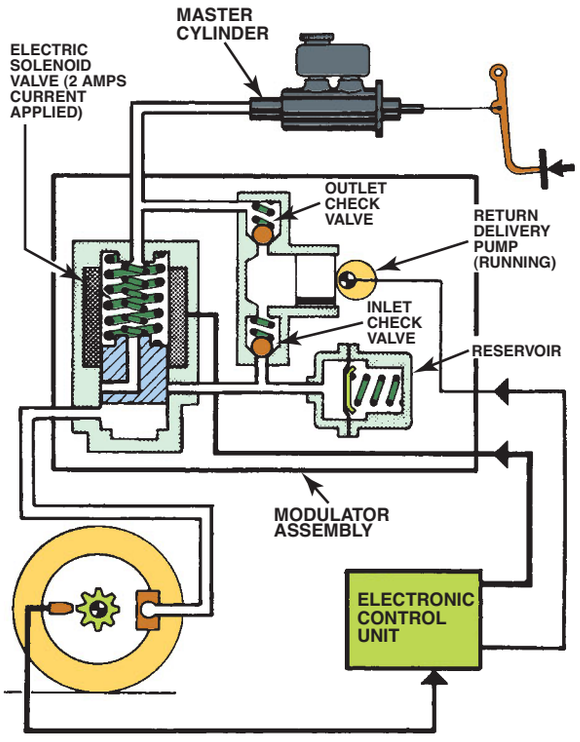


FIGURE 106–17 The isolation or hold phase of an ABS on a Bosch 2 system.

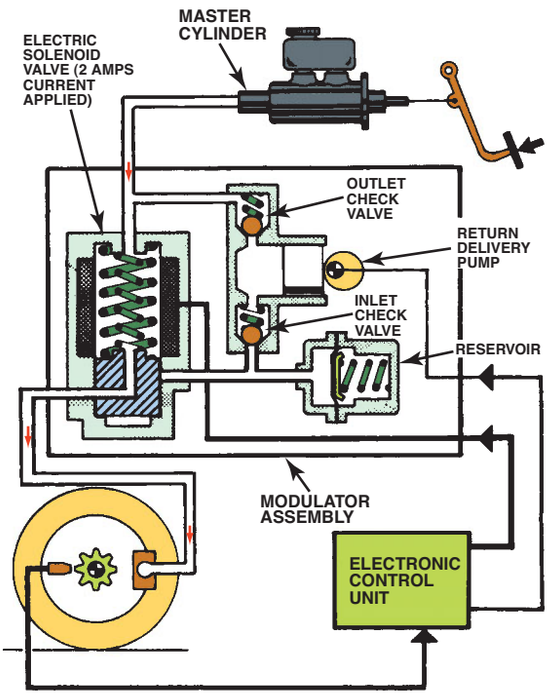


FIGURE 106–19 The control module reapplies pressure to the affected brake circuit once the tire achieves traction so that normal braking can continue.

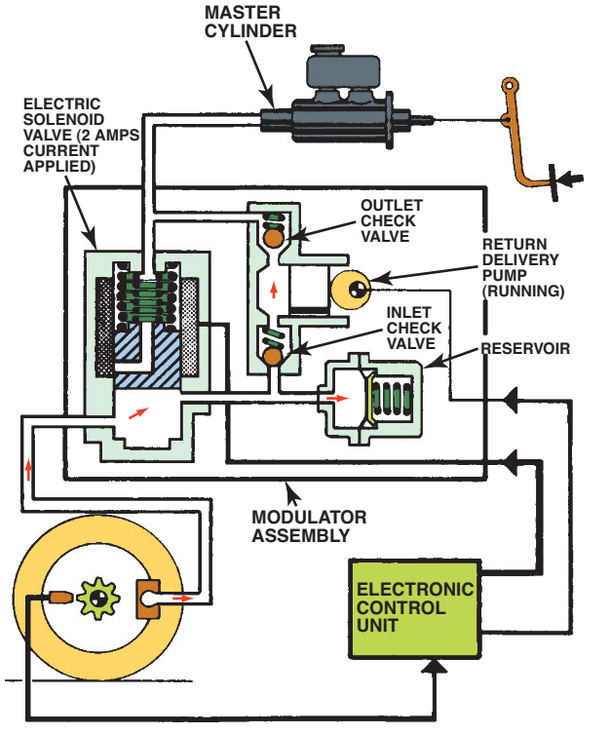


FIGURE 106–18 During the pressure reduction stage, pressure is vented from the brake circuit so the tire can speed up and regain traction.

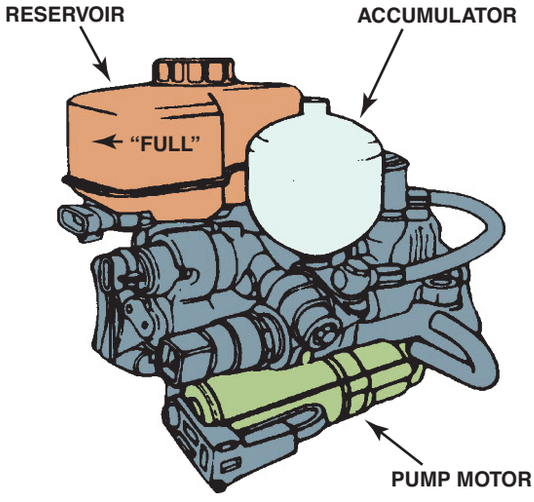


FIGURE 106–20 An integral ABS unit with a pump motor to provide power assist during all phases of braking and brake pressure during ABS stops.

A thick rubber diaphragm forms a barrier between the nitrogen gas and brake fluid. As fluid is pumped into the accumulator, it compresses the gas and stores pressure. When the brake pedal is depressed, pressure from the accumulator flows to the master cylinder to provide power assist.

A pair of pressure switches mounted in the accumulator circuit signals the ABS control module to energize the pump when pressure falls below a preset minimum, then to shut the pump off once pressure is built back up.

Should the pump fail (a warning lamp comes on when reserve pressure drops too low), there is usually enough reserve pressure in the accumulator for 10 to 20 power-assisted stops. After that, there is no power assist. The brakes still work, but with greatly increased effort.

On ABS systems that have a conventional master cylinder and vacuum booster for power assist, a small accumulator or pair of accumulators may be used as temporary storage reservoirs for brake fluid during the hold-release-reapply cycle. This type of accumulator typically uses a spring-loaded diaphragm rather than a nitrogen-charged chamber to store pressure.

ACCUMULATOR PRECAUTIONS A fully charged accumulator in an integral ABS system can store up to 2,700 PSI (19,000 kPa)

TECH TIP

Best to Keep Stock Tire Diameter

Vehicles equipped with antilock brakes are "programmed" to pulse the brakes at just the right rate for maximum braking effectiveness. A larger tire rotates at a slower speed and a smaller-than-normal tire rotates at a faster speed. Therefore, tire size affects the speed and rate of change in speed of the wheels as measured by the wheel speed sensors.

While changing tire size will not prevent ABS operation, it will cause less effective braking during hard braking with the ABS activated. Using the smaller spare tire can create such a difference in wheel speed compared with the other wheels that a false wheel speed sensor code may be set and an amber ABS warning lamp on the dash may light. However, most ABS systems will still function with the spare tire installed, but the braking performance will not be as effective. For best overall performance, always replace tires with the same size and type as specified by the vehicle manufacturer.

of pressure for power-assist braking and for reapplying the brakes during the hold-release-reapply cycle for antilock braking. This stored pressure represents a potential hazard for a brake technician who is servicing the brakes, so the accumulator should be depressurized prior to doing any type of brake service work by pumping the brake pedal 25 to 40 times with the ignition key off.

In nonintegral ABS systems where an accumulator is used to temporarily hold fluid during the release phase of the hold-release-reapply ABS cycle, the accumulator consists of a spring-loaded diaphragm. This type of accumulator does not have to be depressurized prior to performing brake service.

Always check service information for the exact procedures and precautions to follow when servicing any antilock braking system (ABS) service.

BRAKE PEDAL FEEDBACK

Many ABS units force brake fluid back into the master cylinder under pressure during an ABS stop. This pulsing brake fluid return causes the brake pedal to pulsate. Some vehicle manufacturers use the pulsation of the brake pedal to inform the driver that the wheels are tending toward lockup and that the ABS is pulsing the brakes.

NOTE: A pulsating brake pedal may be normal only during an ABS stop. It is not normal for a vehicle with ABS to have a pulsating pedal during normal braking when the ABS system is not functioning. If the brake pedal is pulsating during a non-ABS stop, the brake drums or rotor may be warped.

Some manufacturers use an isolation valve that prevents brake pedal pulsation even during an ABS stop.

BRAKE PEDAL TRAVEL SWITCH (SENSOR)

PURPOSE AND FUNCTION Some ABS systems, such as the Teves Mark IV system, use a brake pedal travel switch (sensor). The purpose of the switch is to turn on the hydraulic pump when the brake pedal has been depressed to 40% of its travel. The pump runs and pumps brake fluid back into the master cylinder, which raises the brake pedal until the switch closes again, turning off the pump.

The brake pedal switch is an input for the electronic controller. When the brakes are applied, the electronic controller "gets ready" to act if ABS needs to "initialize" the starting sequence of events.

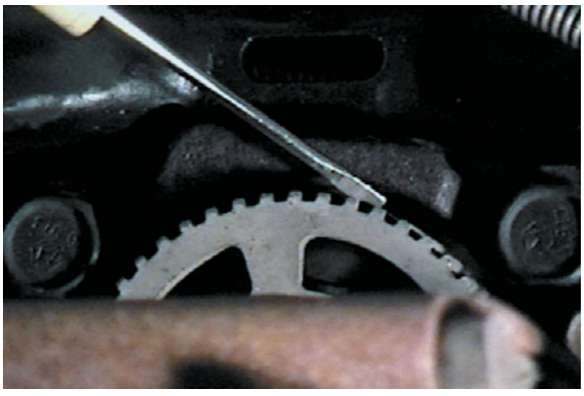
CAUTION: If the driver pumps the brakes during an ABS event, the controller will reset and reinitialization starts over again. This resetting process can disrupt normal ABS operation. The driver need only depress and hold the brake pedal down during a stop for best operation.

TIRE PRESSURE MONITORING SYSTEM (TPMS)

Tire pressure monitoring systems (TPMS) are required on all new vehicles. The type often used before the 2008 model year was an *indirect* system that used the wheel speed sensors. A tire that is underinflated will have a slightly smaller rolling radius than one that is properly inflated. This will create a difference in the wheel speed sensor reading if the difference in inflation pressure is 12 PSI or more. The ABS controller will then turn on the *low tire pressure* warning lamp to warn the driver that tires need attention. To help compensate for speed variation during cornering, an indirect tire pressure monitoring system checks the rotating speeds of diagonally opposed wheels. The system adds the speeds of the right front and left rear and then subtracts that value from the sum of the left front and right rear tires. If the total is less than or equal to a threshold value, no warning is given. However, if the total is greater than a predetermined value, the TPMS warning light is illuminated. The warning lamp will stay on until air is added to the tire and the ignition is cycled off and on.

NOTE: This system cannot detect if all of the tires are underinflated, only if one tire is underinflated and this indirect system is not used in 2008 or newer vehicles because it does not directly measure tire inflation pressure as required by the Tread Act.

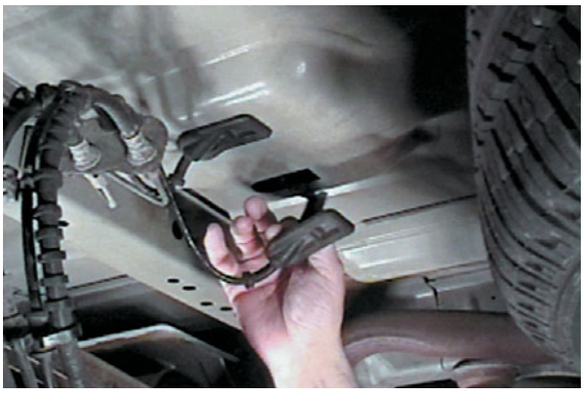
WHEEL SPEED SENSOR



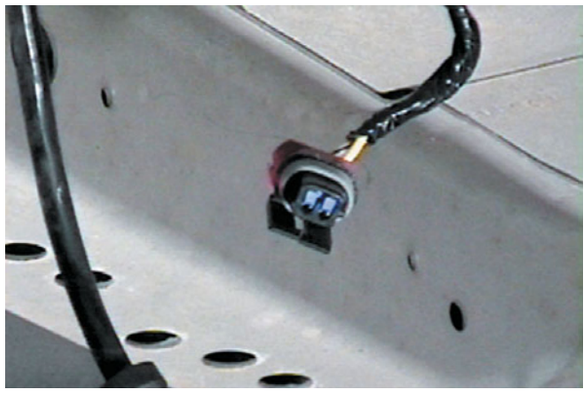
1 A tone ring and a wheel speed sensor on the rear of a Dodge Caravan.



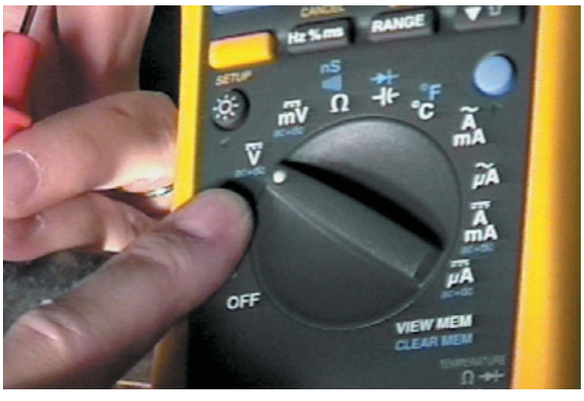
2 The wiring from the wheel speed sensor should be inspected for damage.



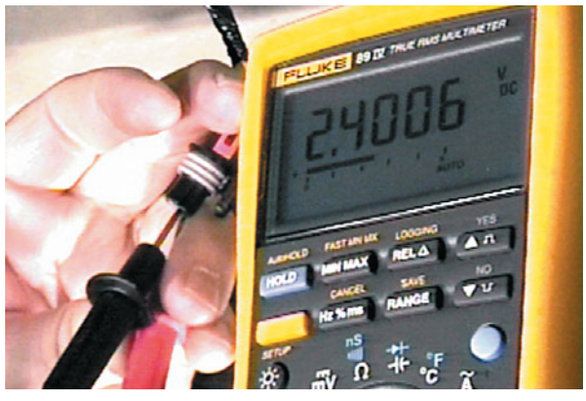
3 To test a wheel speed sensor, disconnect the sensor connector to gain access to the terminals.



4 Pulling down the rubber seal reveals the connector.



5 The ABS controller (computer) on this vehicle supplies a 2.5-volt reference signal to the wheel speed sensors. Set the meter to read DC volts and test at the computer end of the connector for voltage.



6 The meter reads about 2.4 volts, indicating that the ABS controller is supplying the voltage to the wheel speed sensor.



7 Set meter to read Ohms. The test probes are touched to the terminals leading to the wheel speed sensor and the resistance is 1.1032 k ohms or 1,103.2 ohms.



8 With one lead connected to the sensor terminal and the other to a ground, The meter should (and does) read "OL," indicating that the wheel speed sensor and pigtail wiring is not shorted to ground.



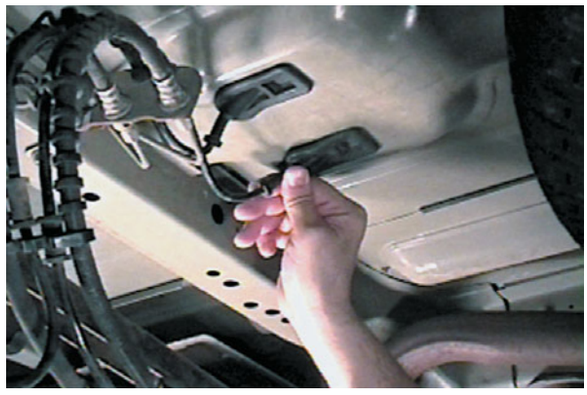
9 To measure the output of the wheel speed sensor, select AC volts on the digital multimeter.



10 Rotate the wheel and tire assembly by hand while observing the AC voltage output on the digital multimeter.



11 A good wheel speed sensor should be able to produce at least 100 mV (0.1 V) when the wheel is spun by hand.



12 After testing, carefully reinstall the wiring connector into the body and under the rubber grommet.

REVIEW QUESTIONS

1. Describe how an antilock braking system (ABS) works.
2. List the three stages of ABS operation.
3. Explain how wheel speed sensors work.
4. Describe the difference between a three- and a four-channel system.

CHAPTER QUIZ

1. Technician A says that the ABS system may not result in shorter stopping distance compared to brakes without ABS. Technician B says that a pulsating brake pedal during normal braking is a characteristic feature of most ABS-equipped vehicles. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
2. The maximum traction between a tire and the road occurs when the tire is _____.
   a. Locked and skidding **c.** Slipping 10% to 20%
   b. Rotating freely **d.** Slipping 80% to 90%
3. Technician A says that ABS-equipped vehicles can stop quickly and without skidding on all road surfaces even if covered with ice. Technician B says that steering is possible during an ABS stop. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
4. A customer wanted the ABS checked because of tire chirp noise during hard braking. Technician A says that the speed sensors may be defective. Technician B says that tire chirp is normal during an ABS stop on dry pavement. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
5. Two technicians are discussing ABS wheel speed sensors. Technician A says that some ABS systems use a sensor located in the rear-axle pinion gear area. Technician B says that all ABS systems use a wheel speed sensor at each wheel. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
6. Technician A says that most ABS units are non-integral. Technician B says that the ABS is disabled (does not function) below about 5 mph (8 km/h). Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
7. Which type of antilock braking system (ABS) requires the use of four wheel speed sensors?
   a. one channel **c.** three channel
   b. two channel **d.** four channel
8. Technician A says that ABS brakes are designed to allow the front wheel to be steered during heavy braking. Technician B says that the ABS dash warning lamp is amber. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
9. The faster a wheel rotates, the higher the frequency produced by a wheel speed sensor.
   a. True **b.** False
10. Technician A says that some wheel speed sensors are enclosed in a wheel bearing assembly. Technician B says that some wheel speed sensors are exposed to possible damage from road debris. Which technician is correct?
    a. Technician A only **c.** Both Technicians A and B
    b. Technician B only **d.** Neither Technician A nor B

chapter 107

ABS DIAGNOSIS AND SERVICE

OBJECTIVES: **After studying Chapter 107, the reader will be able to:** • Prepare for Brakes (A5) ASE certification test content area "F" (Antilock Brake System Diagnosis and Repair). • Explain the purpose and function of the red brake warning lamp. • Describe normal ABS dash lamp operation. • Discuss visual inspection of the various types and brands of ABS. • Explain how to retrieve trouble codes. • List the methods used to clear trouble codes. • Explain the various methods for bleeding ABS systems. • Discuss methods and tools needed to diagnose and service an ABS-equipped vehicle.

KEY TERMS: Amber ABS warning lamp 1221 • Breakout box (BOB) 1221 • Red brake warning lamp (RBWL) 1221

ABS DIAGNOSTIC PROCEDURE

Customer concerns about a fault with the antilock braking system can be best handled by performing the following:

STEP 1 **Verify the customer concern.** This step is very important because often a problem with the base brakes is thought by the customer to be a fault with the antilock braking system. It is helpful for the owner to drive the vehicle with a service technician if the problem is not readily apparent.

STEP 2 **Perform a visual inspection.** If both the red and the amber brake warning lights are on, look for a fault in the hydraulic system, including leaks or faults at the following locations:

- Master cylinder
- Electrohydraulic control unit
- Flexible brake hoses
- Brake lines and fittings
- Calipers and/or wheel cylinders

STEP 3 **Check for stored diagnostic trouble codes (DTCs).** Use a scan tool or other necessary methods to retrieve diagnostic trouble codes. If found, follow the specified factory procedures to isolate and determine the cause.

STEP 4 **Complete the repair.** This step may involve replacing a hydraulic component. If so, then the hydraulic system should be bled using the factory-specified procedure. Clear all diagnostic trouble codes.

STEP 5 **Verify the repair.** Always test drive the vehicle under the same conditions that were needed to verify the problem to be sure that the cause has been corrected.

BRAKE WARNING LAMP OPERATION

The first step in the visual diagnosis of an antilock braking system problem is to check the status of the brake warning lamps. ● **SEE FIGURE 107–1.**

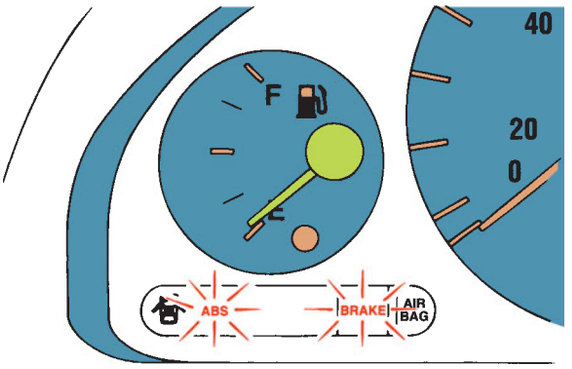


FIGURE 107–1 On most vehicles equipped with ABS, the amber ABS and red BRAKE warning lamp should come on as a bulb check when the ignition is first switched on.



FIGURE 107–2 A thorough visual inspection should include carefully inspecting around the electrohydraulic unit for signs of obvious problems or the installation of aftermarket devices such as alarm systems.

RED BRAKE WARNING LAMP

A **red brake warning lamp (RBWL)** warns of a possible dangerous failure in the base brakes, such as low brake fluid level or low pressure in half of the hydraulic system. The red brake warning lamp will also light if the parking brake is applied and may light due to an ABS failure, such as low brake pressure on an integral system.

AMBER ABS WARNING LAMP

The **amber ABS warning lamp** usually comes on after an engine start during the initialization or start-up self-test sequence. The exact time the amber lamp remains on after the ignition is turned on varies with the vehicle and the ABS design.

THOROUGH VISUAL INSPECTION

Many ABS-related problems can be diagnosed quickly if all the basics are carefully inspected. ● **SEE FIGURE 107–2.**

TECH TIP

Quick and Easy Wheel Speed Sensor Diagnosis

A fault in a wheel speed sensor (WSS) is a common ABS problem. A quick and easy test that works on most Bosch ABS systems (and perhaps others) involves the following steps:

STEP 1 Hoist the vehicle safely.

STEP 2 Turn the ignition on (engine off).

STEP 3 Spin a tire by hand as fast as possible.

STEP 4 The ABS amber warning light should come on, indicating that a speed was detected but not by all the wheel speed sensors.

STEP 5 Turn the ignition off to reset the ABS warning light.

STEP 6 Repeat the test on each of the remaining wheels.

If any wheel fails to turn on the ABS light, carefully inspect the wheel speed sensor for proper resistance and the tone ring and wiring. If the ABS light is on all the time and does not reset when the ignition is turned off, the problem is not caused by a wheel speed sensor.

FREQUENTLY ASKED QUESTION

What's That Noise and Vibration?

Many vehicle owners and service technicians have been disturbed to hear and feel an occasional groaning noise. It is usually heard and felt through the vehicle after first being started and driven. Because it occurs when first being driven in forward or reverse, many technicians have blamed the transmission or related driveline components. This is commonly heard on many ABS vehicles as part of a system check. As soon as the ABS controller senses speed from the wheel speed sensors after an ignition cycles on, the controller will run the pump either every time or whenever the accumulator pressure is below a certain level. This can occur while the vehicle is being backed out of a driveway or being driven forward because wheel sensors can only detect speed—not direction. Before serious and major repairs are attempted to "cure" a noise, make sure that it is not the normal ABS self-test activation sequence of events.

A thorough visual inspection should include the following items:

Brake fluid level	Check the condition and level of the brake fluid.
Brake fluid leaks	Check for cracks in flexible lines or other physical damage. Check for wetness at any fitting or steel brake line.
Fuses and fusible links	Check all ABS-related fuses.
Wiring and connections	Check all wiring, especially wheel speed sensor leads, for damage.
Wheel speed sensors	Check that the sensor ring teeth are not damaged. Clean debris from the sensor if possible.

NOTE: Most wheel speed sensors are magnetic and therefore can attract and hold metallic particles. Be sure to remove any metallic debris from around the magnetic wheel speed sensor.

Base brake components	All base brake components, such as disc brake calipers, drum brake wheel cylinders, and related components, must be in proper working condition.
Parking brake	Check that the parking brake is correctly adjusted and fully released.
Wheel bearings	All wheel bearings must be free of defects and adjusted properly.
Wheels and tires	Check for correct size, proper inflation, and legal tread depth.

TEST DRIVE AND VERIFY THE FAULT

A test drive is a very important diagnostic procedure. Many ABS systems and diagnostic trouble codes (DTCs) will not set unless the vehicle is moving. Often, the driver has noticed something like the self-test while driving and believed it to be a fault in the system.

NOTE: Some ABS units, such as the Delphi VI, will cause the brake pedal to move up and down slightly during cycling of the valves during the self-test. Each system has unique features. The service technician will have to learn to avoid attempting to repair a problem that is not a fault of the system.

Before driving, start the engine and observe the red and amber brake warning lamps. If the red brake warning lamp is on, the base brakes may not be functioning correctly. Do not drive the vehicle until the base brakes are restored to proper operation.

General Motors ABS Summary Guide

Type of ABS System	Code Clearing Procedure	Scan Tool* Code Retrieval
Teves IV Nonintegral	Yes	Yes
Bosch 2U Nonintegral	Yes	Yes
Delphi (Delco) VI	Yes	Yes
Bosch 2S	Yes	Yes
Delco Powermaster III	Yes	Yes
Kelsey-Hayes RWAL	Yes or disconnect the ABS fuse	Yes or flash codes
Kelsey-Hayes 4WAL	Yes	Yes

*A jumper key can be used for some systems. Not all scan tools can perform all functions.

Ford ABS Summary Guide

Type of ABS System	Code Clearing Procedure	Scan Tool* Code Retrieval
Teves IV Nonintegral	Drive the vehicle after the repair.	Yes
Kelsey-Hayes RABS	Drive the vehicle after the repair.	Flash codes
Teves 4WABS	Drive the vehicle after the repair.	Yes

*A jumper wire can be used on some systems. Not all scan tools can perform all functions.

NOTE: Some systems are diagnosed by "antilock" and "brake" warning lamps, vehicle symptoms, and the use of a breakout box.

Chrysler ABS Summary Guide

Type of ABS System	Code Clearing Procedure	Scan Tool* Code Retrieval
Bendix 6 Nonintegral	Yes or disconnect the battery	Yes
Bosch MMC	Yes	Yes
Bosch 2U Nonintegral	No codes available on this system	No codes available on this system
Teves Mark IV	Yes	Yes
Kelsey-Hayes RWAL	Disconnect the battery	Flash codes
Kelsey-Hayes 4WAL	Yes	Yes

*A jumper wire can be used on some systems. Not all scan tools can perform all functions.

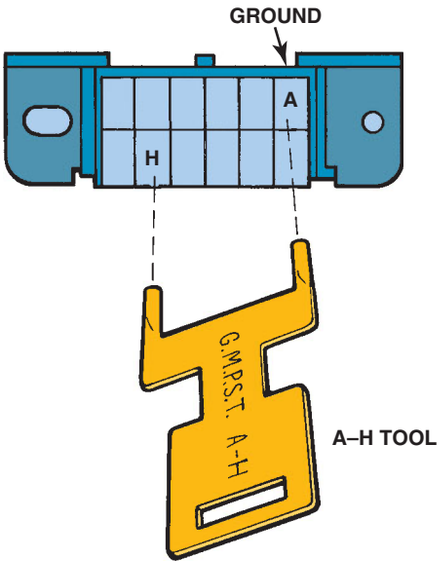


FIGURE 107–3 General Motors diagnostic connector on a pre-1996 vehicle. Flash codes are available by using a jumper wire to ground (terminal A) to terminal H.

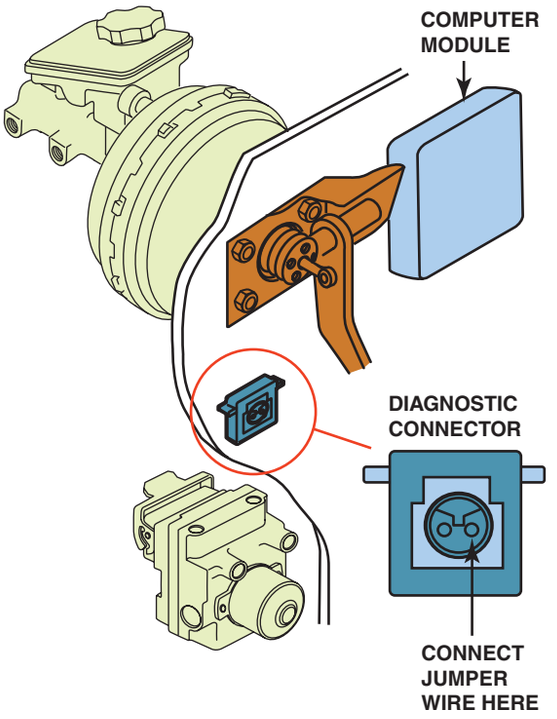


FIGURE 107–4 Connecting a jumper wire from the diagnostic connector to ground. The exact location of this diagnostic connector varies with the exact vehicle model and year.

RETRIEVING DIAGNOSTIC TROUBLE CODES

After performing a thorough visual inspection and after verifying the customer's complaint, retrieve any stored ABS-related diagnostic trouble codes (DTCs). The exact procedure varies with the type of ABS and with the make, model, and year of the vehicle.

Always consult factory service information for the vehicle being diagnosed. Some systems can only display flash codes (flashing ABS or brake lamp in sequence), whereas other systems can perform self-diagnosis and give all information to the technician through a scan tool.

NOTE: With some early antilock braking systems, the diagnostic trouble code is lost if the ignition is turned "off" before grounding the diagnostic connector.

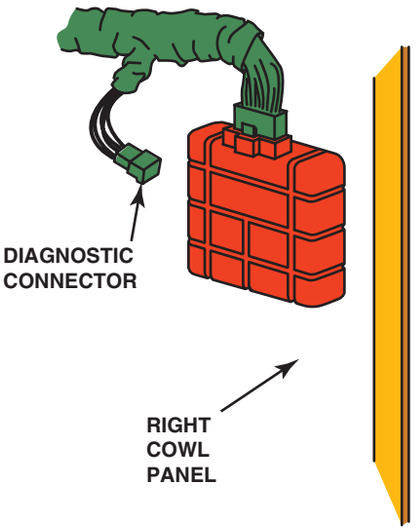


FIGURE 107–5 Chrysler diagnostic connector location varies with the model and year.

KELSEY-HAYES ANTILOCK (NONINTEGRAL)

The Kelsey-Hayes rear-wheel antilock uses two solenoids and valves to control the rear-wheel brakes. Kelsey-Hayes four-wheel antilock uses the computer to pulse the valves rather than turning them on or off. The pulsing is called pulse-width modulated (PWM) and the valve is called a PWM valve.

RETRIEVING DIAGNOSTIC TROUBLE CODES GM trucks' (RWAL) DTCs are retrieved by flash codes or scan data through the use of a scan tool or connect H to A at the data link connector (DLC). ● **SEE FIGURE 107–3.**

NOTE: Be sure that the brake warning lamp is on before trying to retrieve DTCs. If the lamp is not on, a false code 9 could be set.

Ford RABS DTCs are retrieved by jumper lead flash codes only. ● **SEE FIGURE 107–4.**

Dodge light truck DTCs are retrieved by ground diagnostic connections. ● **SEE FIGURE 107–5.**

NOTE: If the ignition is turned off, the failure code will be lost unless it is a hard code that will be present when the ignition is turned back on.

REAL WORLD FIX

RWAL Diagnosis

The owner of an S-10 pickup truck complained that the red brake warning lamp on the dash remained on even when the parking brake was released. The problem could be one of the following:

1. A serious hydraulic problem
2. Low brake fluid
3. A stuck or defective parking brake switch
4. If the brake lamp is dim, RWAL trouble is indicated.

The technician found that the brake lamp was on dimly, indicating that an antilock braking problem was detected. The first step in diagnosing an antilock braking problem with a dash lamp on is to check for stored trouble codes. The technician used a jumper between terminals A and H on the DLC (ALCL), and four flashes of the brake lamp indicated a code 4.

Checking a service manual, code 4 was found to be a grounded switch inside the hydraulic control unit. The hardest part about the repair was getting access to, and the replacement of, the defective (electrically grounded) switch. After bleeding the system and a thorough test drive, the lamp sequence and RWAL functioned correctly.

Kelsey-Hayes RWAL ABS Diagnostic Trouble Codes

Code	Description
2	Open isolation valve solenoid circuit or malfunctioning EBCM/VCM
3	Open dump valve solenoid circuit or malfunctioning EBCM/VCM
4	Grounded valve reset switch circuit
5	Excessive actuations of dump valve during antilock braking
6	Erratic speed signal
7	Shorted isolation valve circuit or faulty EBCM/VCM
8	Shorted dump valve circuit or faulty EBCM/VCM
9	Open or grounded circuit to vehicle speed sensor
10	Brake switch circuit
12 to 17	Computer malfunction

NOTE: A scan tool may or may not be able to retrieve or display diagnostic trouble codes. Check with the technical literature for the specific vehicle being scanned.

BOSCH 2 ABS (NONINTEGRAL)

The Bosch 2U/2S ABS is used on many domestic and imported brands of vehicles.

RETRIEVING DIAGNOSTIC TROUBLE CODES

On General Motors vehicles, DTCs can be retrieved by connecting A to H at the data link connector (DLC). On most Bosch 2 systems, a scan tool can and should be used if available to retrieve DTC.

REAL WORLD FIX

The Nervous Taurus

A customer complained that, sometimes during normal braking, the ABS would be activated just before coming to a stop. However, the ABS light would not come on. The service technician was able to duplicate the condition and there were no DTCs stored. Using a scan tool to monitor the wheel speed sensors, the technician discovered that the left front wheel speed was slightly different than the others. A thorough visual inspection revealed that the tone wheel (sensor ring) was cracked. This crack created a different wheel speed signal to the ABS controller than the other wheels and the controller activated the ABS as it would normally—that was why there were no DTCs.

Other things that could have caused this problem, which is often called "false modulation," include a bent wheel, mismatched tire sizes, or metal debris around the sensor.

Kelsey-Hayes 4WAL Diagnostic Trouble Codes

Code	Description
12	System normal (2WD applications)
13	System normal—brake applied (2WD applications)
14	System normal (4WD/AWD applications)
15	System normal—brake applied (4WD/AWD applications)
21 RF	Speed sensor circuit open
25 LF	
31 RR	
35 LR	
35	VSS circuit open
22 RF	Missing speed sensor signal
26 LF	
32 RR	
36 LR	
36	Missing VSS signal
23 RF	Erratic speed sensor signal
27 LF	
33 RR	
37 LR	
37	Erratic VSS signal
28	Simultaneous dropout of front-wheel speed sensors
29	Simultaneous dropout of all speed sensors
35	Vehicle speed sensor circuit open
36	Missing LR or vehicle speed sensor signal
37	Erratic LR or vehicle speed sensor signal
38	Wheel speed error
41 to 66	Malfunctioning BPMV/EHCU
67	Open motor circuit or shorted EBCM output
68	Locked motor or shorted motor circuit
71 to 74	Memory failure
81	Open or shorted brake switch circuit
86	Shorted ABS warning lamp
88	Shorted red brake warning lamp (RBWL)

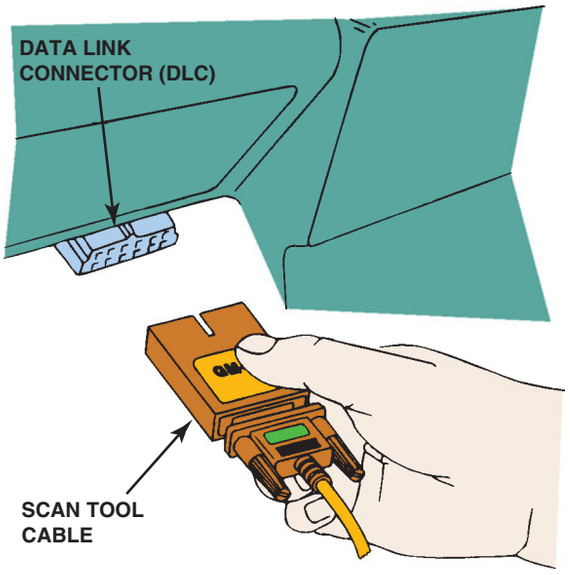


FIGURE 107–6 A scan tool is the recommended method to use to access General Motors Teves Mark IV systems.

Bosch 2U/2S ABS Diagnostic Trouble Codes

Code	Description
12	Diagnostic system operational
21 RF	Wheel speed sensor fault
25 LF	
32 RR	
35 LR	
35	Rear-axle speed sensor fault
22 RF	Toothed wheel frequency error
26 LF	
32 RR	
36 LR	
36	Rear-axle toothed wheel frequency error
41 RF	Valve solenoid fault
45 LF	
55	Rear valve solenoid fault
61	Pump motor or motor relay fault
63	Solenoid valve relay fault
71	Electronic brake control module (EBCM) fault
72	Serial data link fault
74	Low voltage
75	Lateral acceleration sensor fault
76	Lateral acceleration sensor fault

TEVES MARK IV

The Teves Mark IV is a nonintegral (remote) ABS system.

RETRIEVING DIAGNOSTIC TROUBLE CODES Trouble codes are accessed only by a bidirectional scan tool connected to the data link connector (DLC). ● **SEE FIGURE 107–6.**

Teves Mark IV ABS Diagnostic Trouble Codes

Code	Description
21	RF speed sensor circuit open
22	RF speed sensor signal erratic
23	RF wheel speed is 0 mph
25	LF speed sensor circuit open
26	LF speed sensor signal erratic
27	LF wheel speed is 0 mph
31	RR speed sensor circuit open
32	RR speed sensor signal erratic
33	RR wheel speed is 0 mph
35	LR speed sensor circuit open
36	LR speed sensor signal erratic
37	LR wheel speed is 0 mph
41	RF inlet valve circuit
42	RF outlet valve circuit
43	RF speed sensor noisy
45	LF inlet valve circuit
46	LF outlet valve circuit
47	LF speed sensor noisy
51	RR inlet valve circuit
52	RR outlet valve circuit
53	RR speed sensor noisy
55	LR inlet valve circuit
56	LR outlet valve circuit
57	LR speed sensor noisy
61	Pump motor test fault
62	Pump motor fault in ABS stop
71	EBCM check sum error
72	TCC/antilock braking switch circuit
73	Fluid level switch circuit

CLEARING DIAGNOSTIC TROUBLE CODES A scan tool is required to clear DTCs on some vehicles. Driving the vehicle over 20 mph (32 km/h) will clear the codes on some vehicles. Disconnecting the battery will also clear the codes but will cause other "keep-alive" functions of the vehicle to be lost.

DELPHI (DELCO) ABS-VI (NONINTEGRAL)

The Delphi (Delco) ABS-VI is unique from all other antilock systems because it uses motor-driven ball screws and pistons for brake pressure to reduce, hold, and apply. ● **SEE FIGURE 107–7.**

RETRIEVING DIAGNOSTIC CODES The Delphi (Delco) VI antilock braking system has extensive self-diagnostic capability. Access to this vast amount of information requires the use of a scan tool designed to interface (work) with the Delphi VI system.

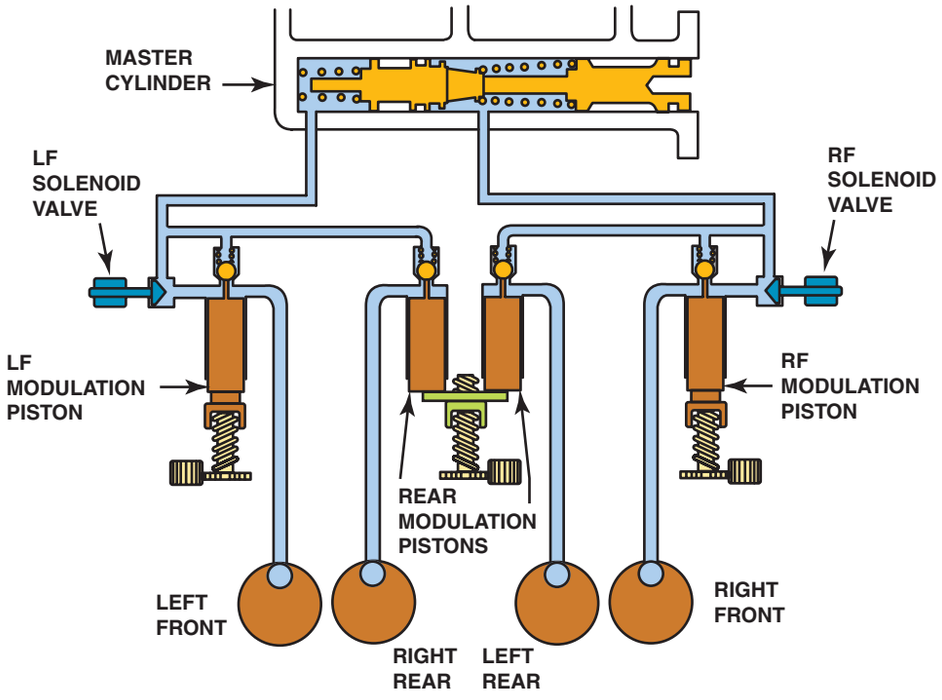


FIGURE 107–7 The Delphi (Delco) VI attaches to the side of the master cylinder and connects hydraulically through transfer tube assemblies.

Delphi (Delco) ABS-VI Diagnostic Trouble Codes

Code	Description
11	ABS lamp open or shorted to ground
13	ABS lamp circuit shorted to battery
14	Enable relay contacts open, fuse open
15	Enable relay contacts shorted to battery
16	Enable relay coil circuit open
17	Enable relay coil shorted to ground
18	Enable relay coil shorted to B1 or 0 ohms
21	Left-front wheel speed
23	Left-rear wheel speed
24	Right-rear wheel speed
25	Excessive left-front wheel acceleration
26	Excessive right-front wheel acceleration
27	Excessive left-rear wheel acceleration
28	Excessive right-rear wheel acceleration
31	Two-wheel speed sensors open
36	System voltage is low
37	System voltage is high
38	Left-front EMB will not hold motor
41	Right-front EMB will not hold motor
42	Rear-axle ESB will not hold motor
44	Left-front EMB will not release motor, gears frozen
45	Right-front EMB will not release motor, gears frozen
46	Rear-axle ESB will not release motor, gears frozen
47	Left-front nut failure (motor free-spins)
48	Right-front nut failure (motor free-spins)
51	Rear-axle nut failure (motor free-spins)
52	Left-front channel in release too long
53	Right-front channel in release too long

Code	Description
54	Rear axle in release too long
55	Motor driver interface (MDI) fault detected
56	Left-front motor circuit open
57	Left-front motor circuit shorted to ground
58	Left-front motor circuit shorted to battery
61	Right-front motor circuit open
62	Right-front motor circuit shorted to ground
63	Right-front motor circuit shorted to battery
64	Rear-axle motor circuit open
65	Rear-axle motor circuit shorted to ground
66	Rear-axle motor circuit shorted to battery
67	Left-front EMB release circuit open or shorted to ground
68	Left-front EMB release circuit shorted to battery or driver open
71	Right-front EMB release circuit open or shorted to ground
72	Right-front EMB release circuit shorted to battery or driver open
76	Left-front solenoid circuit open or shorted to battery
77	Left-front solenoid circuit shorted to ground or driver open
78	Right-front solenoid circuit open or shorted to battery
81	Right-front solenoid circuit shorted to battery or driver open
82	Calibration memory failure
86	ABS controller turned “on”; red brake telltale circuit fault
87	Red brake telltale circuit open

Code	Description
88	Red brake telltale circuit shorted to battery or driver open
91	Open brake switch contacts (deceleration detected)
92	Open brake switch contacts
93	Test 91 or 92 failed last or current ignition cycle
94	Brake switch contacts shorted
95	Brake switch circuit open
96	Brake lamps open, brake lamp ground open, center high-mounted stop lamp open during four-way flasher operations

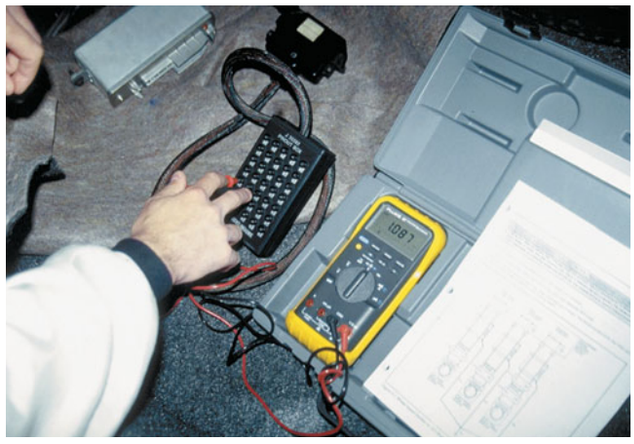


FIGURE 107–8 A breakout box is being used to diagnose an ABS problem. The controller (computer) is located in the trunk of this vehicle, and a digital multimeter is being used to measure resistance and voltage at various points in the system, following the service manual procedure.

REAL WORLD FIX

The Mystery ABS Amber Warning Light

The owner of an Acura Legend complained to a service technician that the ABS warning light would come on but only while driving down from a parking garage. When the driver turned off the ignition and restarted the engine, the ABS amber light was not on and did not come on again until the vehicle was again driven down the spiral parking garage ramp. The service technician used a scan tool and found that no DTCs had been stored.

NOTE: Some ABS systems will not retain a DTC unless the problem is currently present and the ABS amber warning light is on.

All of the brakes were in excellent condition, but the brake fluid level was down a little. After topping off the master cylinder with clean DOT 3 brake fluid, the vehicle was returned to the customer with the following information:

- The ABS amber warning light may have been triggered by the brake fluid level switch. While driving down the steep parking garage ramp, the brake fluid moved away from the fluid level sensor.

  NOTE: While the brake fluid level sensor normally would turn on the red brake warning light, in some systems it turns on the amber ABS light if the brake fluid falls below a certain level in the ABS reservoir.

- The difference in wheel speed between the outboard and the inboard wheels could have triggered a fault code for a wheel speed sensor during the drive down the spiral parking garage ramp.

TECH TIP

Sometimes It Pays to Look at the Entire Vehicle

There are often strange electrical problems that can occur including false DTCs or intermittent operation of electrical sensors, ABS, accessories, or gauges. Sometimes the root of these problems is due to rust and corrosion after a vehicle is involved in a flood. Here are some telltale signs that a vehicle may have been in a flood or in deep water.

- Mud, silt, or caked dust under the dash and inside the doors
- Corroded electrical connectors at the computer, fuse box, or ABS controller (computer)
- Visible water line in the doors or behind panels
- Rust in abnormal places such as seat springs or brackets behind the dash
- Moisture in lenses
- Musty smell and/or strong air freshener smell
- Powdery corrosion on aluminum parts such as intake manifold and inside the throttle bore
- Rust or moisture inside electrical switches or relays
- Areas that are normally dusty such as an ashtray or glove box are very clean

WHEEL SPEED SENSOR DIAGNOSIS

Wheel speed sensor (WSS) circuits are often the cause of many ABS problems. ● **SEE FIGURE 107–8.** These components may suffer from physical damage, buildup of metallic debris on the sensor tip, corrosion, poor electrical connections, and damaged wiring.

Test a WSS by measuring its output voltage and circuit continuity. A **breakout box (BOB)** cable connects to the ABS harness near the ABS module. All WSS resistance checks, including the wiring to the sensors, can be measured at one location. ● **SEE FIGURE 107–9.**

Follow the equipment manufacturer's instructions for connecting the breakout box to the vehicle, and for probing the appropriate pins on the breakout box.

RESISTANCE MEASUREMENT The resistors of most WSS range from 800 Ω to 1,400 Ω. Therefore, a reading of about 1,000 ohms or 1 KΩ would indicate proper sensor coil resistance. ● **SEE FIGURE 107–10.**

CHECKING FOR SHORT-TO-GROUND Connect either lead of the ohmmeter to one of the WSS wires and the other to a good,

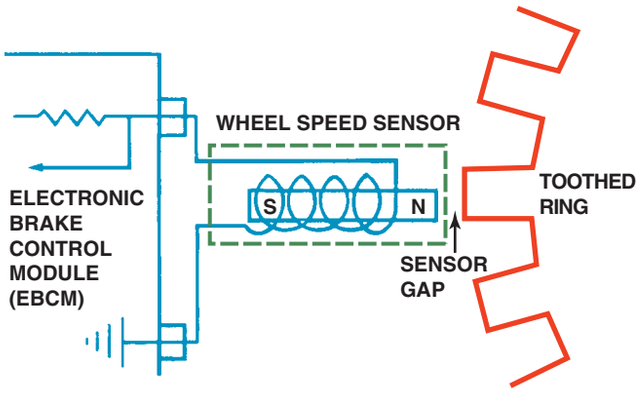


FIGURE 107–9 Typical wheel speed sensor. When a tooth on the sensor ring is close to the sensor, the strength of the magnetic field is stronger because the metal of the tooth conducts magnetic lines of force better than air. When the tooth moves away, the magnetic field strength is reduced. It is this changing magnetic field strength that produces the changing voltage. Frequency of the signal is determined by the speed of the rotating sensor.

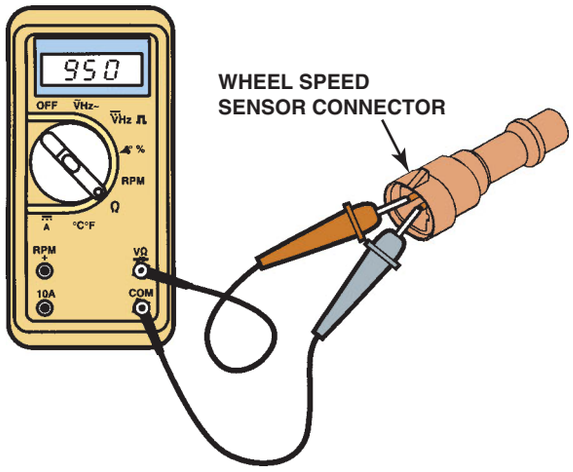


FIGURE 107–10 Measuring the resistance of a wheel speed sensor.

clean chassis ground. The resistance should be infinity (OL). If a low resistance reading is obtained, the sensor or sensor wiring is shorted-to-ground and must be replaced.

AC VOLTAGE CHECK Connect a digital meter to the WSS terminals or input to the controller in the breakout box and set the meter to read AC volts. Rotate the wheel by hand at a rate of one revolution per second. A good WSS should produce voltage of at least 0.1 volt (100 mV). A sensor voltage of lower than 0.1 volt (100 mV) may be caused by three things.

1. Excessive clearance between the sensor and the tone ring.
2. Buildup of debris on the end of the sensor. Most wheel speed sensors are magnetic and can attract metallic particles, which can affect the operation of the sensor.
3. Excessive resistance in the sensor or sensor wiring, which can also cause a weak signal to be produced by the WSS.

DC BIAS VOLTAGE Some ABS system apply a 2.5 volt DC voltage to the wheel speed sensors. This DC voltage is a called a bias voltage and is used by the ABS controller to detect fault in the sensor or sensor wiring such as an open circuit or a short to ground.

SCOPE TESTING Attach the scope leads to the sensor terminals or to the input connector on the breakout box. Rotate the wheel by hand or by using engine power with the vehicle safely hoisted with all four wheels off the ground.

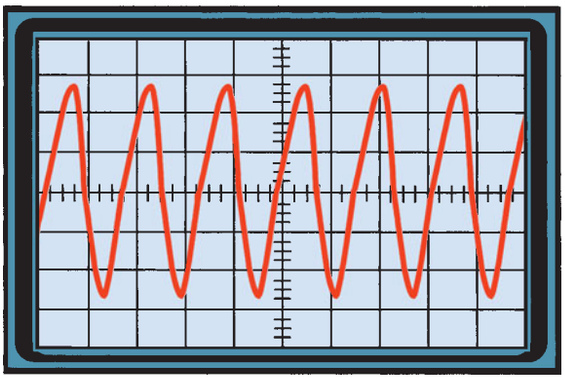


FIGURE 107–11 A scope can be used to check for proper operation of a wheel speed sensor.

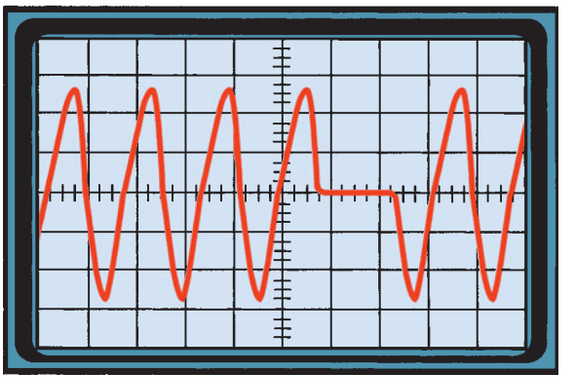


FIGURE 107–12 A broken tooth on a wheel speed sensor tone ring shows on the scope trace as a missing wave.

- A good WSS should produce an alternating current (AC) sine wave signal that increases in frequency and amplitude with increasing wheel speed. ● **SEE FIGURE 107–11.**
- Damaged or missing teeth on the tone ring will cause flat spots or gaps in the sine wave pattern. ● **SEE FIGURE 107–12.**
- A bent axle or hub will produce a wavelike pattern that fluctuates as the strength of the sensor signal changes with each revolution.

SCAN TOOL TESTING A scan tool can be used to check for the proper operation of the WSS. As an assistant drives the vehicle, connect the scan tool and monitor the speed of all of the sensors. All of the sensors should indicate the same speed. If a sensor shows a slower or faster speed than the others, carefully check the tone ring for damage such as a crack.

WHEEL SPEED SENSOR ADJUSTMENT

Some ABS applications use adjustable wheel speed sensors. Most sensors adjust by first loosening a set screw, then inserting a nonmagnetic brass or plastic feeler gauge between the tip of the sensor and a high point on the tone ring. ● **SEE FIGURE 107–13.**

Adjust the position of the sensor so there is a slight drag on the feeler gauge, and then tighten the setscrew to lock the sensor in place.

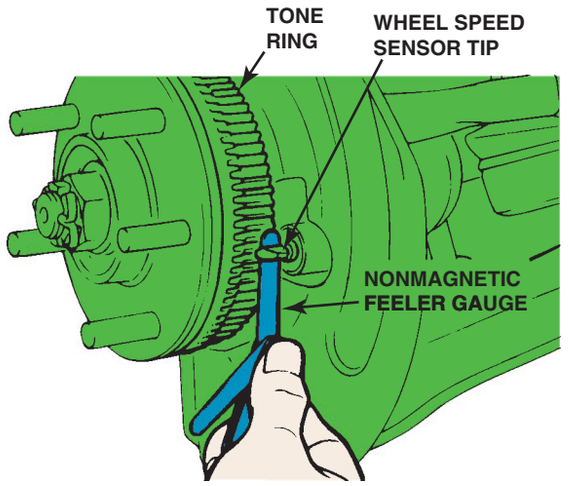


FIGURE 107–13 Use a nonmagnetic brass or plastic feeler gauge to check wheel speed sensor gap. A steel gauge would be attracted by the magnet in the sensor and would produce a drag on the gauge as it is moved between the sensor and the tone ring. This drag could be interpreted as a correct clearance reading.

When installing new sensors, look for a piece of paper or plastic on the tip end of the unit. This is more than a protective covering and must be left in place during installation. The paper or plastic is the precise thickness to guarantee a correct air gap between the tip of the sensor and the tone ring. Adjust the sensor so the tip just touches the tone ring and you can slip the paper or plastic out without ripping it. Tighten the setscrew and the air gap is properly set. ● **SEE FIGURE 107–14.**

Some manufacturers recommend leaving a paper covering in place. The motion of the tone ring removes it after the vehicle is driven for several miles.

DIGITAL WHEEL SPEED SENSOR DIAGNOSIS

Test a digital WSS by first checking that battery voltage is available at the sensor with the key on, engine off. If the sensor does not have 12 volts, then the problem is most likely in the ABS controller or the wiring between the controller and the sensor.

If there are 12 volts at the sensor, measure the signal voltage. The voltage should switch from about 0.8V to about 1.9V as the wheel is rotated by hand.

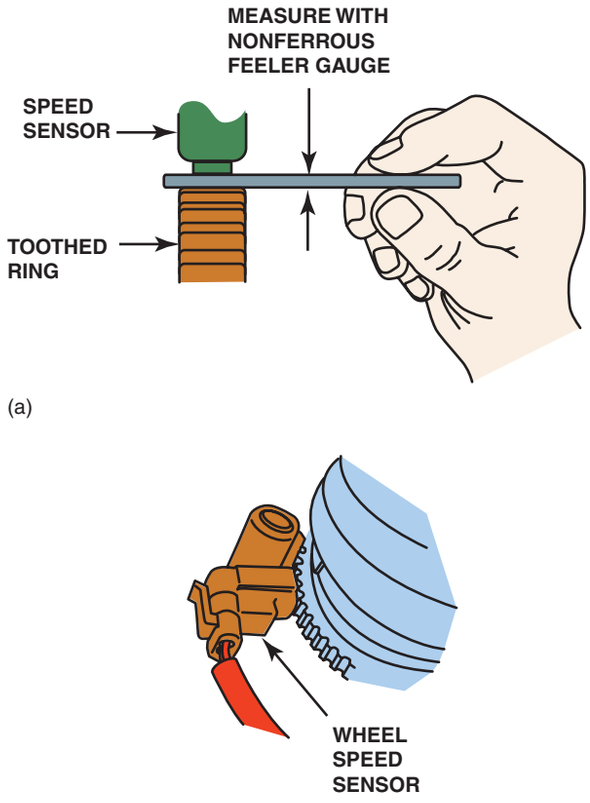


FIGURE 107–14 (a) Always use a nonferrous (brass or plastic) feeler (thickness) gauge when measuring the gap between the toothed ring and the wheel speed sensor. (b) Sometimes a sensor is equipped with a paper spacer that is the exact thickness of the spacing required between the toothed ring and the sensor. If equipped, the sensor is simply installed with the paper touching the toothed wheel. A typical gap ranges from 0.020 to 0.050 in. (0.5 to 1.3 mm).

TECH TIP

Space Saver Spare Tire May Trigger Wheel Speed Fault Code

If a vehicle has been using a small space saver-type spare tire, then the difference in outside diameter may trigger a wheel speed sensor diagnostic trouble code (DTC) and turn on the amber ABS warning lamp. Try to find out from the customer if they had driven on a spare tire before replacing a wheel speed sensor based on a stored DTC.

OBD-II ABS DIAGNOSIS

VEHICLES 1996 AND NEWER

Most vehicle built since 1996 use the OBD-II diagnostic connector to transmit ABS diagnostic trouble code information to a scan tool. A factory scan tool or an enhanced factory level scan tool will be needed to retrieve ABS diagnostic trouble codes (DTCs) and scan tool data such as wheel speed sensor information.

SCAN TOOLS NEEDED FOR ABS DIAGNOSIS

Scan tools are the workhorse for any diagnostic work on all vehicles. Scan tools can be divided into two basic groups:

1. **Factory scan tools.** These are the scan tools required by all dealers that sell and service the brand of vehicle. Examples of factory scan tools include the following:
   - **General Motors**—Tech 2. ● **See FIGURE 107–8.**
   - **Ford**—New Generation Star (NGS) and IDS (Integrated Diagnostic Software).
   - **Chrysler**—DRB III, Star Scan or wiTECH for CAN-equipped vehicles.
   - **Honda**—HDS or Master Tech
   - **Toyota**—Techstream

   All factory scan tools are designed to provide bidirectional capability, which allows the service technician the opportunity to operate components using the scan tool, thereby confirming that the component is able to work when commanded. Also, all factory scan tools are capable of displaying all factory parameters.

2. **Aftermarket scan tools.** These scan tools are designed to function on more than one brand of vehicle. Examples of aftermarket scan tools include the following:
   - *Snap-on* (various models including the MT2500 and Modis) *OTC* (various models including Pegasus, Genisys and Task Master)
   - *AutoEnginuity* and other programs that use a laptop or handheld computer for the display While many aftermarket scan tools can display most if not all of the parameters of the factory scan tool, there can be a difference when trying to troubleshoot some faults.

DIAGNOSTIC PROCEDURE To diagnosis a fault in the antilock brake system, check service information for the exact procedure to follow. These steps usually include:

STEP 1 Verify the fault. Make sure that the fault is in the antilock system and not caused by a fault in the base brakes.

STEP 2 Retrieve any stored diagnostic trouble codes. See ● **see CHART 107–1** for a list of generic antilock braking system related "C" codes.

STEP 3 Perform detailed tests to find the root cause.

STEP 4 Verfity the repair of the fault and clear any stored diagnostic trouble codes.

C0000 - Vehicle Speed Information Circuit Malfunction	C0241 - EBCM Control Valve Circuit
C0035 - Left Front Wheel Speed Circuit Malfunction	C0245 - Wheel Speed Sensor Frequency Error
C0040 - Right Front Wheel Speed Circuit Malfunction	C0254 - EBCM Control Valve Circuit
C0041 - Right Front Wheel Speed Sensor Circuit Range/Performance (EBCM)	C0265 - EBCM Relay Circuit
C0045 - Left Rear Wheel Speed Circuit Malfunction	C0266 - EBCM Relay Circuit
C0046 - Left Rear Wheel Speed Sensor Circuit Range/Performance (EBCM)	C0267 - Pump Motor Circuit Open/Shorted
C0050 - Right Rear Wheel Speed Circuit Malfunction	C0268 - Pump Motor Circuit Open/Shorted
C0051 - LF Wheel Speed Sensor Circuit Range/Performance (EBCM)	C0269 - Excessive Dump/Isolation Time
C0060 - Left Front ABS Solenoid #1 Circuit Malfunction	C0271 - EBCM Malfunction
C0065 - Left Front ABS Solenoid #2 Circuit Malfunction	C0272 - EBCM Malfunction
C0070 - Right Front ABS Solenoid #1 Circuit Malfunction	C0273 - EBCM Malfunction
C0075 - Right Front ABS Solenoid #2 Circuit Malfunction	C0274 - Excessive Dump/Isolation Time
C0080 - Left Rear ABS Solenoid #1 Circuit Malfunction	C0279 - Powertrain Configuration Not Valid
C0085 - Left Rear ABS Solenoid #2 Circuit Malfunction	C0281 - Brake Switch Circuit
C0090 - Right Rear ABS Solenoid #1 Circuit Malfunction	C0283 - Traction Switch Shorted to Ground
C0095 - Right Rear ABS Solenoid #2 Circuit Malfunction	C0284 - EBCM Malfunction
C0110 - Pump Motor Circuit Malfunction	C0286 - ABS Indicator Lamp Circuit Shorted to B[plus]
C0121 - Valve Relay Circuit Malfunction	C0287 - Delivered Torque Circuit
C0128 - Low Brake Fluid Circuit Low	C0288 - Brake Warning Lamp Circuit Shorted to B[plus]
C0141 - Left TCS Solenoid #1 Circuit Malfunction	C0290 - Lost Communications With PCM
C0146 - Left TCS Solenoid #2 Circuit Malfunction	C0292 - Lost Communications With PCM
C0151 - Right TCS Solenoid #1 Circuit Malfunction	C0291 - Lost Communications With BCM
C0156 - Right TCS Solenoid #2 Circuit Malfunction	C0297 - Powertrain Configuration Data Not Received
C0161 - ABS/TCS Brake Switch Circuit Malfunction	C0298 - Powertrain Indicated Traction Control Malfunction
C0221 - Right Front Wheel Speed Sensor Circuit Open	C0300 - Rear Speed Sensor Malfunction
C0222 - Right Front Wheel Speed Signal Missing	C0305 - Front Speed Sensor Malfunction
C0223 - Right Front Wheel Speed Signal Erratic	C0306 - Motor A or B Circuit
C0225 - Left Front Wheel Speed Sensor Circuit Open	C0308 - Motor A/B Circuit Low
C0226 - Left Front Wheel Speed Signal Missing	C0309 - Motor A/B Circuit High
C0227 - Left Front Wheel Speed Signal Erratic	C0310 - Motor A/B Circuit Open
C0229 - Drop Out of Front Wheel Speed Signals	C0315 - Motor Ground Circuit Open
C0235 - Rear Wheel Speed Signal Circuit Open	C0321 - Transfer Case Lock Circuit
C0236 - Rear Wheel Speed Signal Circuit Missing	C0323 - T-Case Lock Circuit Low
C0237 - Rear Wheel Speed Signal Erratic	C0324 - T-Case Lock Circuit High
C0238 - Wheel Speed Mismatch	C0327 - Encoder Circuit Malfunction
	C0357 - Park Switch Circuit High
	C0359 - Four wheel drive Low Range (4LO) Discrete Output Circuit

CHART 107–1

C0362 - 4LO Discrete Output Circuit High	C0584 - Right Front Solenoid Circuit Open
C0367 - Front Axle Control Circuit High	C0587 - Left Rear Solenoid Circuit Low
C0374 - General System Malfunction	C0588 - Left Rear Solenoid Circuit High
C0376 - Front/Rear Shaft Speed Mismatch	C0589 - Left Rear Solenoid Circuit Open
C0379 - Front Axle System	C0592 - Right Rear Solenoid Circuit Low
C0387 - Unable to Perform Shift	C0593 - Right Rear Solenoid Circuit High
C0472 - Steering Handwheel Speed Sensor Signal V Low	C0594 - Right Rear Solenoid Circuit Open
C0473 - Steering Handwheel Speed Sensor Signal V High	C0611 - VIN Information Error
C0495 - EVO Tracking Error	C0615 - Left Front Position Sensor Malfunction
C0498 - Steering Assist Control Actuator Feed Circuit Low	C0620 - Right Front Position Sensor Malfunction
C0499 - Steering Assist Control Solenoid Feed Circuit High	C0625 - Left Rear Position Sensor Malfunction
C0503 - Steering Assist Control Solenoid Return Circuit Low	C0628 - Level Control Position Sensor Circuit High
C0504 - Steering Assist Control Solenoid Return Circuit High	C0630 - Right Rear Position Sensor Malfunction
C0550 - ECU Malfunction - internal write / checksum malfunction	C0635 - Left Front Normal Force Circuit Malfunction
C0559 - EEPROM Checksum Error	C0638 - Left Front Normal Force Circuit High
C0563 - Calibration ROM Checksum Error	C0640 - Right Front Normal Force Circuit Malfunction
C0577 - Left Front Solenoid Circuit Low	C0643 - Right Front Normal Force Circuit High
C0578 - Left Front Solenoid Circuit High	C0655 - Level Control Compressor Relay Malfunction
C0579 - Left Front Solenoid Circuit Open	C0657 - Level Control Compressor Circuit Low
C0582 - Right Front Solenoid Circuit Low	C0658 - Level Control Compressor Circuit High
C0583 - Right Front Solenoid Circuit High	C0660 - Level Control Exhaust Valve Circuit Malfunction

CHART 107–1

ABS SAFETY PRECAUTIONS

1. Avoid mounting the antenna for the transmitting device near the ABS control unit. Transmitting devices include cellular (cell) telephones, citizen-band radios, and so on.
2. Avoid mounting tires of different diameter than that of the original tires. Different size tires generate different wheel speed sensor frequencies, which may not be usable by the ABS controller.
3. Never open a bleeder valve or loosen a hydraulic line while the ABS is pressurized. The accumulator must be depressurized according to the manufacturer's recommended procedures.
4. If arc welding on a vehicle, disconnect all computers (electronic control modules) to avoid possible damage due to voltage spikes.
5. Do not pry against or hit the wheel speed sensor ring.

REVIEW QUESTIONS

1. Describe the proper operation of the red and amber brake warning lamps.
2. List the items that should be checked as part of a thorough visual inspection.
3. Explain how to retrieve a diagnostic trouble code from a General Motors vehicle equipped with Kelsey-Hayes RWAL ABS.
4. Describe how to use a breakout box to check for proper wheel speed sensor operation.

CHAPTER QUIZ

1. The red brake warning lamp is on and the amber ABS lamp is off. Technician A says that a fault is possible in the base brake system. Technician B says that the red brake warning lamp can be turned on by a low brake fluid level in the master cylinder. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
2. Two technicians are discussing magnetic-type wheel speed sensors. Technician A says that wheel speed sensors are magnetic. Technician B says that the toothed sensor ring is magnetic. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B

3. Technician A says that using the space-saving small spare tire may trigger an ABS amber warning lamp. Technician B says the use of the small spare tire may trigger the red brake warning lamp. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
4. Technician A says that, with some antilock braking systems, the diagnostic trouble code may be lost if the ignition is turned off before retrieving the code. Technician B says that some antilock braking systems require that a terminal be grounded to cause the amber ABS warning lamp to flash diagnostic trouble codes. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
5. Technician A says that a scan tool may be required to retrieve data and diagnostic trouble codes from some antilock braking systems. Technician B says that a jumper wire can be used to retrieve diagnostic trouble codes on some antilock braking systems. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
6. Technician A says that a breakout box is sometimes required to diagnose an antilock braking system. Technician B says that a breakout box requires the use of a digital multimeter. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
7. Technician A says that a noise or vibration may be sensed by the driver when the ABS performs a self test. Technician B says that the ABS fuse may have to be removed to erase some ABS diagnostic codes if a scan tool is not used. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
8. The ABS computer uses what signal characteristic from a wheel speed sensor?
   a. Voltage **c.** Resistance
   b. Frequency **d.** Electromagnetic
9. Most wheel speed sensors should measure how much resistance?
   a. 800 to 1,400 ohms **c.** 1 to 3 ohms
   b. 100 to 300 ohms **d.** 0.1 to 1 ohm
10. Technician A says that the ABS electrohydraulic unit can be bled using bleeder screws and the manual method. Technician B says that a scan tool is often required to bleed the ABS electrohydraulic unit. Which technician is correct?
    a. Technician A only **c.** Both Technicians A and B
    b. Technician B only **d.** Neither Technician A nor B

chapter 108 ELECTRONIC STABILITY CONTROL SYSTEMS

OBJECTIVES: **After studying Chapter 108, the reader will be able to:** • Prepare for Brakes (A5) ASE certification test content area "F" (Antilock Brake System Diagnosis and Repair). • Discuss how an electronic stability system works. • List the sensors needed for the ESC system. • Explain how the ESC system helps keep the vehicle under control. • Describe how a traction control system works. • List the steps in the diagnostic process for ESC and TC system faults.

KEY TERMS: Electronic brake control module (EBCM) 1234 • ESC 1232 • Hand-wheel position sensor 1234 • Lateral acceleration sensor 1235 • Oversteer 1233 • Positive slip 1236 • Sine with dwell (SWD) test 1233 • Steering wheel position sensor 1234 • Telltale light 1233 • Traction control (TC) 1236 • Understeer 1233 • Vehicle speed (VS) sensor 1234 • Yaw rate sensor 1235

THE NEED FOR ELECTRONIC STABILITY CONTROL

PURPOSE AND FUNCTION **Electronic stability control (ESC)** is a system designed to help drivers maintain control of their vehicles in situations where the vehicle is beginning to lose control. Keeping the vehicle on the road prevents run-off-road crashes, which are the conditions that lead to most single-vehicle accidents and rollovers.

SYSTEM REQUIREMENTS The ESC is defined as a system that has all of the following features:

1. Helps vehicle directional stability by applying and controlling individual wheel brakes to help bring the vehicle back to the intended direction.
2. Uses sensors to determine when the vehicle is not under control.

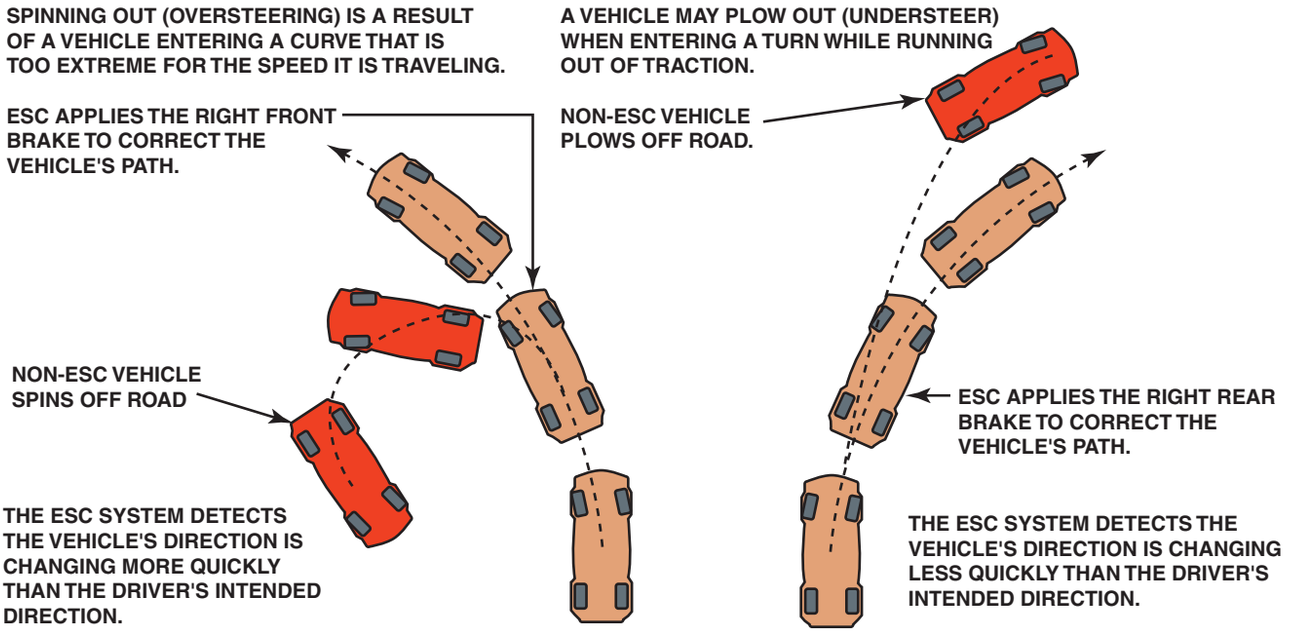


FIGURE 108–1 The electronic stability control (ESC) system applies individual wheel brakes to keep the vehicle under control of the driver.

3. Uses a steering wheel position sensor to determine the intended direction of the driver.
4. Operates at all vehicle speeds, except at low speeds where loss of control is unlikely.

The electronic stability control (ESC) system applies individual wheel brakes to bring the vehicle under control if either of the following conditions occur:

- **Oversteering**—In this condition, the rear of the vehicle tends to move outward or breaks loose, resulting in the vehicle spinning out of control. This condition is also called *loose.* If the condition is detected during a left turn, the ESC system would apply the right front brake to bring the vehicle back under control.
- **Understeering**—In this condition, the front of the vehicle tends to continue straight ahead when turning, a condition that is also called *plowing* or *tight.* If this condition is detected during a right turn, the ESC system would apply the right rear wheel brake to bring the vehicle back under control. ● **SEE FIGURE 108–1.**

NOTE: When the brakes are applied during these corrections, a thumping sound and vibration may be sensed.

TELLTALE LAMP. The ESC lamp, called a **telltale light,** is required to remain on for as long as a malfunction exists, whenever the ignition is in "On" ("Run") position. The ESC malfunction telltale will flash to indicate when the ESC system is operating to help restore vehicle stability.

ESC SWITCH. Some, but not all, vehicle manufacturers install a switch to temporarily disable or limit the ESC functions. This allows the driver to disengage ESC or limit the operation when the full ESC might not be needed such as:

- When a vehicle is stuck in sand/gravel
- When the vehicle is being operated on a racetrack for maximum performance

The electronic stability control system is turned back on when the ignition is turned off and then back on and is in the default position.

FEDERAL MOTOR VEHICLE SAFETY STANDARD (FMVSS) NO. 126

Federal Motor Vehicle Safety Standard (FMVSS) No. 126 (June 26, 2008), Electronic Stability Control Systems, requires that all passenger cars, multipurpose passenger vehicles, trucks, and buses that have a gross vehicle weight rating (GVWR) of 10,000 pounds (4,536 kg) or less to be equipped with an electronic stability control (ESC) system by September 1, 2011 (2012 model year vehicles).

The ESC system must meet the following requirements:

1. The ESC system must be able to apply all four brakes individually. This means that the vehicle must be equipped with a four-channel antilock braking system (ABS) which uses a wheel speed sensor at each wheel.
2. The ESC must be programmed to work during all phases of driving including acceleration, coasting, and deceleration (including braking).
3. The ESC system must work when the antilock brake system (ABS) or Traction Control is activated.

SINE WITH DWELL TEST

The standardized test used to determine if an electronic stability control system functions normally is called the **sine with dwell (SWD) test.** A vehicle is driven at 50 mph (80 km/h) on a curved course that looks like a sine wave or the letter "S" on its side. Then the vehicle is held in a straight-ahead position for 0.5 second (500 milliseconds) and before being steered back onto the curved section of the test. ● **SEE FIGURE 108–2.**

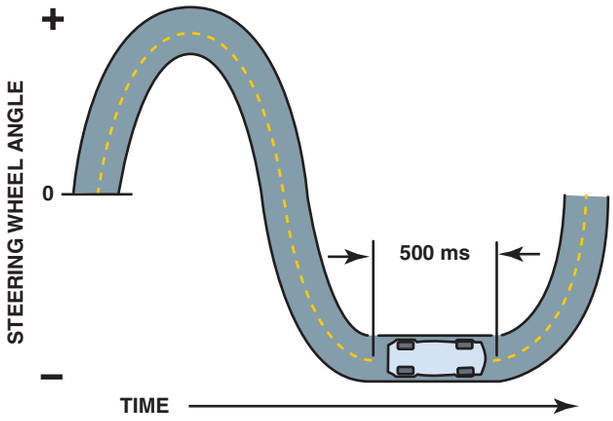


FIGURE 108–2 The sine with dwell test is designed to test the electronic stability control (ESC) system to determine if the system can keep the vehicle under control.

? **FREQUENTLY ASKED QUESTION**

Can a Vehicle with a Modified Suspension Pass the Test?

Yes, if the system is properly engineered. To be sure, check with the company offering a suspension kit to verify that the vehicle will still be able to pass the sine with dwell (SWD) test. This ensures that any changes are within the range where the ESC system can control the vehicle during emergency maneuvers. ● **SEE FIGURE 108–3.**

The quick changes involved in this test are designed to upset the chassis of the vehicle and cause the electronic stability control system to act to keep the vehicle under control during the entire test.

NAMES OF VARIOUS ESC SYSTEMS

Stability control systems are offered under the following names:

- **Acura:** Vehicle Stability Assist (VSA)
- **Audi:** Electronic Stabilization Program (ESP)
- **BMW:** Dynamic Stability Control (DSC), including Dynamic Traction Control
- **Chrysler:** Electronic Stability Program (ESP)
- **Dodge:** Electronic Stability Program (ESP)
- **Ferrari:** Controllo Stabilita (CST)
- **Ford:** AdvanceTrac and Interactive Vehicle Dynamics (IVD)
- **General Motors:** StabiliTrak (except Corvette—Active Handling)
- **Hyundai:** Electronic Stability Program (ESP)
- **Honda:** Electronic Stability Control (ESC), Vehicle Stability Assist (VSA), and Electronic Stability Program (ESP)
- **Infiniti:** Vehicle Dynamic Control (VDC)
- **Jaguar:** Dynamic Stability Control (DSC)
- **Jeep:** Electronic Stability Program (ESP)
- **Kia:** Electronic Stability Program (ESP)
- **Land Rover:** Dynamic Stability Control (DSC)



FIGURE 108–3 Using a simulator is the most cost-effective way for vehicle and aftermarket suspension manufacturers to check that the vehicle is able to perform within the FMVSS No. 126 standard for vehicle stability.

- **Lexus:** Vehicle Dynamics Integrated Management (VDIM) with Vehicle Stability Control (VSC) and Traction Control (TRAC) systems
- **Lincoln:** Advance Trak
- **Maserati:** Maserati Stability Program (MSP)
- **Mazda:** Dynamic Stability Control (DSC)
- **Mercedes:** Electronic Stability Program (ESP)
- **Mercury:** AdvanceTrak
- **Mini Cooper:** Dynamic Stability Control (DSC)
- **Mitsubishi:** Active Skid and Traction Control MULTIMODE
- **Nissan:** Vehicle Dynamic Control (VDC)
- **Porsche:** Porsche Stability Management (PSM)
- **Rover:** Dynamic Stability Control (DSC)
- **Saab:** Electronic Stability Program (ESP)
- **Saturn:** StabiliTrak
- **Subaru:** Vehicle Dynamics Control Systems (VDCS)
- **Suzuki:** Electronic Stability Program (ESP)
- **Toyota:** Vehicle Dynamics Integrated Management (VDIM) with Vehicle Stability Control (VSC)
- **Volvo:** Dynamic Stability and Traction Control (DSTC)
- **VW:** Electronic Stability Program (ESP)

ESC SENSORS

STEERING WHEEL POSITION SENSOR

Depending on the vehicle, the **steering wheel position sensor** may also be called a **hand-wheel position sensor.** The function of this sensor is to provide the computer with signals related to steering wheel position, speed and direction. ● **SEE FIGURES 108–4 AND 108–5.**

VEHICLE SPEED SENSOR

The **vehicle speed (VS) sensor** is used by the **Electronic Brake Control Module (EBCM)** to help control the suspension system. The vehicle speed sensor is a magnetic sensor and generates an analog signal whose frequency increases as the speed increases. ● **SEE FIGURE 108–6.**

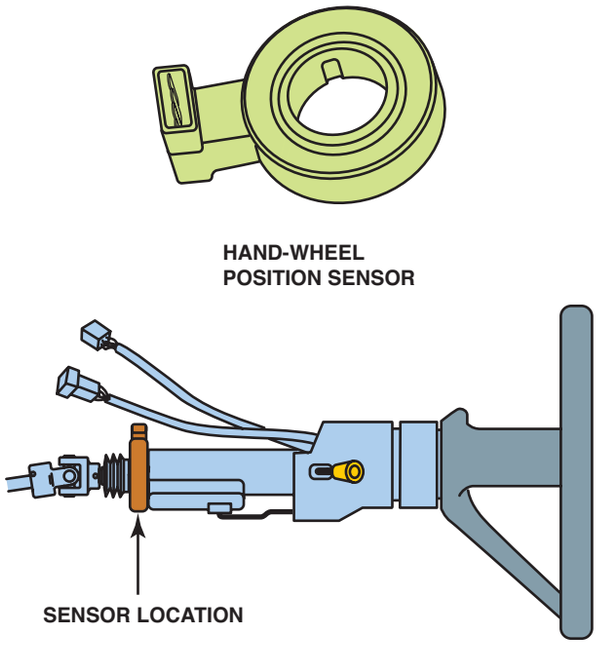


FIGURE 108–4 The hand-wheel position sensor is usually located at the base of the steering column.

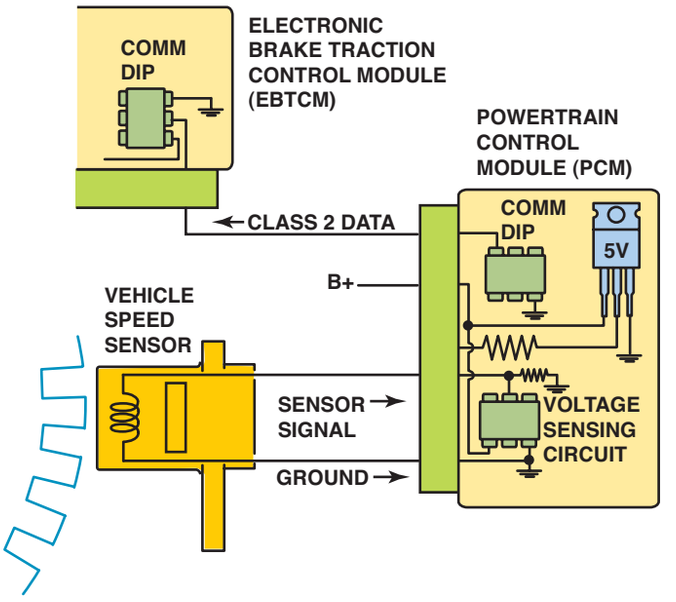


FIGURE 108–6 The VS sensor information is transmitted to the EBCM by Class 2 serial data.

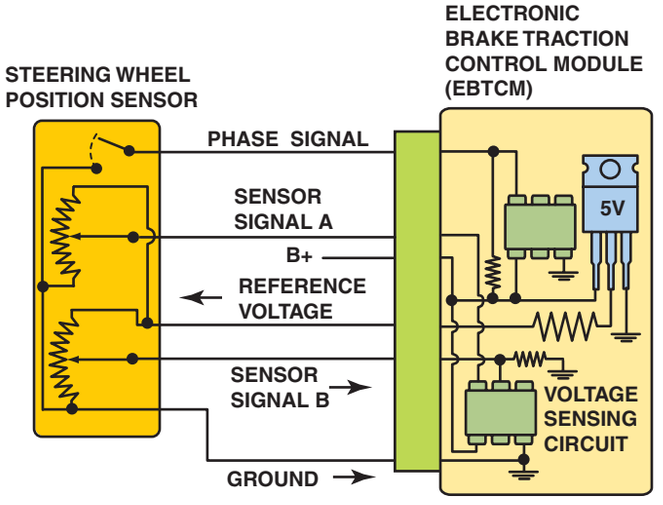


FIGURE 108–5 Hand-wheel (steering wheel) position sensor schematic.

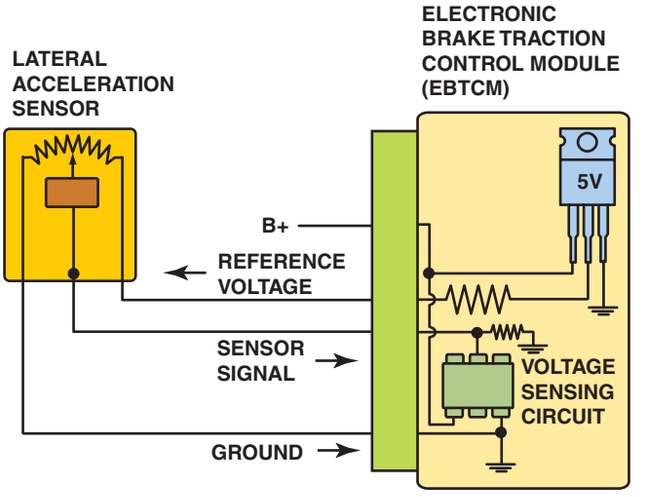


FIGURE 108–7 A schematic showing the lateral acceleration sensor and EBCM.

LATERAL ACCELERATION SENSOR

The function of the **lateral acceleration sensor** is to provide the suspension control module with feedback regarding vehicle cornering forces. This type of sensor is also called a G-sensor, with the letter "G" representing the force of gravity. For example, when a vehicle enters a turn, the sensor provides information as to how hard the vehicle is cornering. This information is processed by the suspension control module to provide appropriate damping on the inboard and outboard dampers during cornering events.

This sensor can be either a stand-alone unit or combined with the yaw rate sensor.

Typically, the sensor is mounted in the passenger compartment:

- under a front seat
- in the center console
- on the package shelf

● **SEE FIGURE 108–7.**

TECH TIP

Quick and Easy Lateral Acceleration Sensor Test

Most factory scan tools will display the value of sensors, including the lateral acceleration sensor. However, the sensor value will read zero unless the vehicle is cornering. A quick and easy test of the sensor is to simply unbolt the sensor and rotate it 90 degrees with the key on engine off. ● **SEE FIGURE 108–8.** Now the sensor is measuring the force of gravity and should display 1.0 G on the scan tool. If the sensor does not read close to 1.0 G or reads zero all of the time, the sensor or the wiring is defective.

YAW RATE SENSOR

The **yaw rate sensor** provides information to the suspension control module and the EBCM. This information is used to determine how far the vehicle has deviated from the driver's intended direction.



FIGURE 108–8 The lateral accelerometer sensor (G-sensor) is usually located under the center console.

This sensor can be either a stand-alone unit or combined with the lateral acceleration sensor. Typically, the sensor is mounted in the passenger compartment under the front seat, in the center console, or on the rear package shelf.

This sensor does set DTC codes. These codes can be found in service information. ● **SEE FIGURE 108–9.**

TRACTION CONTROL

PURPOSE AND FUNCTION

Traction control (TC) can be separate or used as part of the electronic stability control (ESC) system. Traction control allows an ABS system to control wheel spin during acceleration. When tires lose traction during acceleration, it is called **positive slip.**

Low-speed traction control uses the braking system to limit positive slip up to a vehicle speed of about 30 mph (48 km/h). Traction control is usually a part of the electronic stability control system. ● **SEE FIGURE 108–10.**

Traction control uses the same wheel speed sensors as ABS, but requires additional programming in the control module so the system monitors wheel speed continuously, not just when braking. Traction control also requires:

- Additional solenoids in the hydraulic modulator so the brake circuits to the drive wheels can be isolated from the non-drive wheels when braking is needed to control wheel spin.
- A pump and accumulator is used to generate and store pressure for traction control braking. If a wheel speed sensor detects wheel spin in one of the drive wheels during acceleration, the control module energizes a solenoid that allows stored fluid pressure from the accumulator to apply the brakes on the wheel that is spinning. This slows the wheel that is spinning and redirects engine torque through the differential to the opposite drive wheel to restore traction.

Traction control works just as well on front-wheel-drive vehicles as it does on rear-wheel-drive vehicles.

SYSTEM COMPONENTS

The main controller for the traction can include one of the following, depending on make, model, and year of vehicle:

1. The body control module (BCM)
2. The powertrain control module (PCM)
3. The antilock brake system (ABS) controller

The controller uses inputs from several sensors to determine if a loss of traction is occurring. The input signals used for traction control include:

- **Throttle position (TP) sensor** —This indicates the position of the throttle, which is the driver command for power.
- **Wheel speed sensor (WSS)** —The controller monitors all four wheel speed sensors. If one wheel is rotating faster than the other, this indicates that the tire is slipping or has lost traction.
- **Engine speed (RPM)** —This information is supplied from the engine controller powertrain control module (PCM) and indicates the speed of the engine.
- **Transmission range switch** —Determines which gear the driver has selected so that the PCM can take corrective action.

TRACTION CONTROL OPERATION

The outputs of the traction control system can include one or more of the following:

- Retard ignition timing to reduce engine torque.
- Decrease the fuel injector pulse-width to reduce fuel delivery to the cylinder to reduce engine torque.
- Reduce the amount of intake air if the engine is equipped with an electronic throttle control (ETC). Reduced airflow will reduce engine torque.
- Upshift the automatic transmission/transaxle. If the transmission is shifted into a higher gear, the torque applied to the drive wheels is reduced.

Most traction control systems are capable of reducing positive wheel slip at all vehicle speeds. Most speed traction control systems use accelerator reduction and engine power reduction to limit slip before applying the brakes to the wheel that is spinning. This action helps reduce the possibility of overheating the brakes if the vehicle were being driven on an icy or snow-covered road. ● **SEE FIGURE 108–11.**

Therefore the controller usually performs actions to restore traction in the following order:

1. Reduces engine torque to the drive wheels.
2. Applying individual wheel brakes to slow or stop the wheel from spinning. The ABS controller supplies to the wheel brake only the pressure that is required to prevent tire slipping during acceleration. The amount of pressure varies according to the condition of the road surface and the amount of engine power being delivered to the drive wheels. A program inside the controller will disable traction control if brake system overheating is likely to occur.
3. Lights a low traction or traction control warning light on the dash.
   ● **SEE FIGURE 108–12.**

TRACTION ACTIVE LAMP

On most applications, a "TRAC CNTL" indicator light or "TRACTION CONTROL ACTIVE" message flashes on the instrumentation when the system is engaging traction control. This helps alert the driver that the wheels are losing traction.

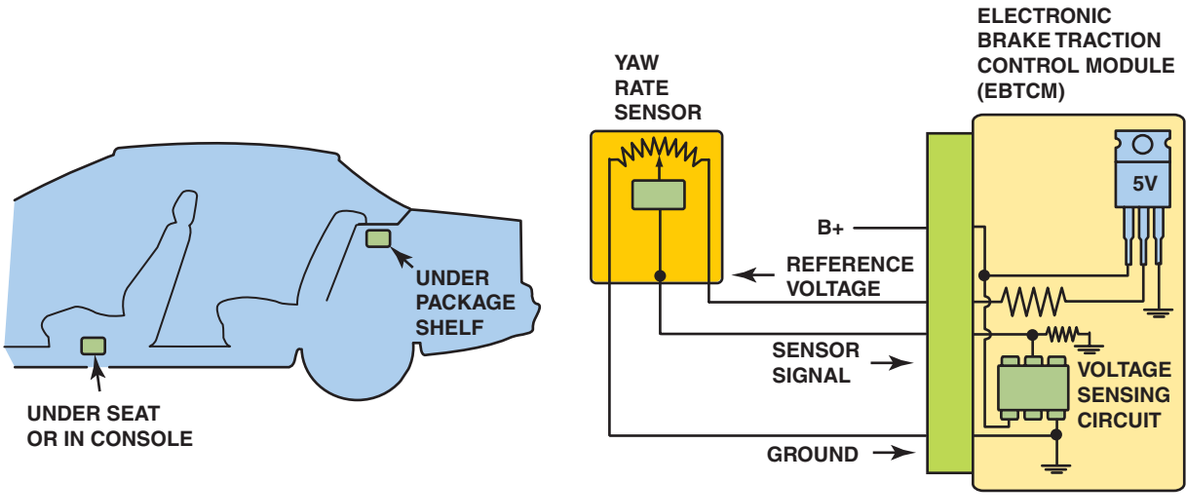


FIGURE 108–9 Yaw rate sensor showing the typical locations and schematic.

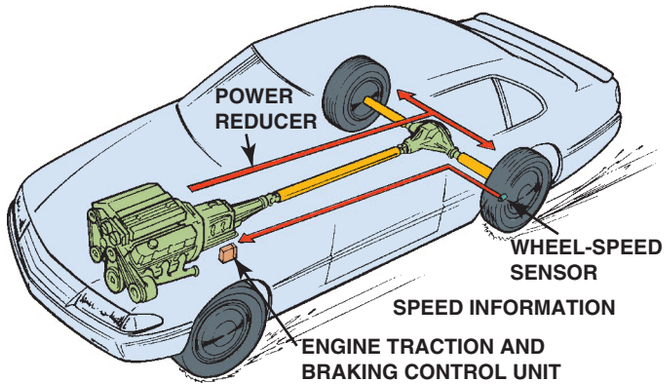


FIGURE 108–10 Typical traction control system that uses wheel speed sensor information and the engine controller (PCM) to apply the brakes at lower speeds and also reduce engine power applied to the drive wheels.

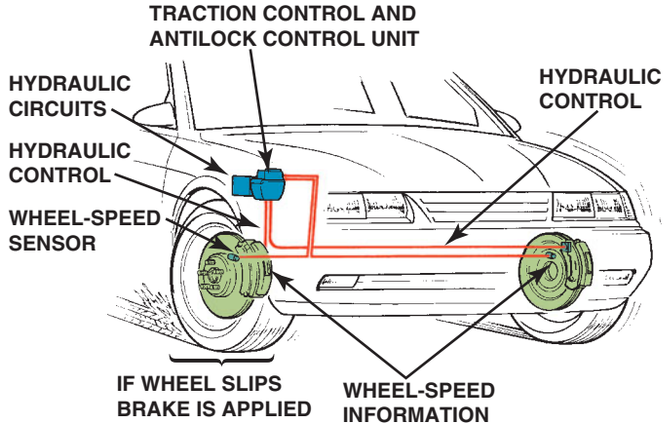


FIGURE 108–11 Wheel speed sensor information is used to monitor if a drive wheel is starting to spin.

In most applications, the message does not mean there is anything wrong with the system—unless the ABS warning lamp also comes on, or the traction control light remains on continuously.

TRACTION DEACTIVATION SWITCH Many vehicles with traction control have a dash-mounted switch that allows the driver to deactivate the system when desired (as when driving in deep snow). An indicator light shows when the system is on or off, and may



FIGURE 108–12 A traction control or low traction light on the dash is confusing to many drivers. When the lamp is on or flashing, it indicates that a low traction condition has been determined and the traction control system is working to restore traction. A flashing traction dash light does not indicate a fault.

FREQUENTLY ASKED QUESTION

Does Traction Control Engage Additional Drive Wheels?

When the term *traction control* is used, many people think of four-wheel-drive or all-wheel-drive vehicles and powertrains. Instead of sending engine torque to other drive wheels, it is the purpose and function of the traction control system to prevent the drive wheel(s) from slipping during acceleration. A slipping tire has less traction than a nonslipping tire—therefore, if the tire can be kept from slipping (spinning), more traction will be available to propel the vehicle. Traction control works with the engine computer to reduce torque delivery from the engine, as well as the controller to apply the brakes to the spinning wheel if necessary to regain traction.



FIGURE 108–13 The use of a factory scan tool is often needed to diagnose the ESC system.

also signal the driver when the traction control system is actively engaged during acceleration.

ESC/TC DIAGNOSIS

Because the electronic stability control (ESC) and traction control (TC) systems use some of the same sensors and controllers, the diagnosis for them is about the same. To diagnose faults with either system, follow the recommended procedures found in service information. The usual procedure involves the following steps.

STEP 1 **Verify the customer concern (complaint).** This step includes trying to duplicate what the customer or driver is concerned about the system. If the traction control or ESC light is flashing, this indicates that it is trying to bring the vehicle under control. This may be normal operation if the following conditions exist:
- Icy or slippery road conditions
- Worn tires that lack traction

STEP 2 **Perform a thorough visual inspection** including:
- Check that all tires are the same size and tread depth.

NOTE: Using a spare tire on the drive wheel could cause the traction control and/or ESC amber warning light to flash because the controller is seeing that the smaller tire is rotating faster than the other side.

STEP 3 **Check service information** for the specified procedure to follow to retrieve diagnostic trouble codes as well as any related technical service bulletins (TSBs). Most vehicles require the use of a factory-brand scan tool. **SEE FIGURE 108–13.**

STEP 4 **Follow the troubleshooting procedure** as specified to fix the root cause of the problem. This means following the instructions displayed on the scan tool or service information. The steps usually include all or many of the following:
- Brake fluid level
- Wheel speed sensor resistance
- Fault with the base brake system, such as air in the lines that could prevent the traction control controller from applying the wheel brakes

STEP 5 **Repair the fault.**

STEP 6 **Road test the vehicle** under the same conditions that were performed to verify the fault to be sure that the fault has been repaired.

REVIEW QUESTIONS

1. What is the difference between oversteering and understeering?
2. What is the "sine with dwell" test?
3. What are some of the other names used to identify an electronic stability control (ESC) system?
4. What sensors are used in the electronic stability control system?
5. What action does the traction control system perform to help the drive wheels maintain traction during acceleration?
6. What is the typical diagnostic procedure to follow when troubleshooting a fault with the electronic stability control or traction control system?

CHAPTER QUIZ

1. The electronic stability control (ESC) system requires that the vehicle be equipped with what type of brake system?
   a. Four-wheel disc brakes
   b. Four-channel ABS
   c. Three-channel ABS
   d. Front disc with rear drum brakes
2. Which Federal Motor Safety Standard requires electronic stability control to be on all vehicles by 2011?
   a. 126
   b. 113
   c. 109
   d. 101
3. What is the name of the standard test that is performed to verify ESC operation?
   a. ESC plus
   b. Vehicle stability enhancement test
   c. Sine with dwell
   d. Anti-skid test
4. What other name is used to describe an electronic stability control (ESC) system?
   a. Vehicle Stability Assist (VSA)
   b. Electronic Stability Program (ESP)
   c. Vehicle Dynamic Control (VDC)
   d. Any of the above

5. Which sensor is used by the ESC controller to determine the driver's intended direction?
   a. Yaw sensor
   b. Steering wheel (hand-wheel) position sensor
   c. Vehicle speed (VS) sensor
   d. Lateral acceleration sensor

6. A diagnostic trouble code (DTC) has been set for a fault with lateral acceleration sensor or circuit. What test could be performed to check if the sensor is working?
   a. Unplug it and see if the scan tool reads 1.0G
   b. Disconnect the sensor and hold it sideways to see if a scan tool reads 0.0G
   c. Disconnect the sensor and hold it sideways to see if a scan tool reads 1.0G
   d. Drive the vehicle in a circle to see if the scan tool reads 0.0G

7. A lateral acceleration sensor is usually located where in the vehicle?
   a. Under the front seat
   b. In the center console
   c. On the package shelf
   d. Any of the above locations

8. If a vehicle tends to continue straight ahead while cornering, this condition is called _____.
   a. Understeer
   b. Plowing
   c. Tight
   d. All of the above

9. Traction control uses the antilock braking system and other devices to limit _____ of the drive wheels during acceleration.
   a. Positive slip
   b. Negative slip

10. A traction control system can often control all *except* _____.
    a. Limit engine torque delivered to the drive wheel
    b. Engage four-wheel drive
    c. Upshift the automatic transmission
    d. Apply the wheel brake to the wheel that is losing traction

SECTION XII Suspension and Steering

109 Tires and Wheels
110 Tire Pressure Monitoring Systems
111 Tire and Wheel Service
112 Suspension System Components and Operation
113 Front Suspension and Service
114 Rear Suspension and Service
115 Electronic Suspension Systems
116 Steering Columns and Gears
117 Steering Linkage and Service
118 Power-Assisted Steering Operation and Service
119 Wheel Alignment Principles
120 Alignment Diagnosis and Service

chapter 109 TIRES AND WHEELS

OBJECTIVES: After studying Chapter 109, the reader will be able to: • Prepare for ASE Suspension and Steering (A4) certification test content area "E" (Wheel and Tire Diagnosis and Repair). • Discuss how tires are constructed. • Describe how Run Flat tires work. • Discuss tire sizes and ratings. • Describe tire purchasing considerations and maintenance. • Explain the construction and sizing of steel and alloy wheels and attaching hardware. • Demonstrate the correct lug nut tightening procedure and torque.

KEY TERMS: Aspect ratio 1243 • Back spacing 1255 • Bead 1241 • Belt 1212 • Body ply 1241 • Bolt circle 1256 • Carcass ply 1241 • Center section 1254 • Conicity 1247 • DOT tire code 1251 • E-metric tire 1253 • Green tire 1242 • High-flotation tires 1245 • Hydroplaning 1240 • Inner liner 1242 • JWL 1256 • Load index 1246 • LRR 1253 • Lug nuts 1257 • Major splice 1242 • Offset 1254 • Ply steer 1247 • Rim width 1249 • Run-flat tires 1252 • Schrader valve 1257 • Sidewall 1241 • Speed ratings 1246 • Spider 1254 • TPC 1253 • Tread 1240 • Unsprung weight 1257 • UTQGS 1250 • Wear bars 1240

INTRODUCTION TO TIRES

PURPOSE OF TIRES The friction (traction) between the tire and the road determines the handling characteristics of any vehicle. Think about this statement for a second. The compounding, construction, and condition of tires are some of the most important aspects of the steering, suspension, alignment, and braking systems of any vehicle. A vehicle that handles poorly or that pulls, darts, jumps, or steers "funny" may be suffering from defective or worn tires. Understanding the construction of a tire is important for the technician to be able to identify tire failure or vehicle handling problems.

FUNCTION OF TIRES Tires are mounted on wheels that are bolted to the vehicle to provide the following:

1. Shock absorber action when driving over rough surfaces
2. Friction (traction) between the wheels and the road

All tires are assembled by hand from many different component parts consisting of various rubber compounds, steel, and various types of fabric material. Tires are also available in many different designs and sizes.

PARTS OF A TIRE

TREAD **Tread** refers to the part of the tire that contacts the ground. *Tread rubber* is chemically different from other rubber parts of a tire, and is compounded for a combination of traction and tire wear. *Tread depth* is usually 11/32 in. deep on new tires (this could vary, depending on manufacturer, from 9/32 to 15/32 in.). ● **FIGURE 109–1** shows a tread depth gauge.

NOTE: The tread depth gauge is used to measure the thickness of the tire tread. A tread depth is always expressed in 1/32s of an inch, even if the fraction can be reduced to 1/16s or 1/8s.

Wear indicators are also called **wear bars.** When tread depth is down to the legal limit of 2/32 in., bald strips appear across the tread. ● **SEE FIGURE 109–2.**

Tie bars are molded into the tread of most all-season-rated tires. These rubber reinforcement bars are placed between tread blocks on the outer tread rows to prevent unusual wear and to reduce tread noise. As the tire wears normally, the tie bars will gradually appear. This should not be mistaken for an indication of excess outer edge wear. A tire tread with what appears to be a solid band across the entire width of the tread is what the service technician should consider the wear bar indicator.

Grooves are large, deep recesses molded in the tread and separating the tread blocks. These grooves are called *circumferential grooves* or *kerfs.* Grooves running sideways across the tread of a tire are called *lateral grooves.* ● **SEE FIGURE 109–3.**

Grooves in both directions are necessary for wet traction. The trapped water can actually cause the tires to ride up on a layer of water and lose contact with the ground, as shown in ● **FIGURE 109–4.** This is called **hydroplaning.** With worn tires, hydroplaning can occur at



(a)



(b)

FIGURE 109–1 (a) A typical tire tread depth gauge. The center movable plunger is pushed down into the groove of the tire. (b) The tread depth is read at the top edge of the sleeve. In this example, the tread depth is 6/32 in.



FIGURE 109–2 Wear indicators (wear bars) are strips of bald tread that show when the tread depth is down to 2/32 in., the legal limit in many states.

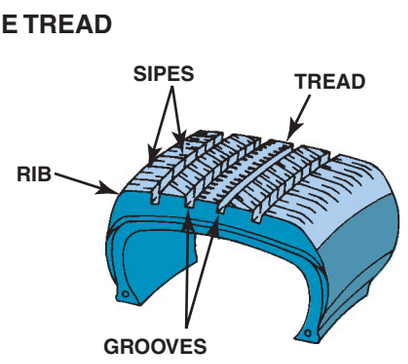


FIGURE 109–3 The tire tread runs around the circumference of the tire, and its pattern helps maintain traction. The ribs provide grip, while the grooves direct any water on the road away from the surface. The sipes help the tire grip the road.

speeds as low as 30 mph on wet roads. Stopping and cornering is impossible when hydroplaning occurs. *Sipes* are small slits in the tread area to increase wet and dry traction.

SIDEWALL

The **sidewall** is that part of the tire between the tread and the wheel. The sidewall contains all the size and construction details of the tire.

Some tires turn brown on the sidewalls after a short time. This is due to ozone (atmosphere) damage that actually causes the rubber to oxidize. Premium-quality tires contain an anti-oxidizing chemical additive blended with the sidewall rubber to prevent this discoloration.

WHITE SIDEWALL/LETTERED. When pneumatic tires were first constructed in the early 1900s, only natural rubber was used. The entire tire was white. When it was discovered that carbon black greatly increased the toughness of a tire, it was used. The public did not like the change from white tires to black, so tire manufacturers put the carbon black (lamp black) only in the rubber that was to be used for the tread portion of the tire. This tire lasted a lot longer because

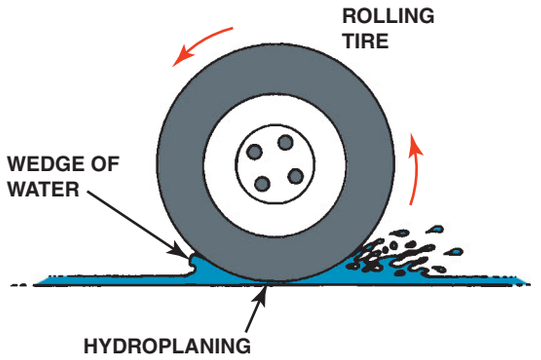


FIGURE 109–4 Hydroplaning can occur at speeds as low as 30 mph (48 km/h). If the water is deep enough and the tire tread cannot evacuate water through its grooves fast enough, the tire can be lifted off the road surface by a layer of water. Hydroplaning occurs at lower speeds as the tire becomes worn.

the black rubber tread that touched the ground was stronger and tougher; it sold well because the sidewalls were white.

White sidewall or white lettered tires actually contain a strip of white rubber under the black sidewall. This is ground off at the factory to reveal the white rubber. Only whitewalls or white letter lines contain this expensive white rubber. Various widths of whitewalls are made possible simply by changing the width of the grinding wheel.

BEAD

The **bead** is the foundation of the tire and is located where the tire grips the inside of the wheel rim.

1. The bead is constructed of many turns of copper- or bronze-coated steel wire.
2. The main body plies (layers of material) are wrapped around the bead.

   CAUTION: If the bead of a tire is cut or damaged, the tire must be replaced!
3. Most radial-ply tires and all truck tires wrap the bead with additional material to add strength.

BODY PLY

A tire gets its strength from the layers of material wrapped around both beads under the tread and sidewall rubber. This creates the main framework, or "carcass," of the tire; these **body plies** are often called **carcass plies.** A 4-ply tire has four separate layers of material. If the body plies overlap at an angle (bias), the tire is called a *bias-ply* tire. If only one or two body plies are used and they do not cross at an angle, but lie directly from bead to bead, then the tire is called *radial ply.* ● **SEE FIGURE 109–5.**

1. Rayon is a body ply material used in many tires because it provides a very smooth ride. A major disadvantage of rayon is that it rots if exposed to moisture.
2. Nylon is a strong body ply material. Though it is still used in some tires, it tends to "flat-spot" after sitting overnight.
3. Aramid is the generic name for aromatic polyamide fibers developed in 1972. Aramid is several times stronger than steel (pound for pound), and is used in high-performance-tire construction. Kevlar is the DuPont brand name for aramid and a registered trademark of E.I. Dupont de Nemours and Co.
4. Polyester is the most commonly used tire material because it provides the smooth ride characteristics of rayon with the rot resistance and strength of nylon.

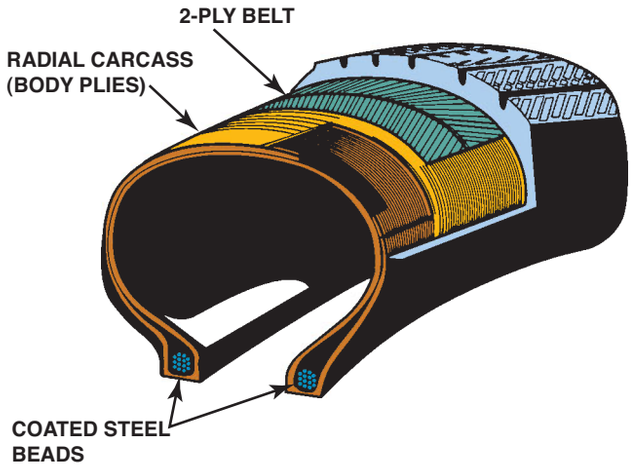


FIGURE 109–5 Typical construction of a radial tire. Some tires have only one body ply, and some tires use more than two belt plies.

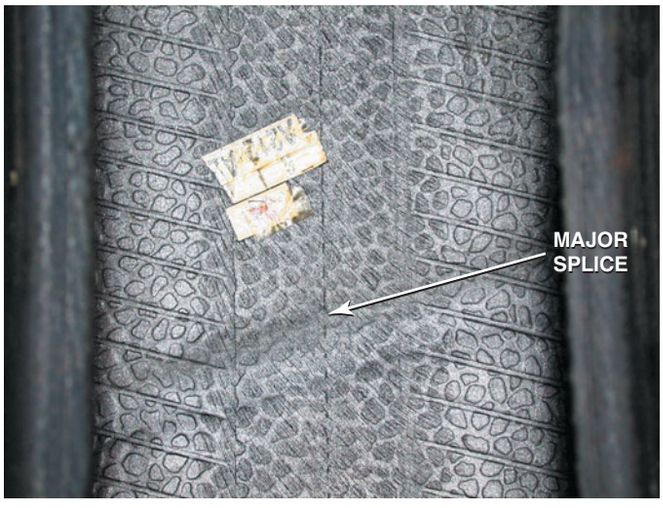


FIGURE 109–6 The major splice of a tire can often be seen and felt on the inside of the tire. The person who assembles (builds) the tire usually places a sticker near the major splice as a means of identification for quality control.

BELT A tire **belt** is two or more layers of material applied over the body plies and under the tread area only, to stabilize the tread and increase tread life and handling.

1. Belt material can consist of the following:
   - **a.** Steel mesh
   - **b.** Nylon
   - **c.** Rayon
   - **d.** Fiberglass
   - **e.** Aramid
2. **All radial tires are belted.**

NOTE: Most tires rated for high speed use a nylon "overlay" or "cap belt" between the 2-ply belt and the tread of the tire. This overlay helps stabilize the belt package and helps hold the tire together at high speeds, when centrifugal force acts to tear a tire apart.

INNER LINER The **inner liner** is the soft rubber lining (usually a butyl rubber compound) on the inside of the tire that protects the body plies and helps provide for self-sealing of small punctures.

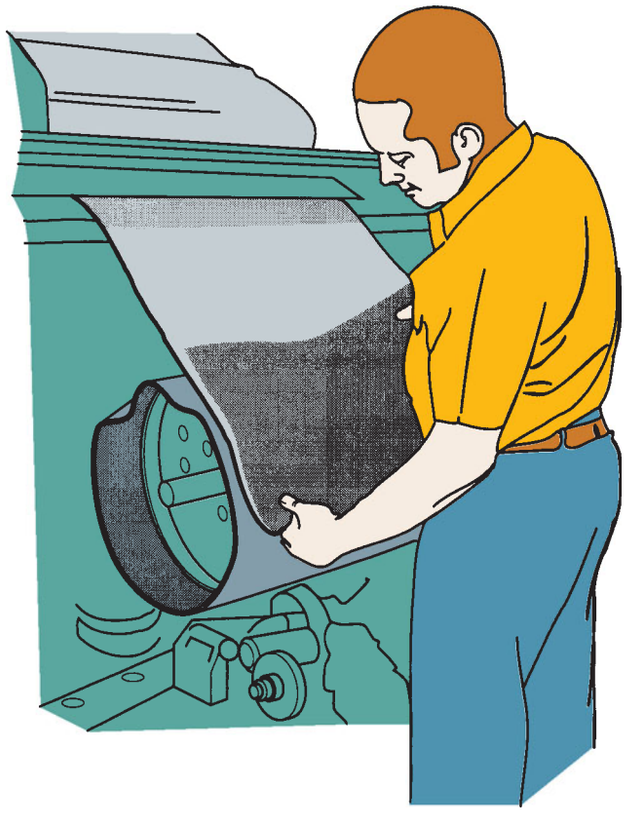


FIGURE 109–7 Tire construction is performed by assembling the many parts of a tire together on a tire-building machine.

MAJOR SPLICE When the tire is assembled by a craftsperson on a tire-building machine, the body plies, belts, and tread rubber are spliced together. The fabric is overlapped approximately five threads. The point where the majority of these overlaps occur is called the **major splice,** which represents the stiffest part of the tire. This major splice is visible on most tires on the inside, as shown in ● **FIGURE 109–6.**

NOTE: On most new vehicles and/or new tires, the tire manufacturer paints a dot on the sidewall near the bead, indicating the largest diameter of the tire. The largest diameter of the tire usually is near the major splice. The wheel manufacturer either marks the wheel or drills the valve core hole at the smallest diameter of the wheel. Therefore, the dot should be aligned with the valve core or marked for best balance and minimum radial runout.

TIRE MOLDING

After the tire has been assembled by the tire builder, it is called a **green tire.** ● **SEE FIGURE 109–7.** At this stage in construction, the rubber can be returned and reused because it has not been changed chemically. The completed green tire is then placed in a mold where its shape, tread design, and all sidewall markings are formed. ● **SEE FIGURE 109–8.**

While in the mold, a steam bladder fills the inside of the tire and forces the tire against the outside of the mold. After approximately 30 minutes at 300°F (150°C), the heat changes the chemistry of the rubber. The tire is no longer called a green tire but a *cured tire,* and after inspection and cleaning, it is ready for shipment.

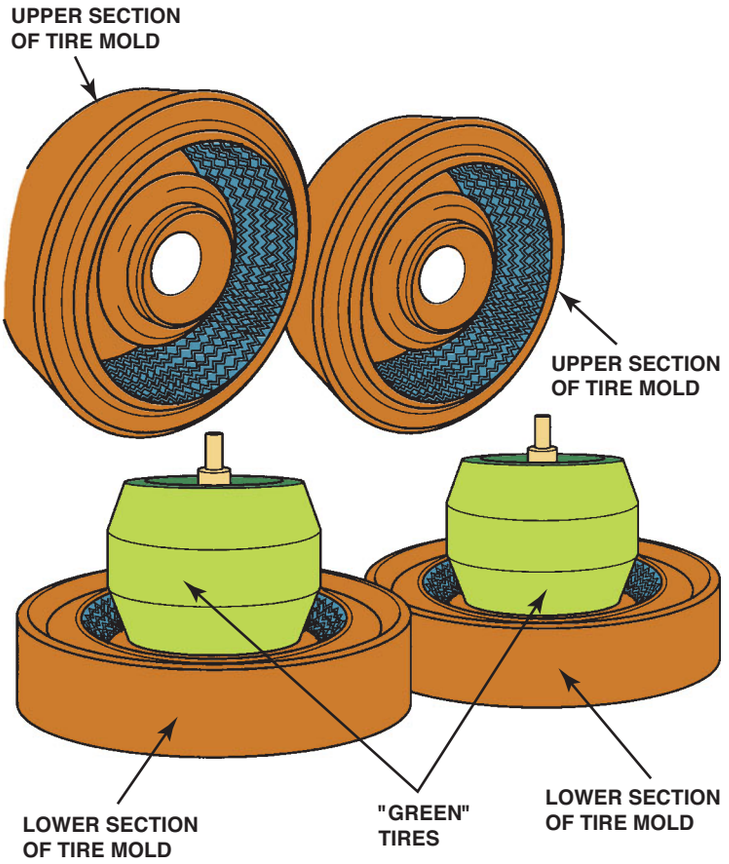


FIGURE 109–8 After the entire tire has been assembled into a completed "green" tire, it is placed into a tire-molding machine where the tire is molded into shape and the rubber is changed chemically by the heat. This nonreversible chemical reaction is called vulcanization.

FREQUENTLY ASKED QUESTION

Why Do I Get Shocked by Static Electricity When I Drive a Certain Vehicle?

Static electricity builds up in insulators due to friction of the tires with the road. Newer tires use silica and contain less carbon black in the rubber, which makes the tires electrically conductive. Because the tires cannot conduct the static electricity to the ground, static electricity builds up inside the vehicle and is discharged through the body of the driver and/or passenger whenever the metal door handle is touched.

NOTE: Toll booth operators report being shocked by many drivers as money is being passed between the driver and the toll booth operator.

Newer tire sidewall designs that use silica usually incorporate carbon sections that are used to discharge the static electricity to ground. To help reduce the static charge buildup, spray the upholstery with an antistatic spray available at discount and grocery stores.

TIRE SIZE DESIGNATIONS

METRIC DESIGNATION European and Japanese tires use metric designations. For example, 185SR × 14 denotes the following:

FREQUENTLY ASKED QUESTION

How Much Does Tire Pressure Change with a Change in Temperature?

As the temperature of a tire increases, the pressure inside the tire also increases. The general amount of pressure gain (when temperatures increase) or loss (when temperatures decrease) is as follows:

10°F increase causes 1 PSI increase

10°F decrease causes 1 PSI decrease

For example, if a tire is correctly inflated to 35 PSI when cold and then driven on a highway, the tire pressure may increase 5 PSI or more.

CAUTION: DO NOT LET AIR OUT OF A HOT TIRE! If air is released from a hot tire to bring the pressure down to specifications, the tire will be *underinflated* when the tire has cooled. The tire pressure specification is for a cold tire.

Always check the tire pressures on a vehicle that has been driven fewer than 2 miles (3.2 km).

Air pressure in the tires also affects fuel economy. If all four tires are underinflated (low on air pressure), fuel economy is reduced about **0.1 mile per gallon (mpg) for each 1 PSI low.** For example, if all four tires were inflated to 25 PSI instead of 35 PSI, not only is tire life affected but fuel economy is reduced by about 1 mile per gallon (10 × 0.1 = 1 mpg).

185	the tire is 185 millimeters (mm) wide (cross-sectional width)
S	the speed rating
R	radial design
14	fits a 14-in.-diameter wheel

The European size indicates the exact physical size (width) of the tire and the speed ratings. Because of the lack of speed limits in many countries, this information is important. Because of tire design changes needed for H- and V-rated tires, their cost is usually much higher. European sizes also include the tire's aspect ratio, for example, 185/70SR × 14. If the aspect ratio of a European-sized tire is not indicated, it is generally 83% for most radials.

AMERICAN METRIC TIRE SIZE DESIGNATIONS After 1980, American tires were also designated using the metric system. For example, P205/75R × 14 denotes the following:

P	passenger vehicle
205	205-mm cross-sectional width
75	75% aspect ratio. The height of the tire (from the wheel to the tread) is 75% as great as its cross-sectional width (the width measured across its widest part). This percentage ratio of height to width is called the **aspect ratio.** (A 60 series tire is 60% as high as it is wide.)
R	radial
14	14-in.-diameter wheel

If a tire is constructed as a bias-ply tire only, then its size designation uses the letter D to indicate *diagonal:* P205/75D × 14.

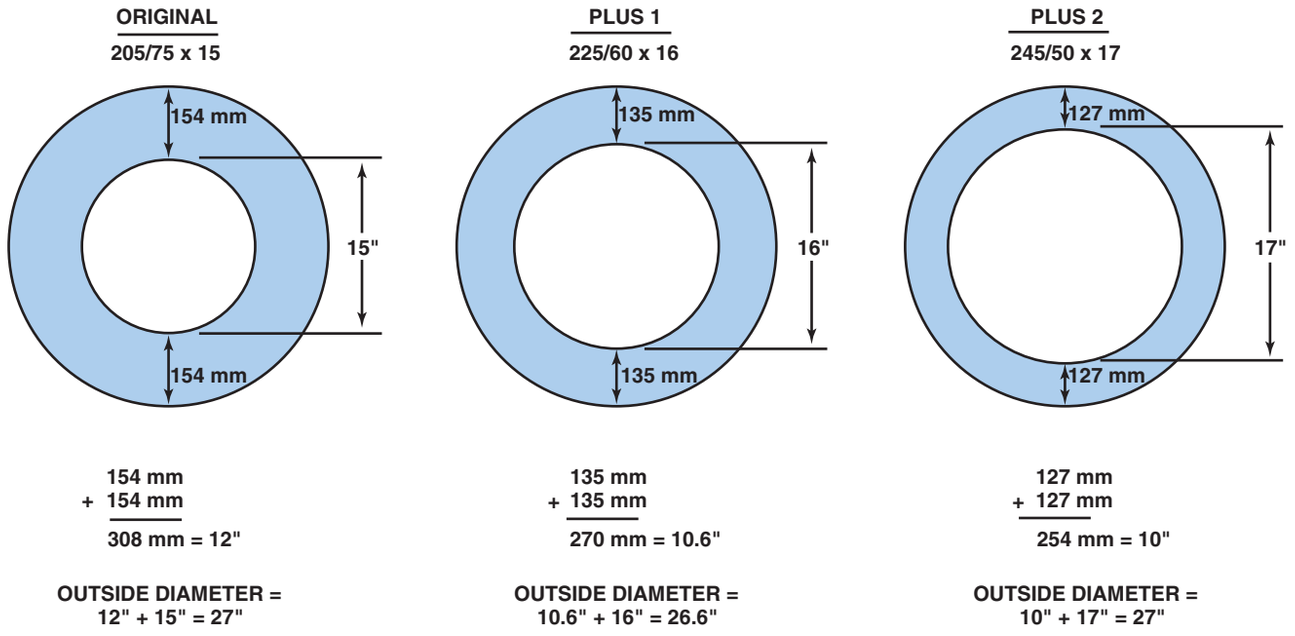


FIGURE 109–9 Notice that the overall outside diameter of the tire remains almost the same and at the same time the aspect ratio is decreased and the rim diameter is increased.

FREQUENTLY ASKED QUESTION

How Much Bigger Can I Go?

Many owners think they can improve their vehicle by upgrading the tire size over the size that comes from the factory to make their vehicle look sportier and ride and handle better. When changing tire size, there are many factors to consider:

1. The tire should be the same outside diameter as the original to maintain the proper suspension, steering, and ride height specifications.
2. Tire size affects vehicle speed sensor values, ABS brake wheel sensor values that can change automatic transmission operation, and ABS operation.
3. The tire should not be so wide as to contact the inner wheel well or suspension components.
4. Generally, a tire that is 10 mm wider is acceptable. For example, an original equipment tire size 205/75 × 15 (outside diameter = 27.1 in.) can be changed to 215/75 × 15 (outside diameter = 27.6 in.). This much change is less than 1/2 in. in width and increases the outside diameter by 1/2 in.

NOTE: Outside diameter is calculated by adding the wheel diameter to the cross-sectional height of the tire, multiplied by 2. ● **SEE FIGURE 109–9.**

5. Whenever changing tires, make sure that the load capacity is the same or greater than that of the original tires.
6. If wider tires are desired, a lower aspect ratio is required to maintain the same, or close to the same, overall outside diameter of the tire.

Old	New
P205/75 × 15	P215/70 × 15
205 × 0.75 = 154 mm	215 × 0.70 = 151 mm

Notice that the overall sidewall height is generally maintained.

If even larger tires are needed, then 225/60 × 15s may be OK–let's check the math:

225 × 0.60 = 135 mm

Notice that this is much too short a sidewall height when compared with the original tire (see no. 6).

7. Use the "plus 1" or "plus 2" concept. When specifying wider tires, the sidewall height must be reduced to maintain the same, or close to the same, original equipment specifications. The "plus 1" concept involves replacing the wheels with wheels 1 in. larger in diameter to compensate for the lower aspect of wider tires.

Original	Plus 1
205/75 × 15	225/60 × 16

The overall difference in outside diameter is only 0.5 in., even though the tire width has increased from 205 mm to 225 mm and the wheel diameter has increased by 1 in. If money is no object and all-out performance is the goal, a "plus 2" concept can also be used (use a P245/50 × 17 tire and change to 17-in.-diameter wheels).

Here the overall diameter is within 1/20″ of the original tire/wheel combination, yet the tire width is 1.6 inches (40 mm) wider than the original tire. Refer to the section entitled "Wheels" later in this chapter for proper wheel back spacing and offset when purchasing replacement wheels.

FREQUENTLY ASKED QUESTION

What Effect Does Tire Size Have on Overall Gear Ratio?

Customers often ask what effect changing tire size has on fuel economy and speedometer readings. If larger (or smaller) tires are installed on a vehicle, many other factors also will change. These include the following:

1. **Speedometer reading.** If larger-diameter tires are used, the speedometer will read slower than you are actually traveling. This can result in speeding tickets!
2. **Odometer reading.** Even though larger tires are said to give better fuel economy, just the opposite can be calculated! Since a larger-diameter tire travels farther than a smaller-diameter tire, the larger tire will cause the odometer to read a shorter distance than the vehicle actually travels. For example, if the odometer reads 100 miles traveled on tires that are 10% oversized in circumference, the actual distance traveled is 110 miles.
3. **Fuel economy.** If fuel economy is calculated on miles traveled, the result will be *lower* fuel economy than for the same vehicle with the original tires.

$$\text{Calculation: mph} = \frac{\text{RPM} \times \text{diameter} \times 3.14}{\text{gear ratio}}$$

$$\frac{\text{RPM} = \text{mph} \times \text{gear ratio}}{\text{diameter} \times 3.14}$$

$$\frac{\text{gear ratio} = \text{RPM} \times \text{diameter} \times 3.14}{\text{mph}}$$

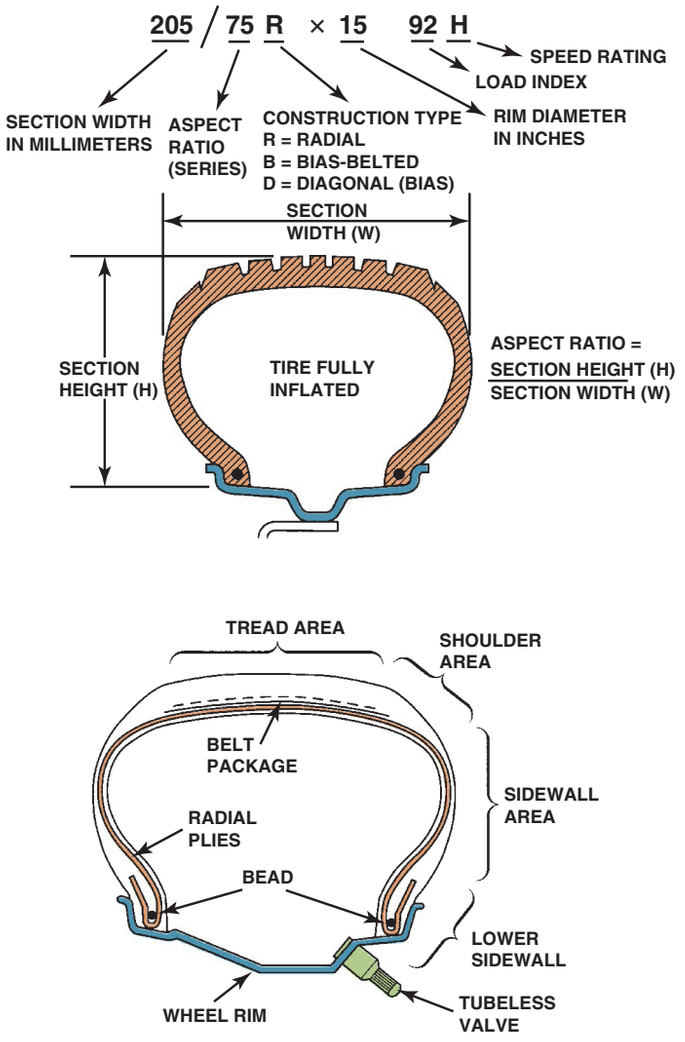


FIGURE 109–10 Cross-sectional view of a typical tire showing the terminology.

NOTE: Many "temporary use only" spare tires are constructed with diagonal (bias) plies; the size designation is *T* for *temporary*.

If a tire is constructed as a bias ply with a belt of additional material under the tread area, its size designation uses the letter B to indicate belted: P205/75B × 14. Some tires use letters at the end of the tire size (suffixes) to indicate special applications, including the following:

LT	light truck
ML	mining and logging
MH	mobile home
ST	special trailer
TR	truck

SERVICE DESCRIPTION

Tires built after 1990 use a "service description" method of sidewall information in accordance with ISO 4000 (International Standards Organization) that includes size, load, and speed rating together in one easy-to-read format. ● **SEE FIGURE 109–10.**

P-Metric Designation	Service Description
P205/75HR × 15	205/75R × 15 92H
P passenger vehicle	205 cross-sectional width in mm
205 cross-sectional width in mm	75 aspect ratio
75 aspect ratio	R radial construction
H speed rating (130 mph/210 km/h)	15 rim diameter in inches
R radial construction	92 load index
15 rim diameter in inches	H speed rating (130 mph/210 km/h)

HIGH-FLOTATION TIRE SIZES

High-flotation tires for light trucks are designed to give improved off-road performance on sand, mud, and soft soil and still provide acceptable hard-road surface performance. These tires are usually larger than conventional tires and usually require a wider-than-normal wheel width. High-flotation tires have a size designation such as 33 × 12.50R × 15LT:

33	approximate overall tire diameter in inches
12.50	approximate cross-sectional width in inches
R	radial-type construction
15	rim diameter in inches
LT	light-truck designation

FREQUENTLY ASKED QUESTION

If I Have an Older Vehicle, What Size Tires Should I Use?

Newer radial tires can be used on older-model vehicles if the size of the tires is selected that best matches the original tires. See the following cross-reference chart.

Cross-Reference Chart
(This Chart Does Not Imply Complete Interchangeability.)

Pre-1964	1965 to 1972	80 Series Metric	Alpha Numeric 78 Series	P-Metric 75 Series Radial	P-Metric 70 Series Radial
590-13	600-13	165-13	A78-13	P165/75R13	P175/70R13
640-13	650-13	175-13	B78-13	P175/75R13	P185/70R13
725-13	700-13	185-13	D78-13	P185/75R13	P205/70R13
590-14	645-14	155-14	B78-14	P175/75R14	P185/70R14
650-14	695-14	175-14	C78-14	P185/75R14	P195/70R14
700-14	735-14	185-14	E78-14	P195/75R14	P205/70R14
750-14	775-14	195-14	F78-14	P205/75R14	P215/70R14
800-14	825-14	205-14	G78-14	P215/75R14	P225/70R14
850-14	855-14	215-14	H78-14	P225/75R14	P235/70R14
590-15	600-15	165-15	A78-15	P165/75R15	P175/70R15
650-15	685-15	175-15	C78-15	P175/75R15	P185/70R15
640-15	735-15	185-15	E78-15	P195/75R15	P205/70R15
670-15	775-15	195-15	F78-15	P205/75R15	P215/70R15
710-15	815-15	205-15	G78-15	P215/75R15	P225/70R15
760-15	855-15	215-15	H78-15	P225/75R15	P235/70R15
800-15	885-15	230-15	J78-15	P225/75R15	P235/70R15
820-15	900-15	235-15	L78-15	P235/75R15	P255/70R15

NOTE: Vehicles designed for older bias-ply tires may drive differently when equipped with radial tires.

LOAD INDEX AND EQUIVALENT LOADS

The **load index,** as shown in ● **FIGURE 109–11,** is an abbreviated method to indicate the load-carrying capabilities of a tire. The weights listed in the chart represent the weight that *each tire* can safely support. Multiply this amount by 4 to get the maximum that the vehicle should weigh fully loaded with cargo and passengers.

SPEED RATINGS

Tires are rated according to the maximum *sustained* speed. A vehicle should never be driven faster than the **speed rating** of the tires. ● **SEE CHART 109–1.**

CAUTION: A high speed rating does not guarantee that the tires will not fail, even at speeds much lower than the rating. Tire condition, inflation, and vehicle loading also affect tire performance.

As the speed rating of a tire increases, fewer compromises exist for driver comfort and low noise level. The higher speed rating does not mean a better tire. To survive, a high-speed tire must be built with stiff tread compounds, reinforced body (carcass) construction, and fabric angles that favor high speed and high performance over other considerations. For example, a V-rated tire often has less tread depth than a similar tire with an H-speed rating, and therefore will often not give as long of a service life. Since the speed ratings were first developed in Europe, the letters correspond to metric speed in kilometers per hour, with a conversion to miles per hour as noted.

TIRE PRESSURE AND TRACTION

All tires should be inflated to the specifications given by the vehicle manufacturer. Most vehicles have recommended tire inflation figures written in the owner's manual or on a placard

FREQUENTLY ASKED QUESTION

What Does the Little "e" Mean on the Sidewall?

Most countries have government agencies that regulate standards for motor vehicles sold and/or driven within their jurisdiction. In the United States, the U.S. Department of Transportation and National Highway Traffic Safety Administration are responsible for developing many of the nationwide standards for vehicles. Tires that are certified by their manufacturers to meet U.S. standards are branded with "DOT" (Department of Transportation) preceding the Tire Identification Code on their sidewall.

In Europe, because so much personal and commercial travel extends beyond the borders of any one country, the Economic Commission for Europe (E.C.E.) helps develop uniform motor vehicle standards for its member countries to regulate and standardize passenger and commercial vehicle components.

Besides physical specifications, the E.C.E. standards now require tire "pass-by" noise to meet specific limits. These standards were phased-in starting in 2004. The tires must pass noise emission testing, and the standards will continue to expand in scope until 2009, when the standards will be applied to all tires sold in Europe.

The E.C.E. symbol on a tire's sidewall identifies that the manufacturer certifies that the tire meets all regulations, including the load index and speed symbol that appear in its service description.

The letter "e" and number code combination (positioned in a circle or rectangle) identify the country originally granting approval, followed by two digits indicating the Regulation Series under which the tire was approved. Tires that have also been tested and meet the "pass-by" noise limits can have a second E.C.E. branding followed by an "-s" (for *sound*). ● **SEE FIGURE 109–12.**

The following list indicates selected E.C.E. codes and the countries they represent:

Code	Country	Code	Country
E1	Germany	E14	Switzerland
E2	France	E15	Norway
E3	Italy	E16	Finland
E4	Netherlands	E17	Denmark
E5	Sweden	E18	Romania
E6	Belgium	E19	Poland
E7	Hungary	E20	Portugal
E8	Czech Republic	E21	Russian Federation
E9	Spain	E22	Greece
E10	Yugoslavia	E23	Ireland
E11	United Kingdom	E24	Croatia
E12	Austria	E25	Slovenia
E13	Luxembourg	E26	Slovakia

or sticker on the door post or glove compartment. ● **SEE FIGURE 109–13.**

The pressure number molded into the sidewall of a tire should be considered the maximum pressure when the tire is cold. (Pressures higher than that stated on the sidewall may be measured on a hot tire.)

LETTER	MAXIMUM RATED SPEED
L	120 km/h (75 mph)
M	130 km/h (81 mph)
N	140 km/h (87 mph)
P	150 km/h (93 mph)
Q	160 km/h (99 mph)
R	170 km/h (106 mph)
S	180 km/h (112 mph)
T	190 km/h (118 mph)
U	200 km/h (124 mph)
H	210 km/h (130 mph)
V	240 km/h (149 mph)
W	270 km/h (168 mph)
Y	300 km/h (186 mph)
Z	open-ended*

CHART 109–1

Speed ratings are based on continuous operation at the speed rating speed.
*The exact speed rating for a particular Z-rated tire is determined by the tire manufacturer and may vary according to size. For example, not all Brand X Z-rated tires are rated at 170 mph, even though one size may be capable of these speeds.

TIRE CONICITY AND PLY STEER

Tire **conicity** can occur during the construction of any radial or belted tire when the parts of the tire are badly positioned, causing the tire to be smaller in diameter on one side. When this tire is installed on a vehicle, it can cause the vehicle to pull to one side of the road due to the cone shape of the tire. ● **SEE FIGURE 109–14.**

Since the cause of conicity is due to the construction of the tire itself, there is nothing the service technician can do to correct the condition except to replace the tire. The exact cause of the conicity is generally due to the slight movement of the belt and tread in the mold during inflation. If a vehicle pulls to one side of the road, the service technician should switch tires left to right (left-side tires to the right side and the right-side tires to the left side of the vehicle). If this swap of tires corrects the pulling condition, then tire conicity was the possible cause.

NOTE: *Radial pull* or *radial tire pull* are other terms often used to describe tire conicity.

Ply steer is another term that describes a slight pulling force on a vehicle due to tire construction. Ply steer is due to the angle of the cords in the belt layers, as seen in ● **FIGURE 109–15,** and not in the ply layer of the carcass (body), as the name implies. Ply steer will cause a slight drift regardless of its direction of rotation. Switching tires left to right will *not* correct a ply steer condition.

NOTE: Whenever a wheel and tire assembly is switched from one side of a vehicle to the other, the tire revolves in the opposite direction.

Load Index	Load (kg)	Load (lb)	103	875	1,929
75	387	853	104	900	1,934
76	400	882	105	925	2,039
77	412	908	106	950	2,094
78	425	937	107	975	2,149
79	437	963	108	1,000	2,205
80	450	992	109	1,030	2,271
81	462	1,019	110	1,060	2,337
82	475	1,047	111	1,090	2,403
83	487	1,074	112	1,120	2,469
84	500	1,102	113	1,150	2,535
85	515	1,135	114	1,180	2,601
86	530	1,168	115	1,215	2,679
87	545	1,201			
88	560	1,235			
89	580	1,279			
90	600	1,323			
91	615	1,356			
92	630	1,389			
93	650	1,433			
94	670	1,477			
95	690	1,521			
96	710	1,565			
97	730	1,609			
98	750	1,653			
99	775	1,709			
100	800	1,764			
101	825	1,819			
102	850	1,874			

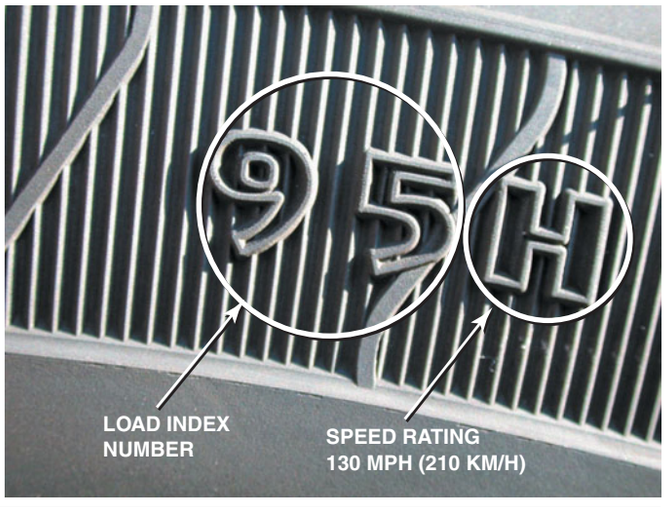


FIGURE 109–11 Typical sidewall markings for load index and speed rating following the tire size.



FIGURE 109–12 The E.C.E. symbol on a sidewall of a tire. Notice the small -s at the end, indicating that the tire meets the "pass-by" noise limits.

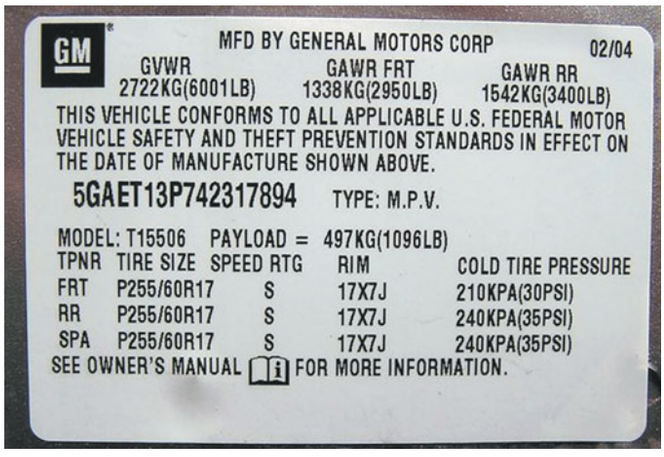


FIGURE 109–13 A typical door placard used on a General Motors vehicle indicating the recommended tire inflation. Note that the information also includes the tire size and speed rating of the tire as well as the recommended wheel size.

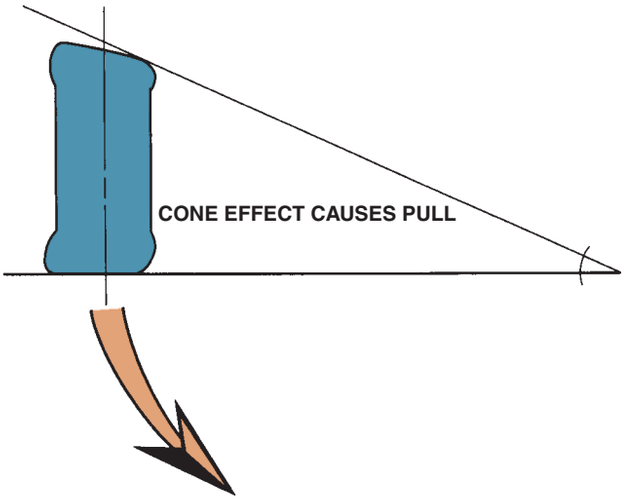


FIGURE 109–14 Conicity is a fault in the tire that can cause the vehicle to pull to one side due to the cone effect (shape) of the tire.

Ply steer is built into the tire during construction. There is nothing a service technician can do to correct ply steer, except to compensate for it with alignment angles. (See Chapter 93 for details on alignment diagnosis and correction.)

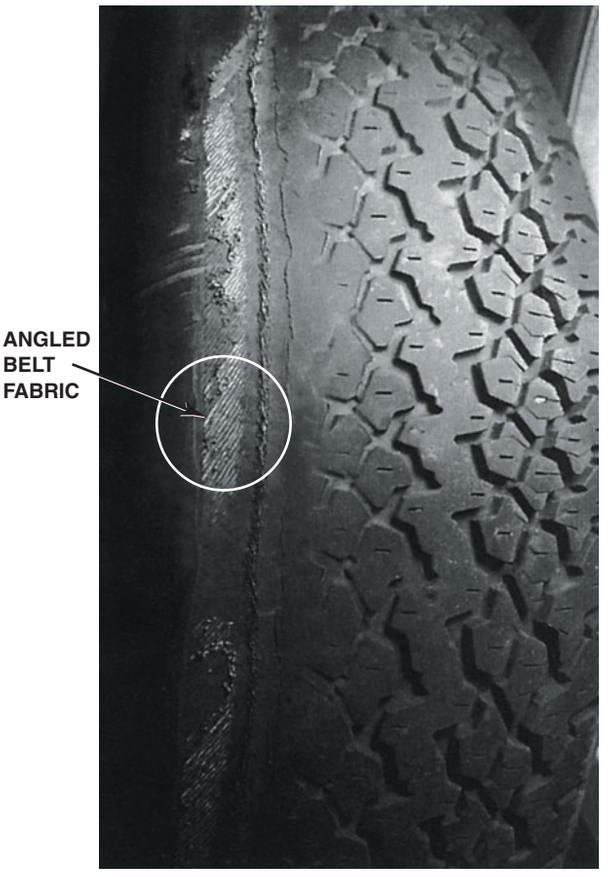


FIGURE 109–15 Notice the angle of the belt material in this worn tire. The angle of the belt fabric can cause a "ply steer" or slight pulling force toward one side of the vehicle.

VEHICLE HANDLING AND TIRE SLIP ANGLE

The tire surface contact area or tire patch size is about one-half the area of one page of this book. All accelerating, braking, and cornering forces of a vehicle are transferred to the pavement at just four spots. The combined area of these four spots is about equal to the size of this opened book.

Think about this whenever braking or cornering. As a vehicle is turned, the wheels are moved while the tires remain in contact with the road. These actions "twist" the carcass of the tire and create a slip angle between the direction the wheel is pointing and the direction the tread is pointing. ● **SEE FIGURE 109–16.**

The contact patch is deformed and snaps back into place as the twisted tire carcass returns to its original shape. This movement causes a slight delay in the turning of the vehicle and causes tire wear as the tread rubber moves in relation to the pavement during cornering.

RIM WIDTH AND TIRE SIZE

As a general rule, for a given **rim width** it is best not to change tire width more than 10 mm (either wider or narrower). For a given tire width, it is best not to vary rim width more than 1/2 in. in either direction. For example, if the original tire size is 195/70 × 14, then either a 185/70 × 14 (−10 mm) or a 205/70 × 14 (+10 mm) *could* be used on the original rim (wheel) without undue harm *if* the replacement tire has proper clearance with the body and suspension components.

? FREQUENTLY ASKED QUESTION

Is There a Rule-of-Thumb for Rim Size?

According to the Tire and Rim Association, Inc., the answer is no. Each tire size has a designated rim width on which it is designed to be mounted so as to provide the best performance and wear. The width of the specified rim also varies with rim diameter. A 235/45 × 17 tire may require a 7.5-in. rim but a 235/45 × 19 tire may require an 8.0-in. rim. A rule-of-thumb that has been used is to multiply the width of the rim by 33.55 to determine the approximate tire size for the rim. For example, consider the following.

Rim width 5.0 in. × 33.55 = 167.85 (165 mm) tire
Rim width 5.5 in. × 33.55 = 184.50 (185 mm) tire
Rim width 6.0 in. × 33.55 = 201.30 (195 mm) tire
Rim width 6.5 in. × 33.55 = 218.00 (215 mm) tire
Rim width 7.0 in. × 33.55 = 234.90 (235 mm) tire
Rim width 7.5 in. × 33.55 = 252.00 (245 mm) tire
Rim width 8.0 in. × 33.55 = 268.00 (265 mm) tire
Rim width 8.5 in. × 33.55 = 285.00 (285 mm) tire
Rim width 9.0 in. × 33.55 = 302.00 (305 mm) tire
Rim width 10.0 in. × 33.55 = 335.60 (335 mm) tire

Always check with the tire manufacturer as to the specified tire rim width that should be used.

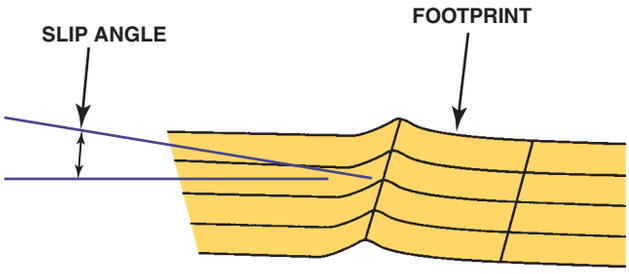


FIGURE 109–16 Slip angle is the angle between the direction the tire tread is heading and the direction it is pointed.

Installing a tire on too narrow a wheel will cause the tire to wear excessively in the center of the tread. Installing a tire on too wide a wheel will cause excessive tire wear on both edges.

See a tire store representative for recommended tire sizes that can be safely installed on your rims.

UNIFORM TIRE QUALITY GRADING SYSTEM

The U.S. Department of Transportation (DOT) and the National Highway Traffic Safety Administration (NHTSA) developed a system of tire grading, the **Uniform Tire Quality Grading System (UTQGS),** to help customers better judge the relative performance of tires. The three areas of tire performance are tread wear, traction, and temperature resistance, as shown in ● **FIGURE 109–17.**

NOTE: All tires sold in the United States must have UTQGS ratings molded into the sidewall.

TREAD WEAR The tread wear grade is a comparison rating based on the wear rate of a standardized tire, tested under carefully controlled conditions, which is assigned a value of 100. A tire rated 200 should have a useful life twice as long as the standard tire's.

NOTE: The standard tire has a rating for tread wear of 100. This value has generally been accepted to mean a useful life of 20,000 miles of normal driving. Therefore, a tire rated at 200 could be expected to last 40,000 miles.

Tread Wear Rating Number	Approximate Number of mi/km
100	20,000/32,000
150	30,000/48,000
200	40,000/64,000
250	50,000/80,000
300	60,000/96,000
400	80,000/129,000
500	100,000/161,000

The tread wear life of any tire is affected by driving habits (fast stops, starts, and cornering will decrease tread life), tire rotation (or lack of tire rotation), inflation, wheel alignment, road surfaces, and climate conditions.

TRACTION Traction performance is rated by the letters AA, A, B, and C, with AA being the highest.



FIGURE 109–17 Typical "Uniform Tire Quality Grading System" (UTQGS) ratings imprinted on the tire sidewall.

NOTE: The traction rating is for wet braking distance only! It does not include cornering traction or dry braking performance.

The traction rating is only one of many other factors that affect wet braking traction, including air inflation, tread depth, vehicle speed, and brake performance.

TEMPERATURE RESISTANCE Temperature resistance is rated by the letters A, B, and C, with A being the highest rating. Tires generate heat while rotating and flexing during normal driving conditions. A certain amount of heat buildup is desirable because tires produce their highest coefficient of traction at normal operating temperatures. For example, race car drivers frequently swerve their cars left and right during the pace laps, causing increased friction between the tire and the road surface, which warms their tires to operating temperature. However, if temperatures rise too much, a tire can start to come apart–the oils and rubber in the tire start to become a liquid! Grade C is the minimum level that all tires must be able to pass under the current Federal Motor Vehicle Safety Standard No. 109.

ALL-SEASON TIRE DESIGNATION

DESIGNATION LABELS Most all-season tires are rated and labeled as *M & S, MS,* or *M + S,* and therefore must adhere to general design features as specified by the Rubber Manufacturers Association (RMA).

Tires labeled M & S are constructed with an aggressive tread design as well as tread compounds and internal construction that are designed for mud and snow. One design feature is that the tire has at least 25% void area. This means that the tread blocks have enough open space around them to allow the blocks to grab and clean themselves of snow and mud. Block angles, dimensional requirements, and minimum cross-sectional width are also a requirement for the M & S designation.

RUBBER COMPOUND DIFFERENCES The tread rubber used to make all-season tires is also more flexible at low temperatures. This rubber compound is low-bounce (called high-hysteresis)

REAL WORLD FIX

Tire Date Code Information Saved Me Money!

This author was looking at a three-year-old vehicle when I noticed that the right rear tire had a build date code newer than the vehicle. I asked the owner, "How badly was this vehicle hit?" The owner stumbled and stuttered a little, then said, "How did you know that an accident occurred?" I told the owner that the right rear tire, while the exact same tire as the others, had a date code indicating that it was only one year old, whereas the original tires were the same age as the vehicle. The last three numbers of the DOT code on the sidewall indicate the week of manufacture (the first two numbers of the three-digit date code) followed by the last number of the year.

The owner immediately admitted that the vehicle slid on ice and hit a curb, damaging the right rear tire and wheel. Both the tire and wheel were replaced and the alignment checked. The owner then dropped the price of the vehicle $500! Knowing the date code helps assure that fresh tires are purchased and can also help the technician determine if the tires have been replaced. For example, if new tires are found on a vehicle with 20,000 miles, then the technician should check to see if the vehicle may have been involved in an accident or may have more miles than indicated on the odometer.

and is more likely to remain in contact with the road surface. The rubber compound is also called *hydrophilic,* meaning that the rubber has an affinity for water (rather than being *hydrophobic* rubber, which repels water).

NOTE: Most vehicle manufacturers recommend that the same *type* of tire be used on all four wheels even though the size of the tire may vary between front and rear on some high-performance vehicles. Therefore, if all-season replacement tires are purchased, a complete set of four should be used to be assured of proper handling and uniform traction characteristics. While *tire* manufacturers have been recommending this for years—since the late 1980s—most *vehicle* manufacturers are also recommending that all four tires be of the same construction and tread type to help ensure proper vehicle handling.

DOT TIRE CODE

All tires sold in the United States must be approved by the U.S. Federal Department of Transportation (DOT). The **DOT tire code** requirements include resistance to tire damage that could be caused by curbs, chuckholes, and other common occurrences for a tire used on public roads.

NOTE: Most race tires are *not* DOT-approved and must never be used on public streets or highways.

Each tire that is DOT-approved has a DOT number molded into the sidewall of the tire. This number is usually imprinted on only one side of the tire and is usually on the side *opposite the whitewall.* The DOT code includes letters and numbers, such as **MJP2CBDX264.** See appendix 2 for a list of where tires are built.



FIGURE 109–18 Typical DOT date code. This tire was built the sixth week of 2005.

The first two letters identify the manufacturer and location. For this example, the first two letters (MJ) mean that the tire was made by the Goodyear Tire and Rubber Company in Topeka, Kansas. The last three numbers are the build date code. The last of these three numbers is the year (1994), and the 26 means that it was built during the 26th week of 1994. Starting with tires manufactured after January 1, 2000, the tire build date includes four digits rather than three digits. A new code such as "3406" means the 34th week of 2006 ("3406"). ● **SEE FIGURE 109–18.**

SPARE TIRES

Most vehicles today come equipped with space-saver spare tires that are smaller than the wheels and tires that are on the vehicle. The reason for the small size is to reduce the size and weight of the entire vehicle and to increase fuel economy by having the entire vehicle weigh less by not carrying a heavy spare tire and wheel around. The style and type of these spare tires have changed a great deal over the last several years, and different makes and types of vehicles use various types of spare tires.

CAUTION: Before using a spare tire, always read the warning label (if so equipped) and understand all use restrictions. For example, some spare tires are not designed to exceed 50 mph (80 km/h) or be driven more than 500 miles (800 km).

Many small, space-saving spare tires use a higher-than-normal air inflation pressure, usually 60 PSI (414 kPa). Even though the tire often differs in construction, size, diameter, and width from the vehicle's original tires, it is amazing that the vehicle usually handles the same during normal driving. Obviously, these tires are not constructed with the same durability as a full-size tire and should be removed from service as soon as possible.

NOTE: When was the last time you checked the tire pressure in your spare tire? The spare tire pressure should be checked regularly.

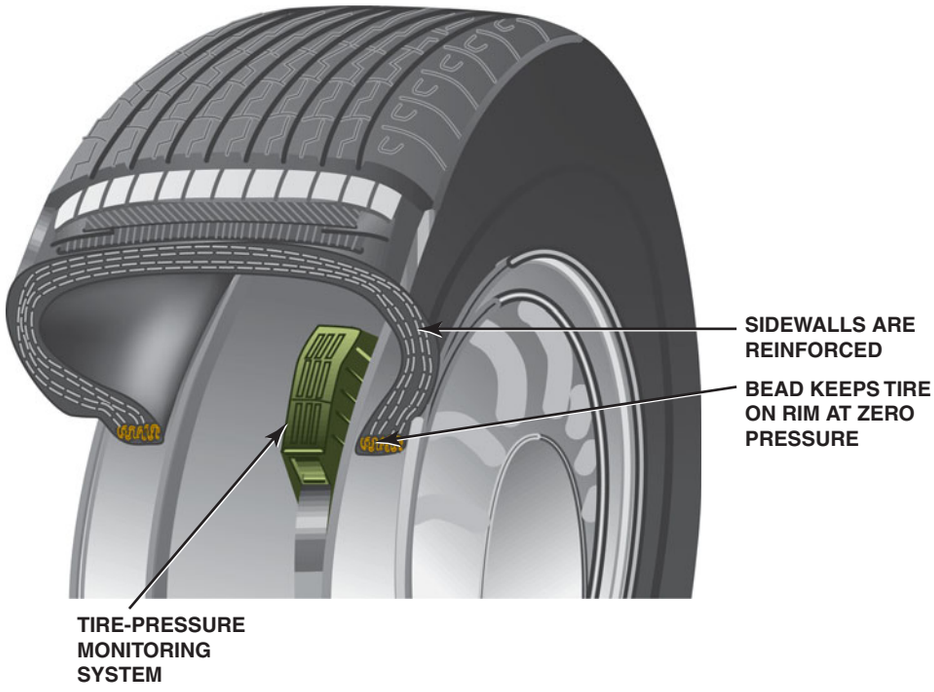


FIGURE 109–19 Cutaway of a run-flat tire showing the reinforced sidewalls and the required pressure sensor.

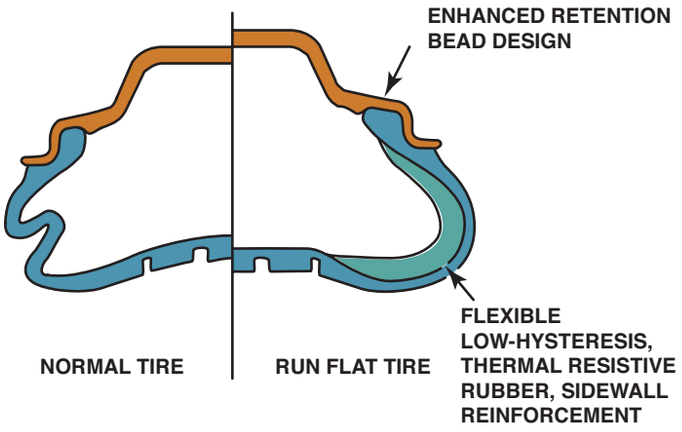


FIGURE 109–20 A conventional tire on the left and a run-flat tire on the right, showing what happens when there is no air in the tire.

RUN-FLAT TIRES

Run-flat tires (abbreviated RFT) are designed to operate without any air for a limited distance (usually 50 miles at 55 mph). This feature allows vehicle manufacturers to build vehicles without the extra room and weight of a spare tire and jack assembly.

A typical run-flat tire (also called *extended mobility tire* [EMT] or *zero pressure* [ZP] *tire*) requires the use of an air pressure sensor/transmitter and a dash-mounted receiver to warn the driver that a tire has lost pressure. Because of the reinforced sidewalls, the vehicle handles almost the same with or without air pressure. ● **SEE FIGURES 109–19 AND 109–20.**

CAUTION: Tire engineers warn that rapid cornering should be avoided if a run-flat tire has zero air pressure. The handling during quick maneuvers is often unpredictable and could be dangerous.

TECH TIP

PAX Replacement Tip

In most cases, the fastest and easiest approach to follow if a PAX tire requires replacement is to purchase a replacement tire/wheel assembly. While more expensive than replacing just the tire, this approach is often used to help the vehicle owner get back on the road faster without any concerns as to whether the replacement tire was properly installed.

PAX RUN-FLAT TIRES

Michelin developed a run-flat tire that has three unique components:

- A special wheel that has two bead seats that are of different diameters. The outside bead seat is 10 mm smaller in diameter than the inside bead seat. This means that a conventional tire cannot be installed on a PAX-style wheel.
- A urethane support ring that is designed to support the weight of the vehicle in the event of a flat tire.
- A special tire that is designed to operate without air. ● **SEE FIGURE 109–21.**

The PAX tire design has a unique sizing, such as:

P245/680R 460A 102V

P	= passenger
245	= the cross-section width in millimeters (mm)
680	= the tire diameter in mm (26.77 inches)
R	= radial ply construction
460	= the wheel, diameter in mm (18.1 inches)
A	= asymmetric wheel, meaning that one bead is smaller than the other bead by 10 mm (0.040 in.)
102	= the load index
V	= the speed rating



FIGURE 109–21 The PAX run-flat tire system is composed of three unique components—a special asymmetrical wheel, a urethane support ring, and special tire.

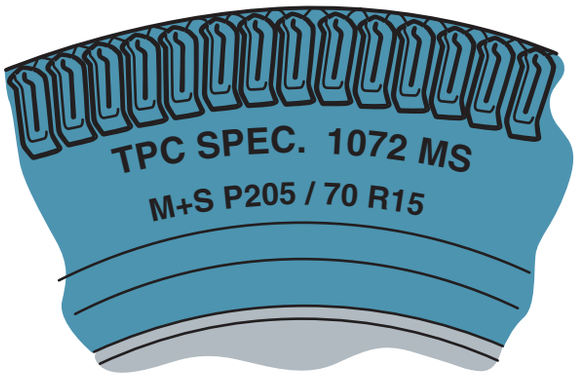


FIGURE 109–22 The Tire Performance Criteria (TPC) specification number is imprinted on the sidewall of all tires used on General Motors vehicles from the factory.

SERVICING A PAX WHEEL/TIRE ASSEMBLY If a flat tire occurs or when a PAX tire becomes worn and requires replacement, special care should be taken to properly remove the tire from the wheel. Because the urethane support ring prevents the tire bead from entering the dropped center section of the wheel, the outside bead should be broken from the wheel, and then the support ring removed before the tire can be removed from the wheel.

GENERAL MOTORS TPC RATING

All General Motors original equipment (OE) tires have a rating that identifies the size as well as the tread design, wear, traction, and heat resistance factors. All of these factors are combined in a set of numbers and letters that is imprinted in the tire mold. This is referred to as the **Tire Performance Criteria (TPC)** rating of the tire. If a customer wants to have the same tire performance in a replacement tire, then replace the tire with any brand of tire that has the same TPC identification. ● **SEE FIGURE 109–22.**

TIRE SELECTION CONSIDERATIONS

Selecting the proper tire is very important for the proper handling and safety of any vehicle. Do not select a tire by styling or looks alone. For best value and highest satisfaction, follow these guidelines:

Purchasing Suggestions	Reason Why
1. Purchase the same type of tire that came on your vehicle when new.	1. Chassis and tire engineers spend hundreds of hours testing and evaluating the best tire to use for each vehicle.
2. Purchase the same size as the original tire. The width of the tire should be within 10 mm of the width of the original tire. For example, a stock 195/75 × 14 tire's acceptable replacement *could be* 185/75 × 14 or 205/75 × 14.	2. The size of the tire is critical to the handling of any vehicle. Tire width, size, and aspect ratio affect the following: a. Braking effectiveness b. Headlight aiming c. Vehicle height d. Acceleration potential e. Speedometer calibration

? FREQUENTLY ASKED QUESTION

What Is a Low-Rolling-Resistance Tire?

Low-rolling-resistance (LRR) tires reduce rolling resistance, which is the power-robbing friction between the tire and crown. The **E-metric tire,** designated for use on electric or hybrid vehicles, operates at higher inflation pressures, reduced load percentages, and lower rolling resistance. These tires were first used on the GM EV1 electric vehicle.

To soften the ride of tires pumped with additional air, a new tire profile was developed. Narrower rim width and rounder sidewalls make the tire more shock absorbent.

To make the tires roll more freely, low-rolling-resistant tread compounds are molded into smaller tread elements that flex easily and with less friction when they touch the road. LRR tires are available from most major tire manufacturers, including Michelin the Energy MXV4 Plus and Goodyear VIVA 2. According to tire engineers, the basic tradeoff of low rolling resistance is poor wet traction performance. To improve wet road performance and traction requires the use of more silica in the tread, which increases the cost of the tire. Neither a technician nor a vehicle owner can determine the relative rolling resistance unless the tires are compared using a coast-down test from highway speed to zero or a laboratory testing machine.

Purchasing Suggestions	Reason Why
3. Purchase tires with the same speed rating as the original.	3. When any vehicle is manufactured, it is optimized for its designed use. High-performance tires are generally stiffer and have a speed rating as well. If you purchase non-high-performance tires, the carcass is not as stiff and the suspension is not designed to work with softer tires. Therefore, the cornering and handling, especially fast evasive maneuvers, could be dangerous. The vehicle may be capable of far more speed than the tires are designed to handle.
4. Purchase four of the same type of tire. Most vehicle manufacturers recommend against installing snow tires or all-season tires on just the drive wheels.	4. Every vehicle is designed to function best with four tires of the same size, construction, and tread design, unless the vehicle is specifically designed for different sizes of tires at the front and rear. Different tire styles and tread compounds have different slip angles. It is these different slip angles that can cause a vehicle to handle "funny" or cause the vehicle to get out of control in the event of a sudden maneuver.
5. Purchase the same *brand* of tire for both front and/or both rear wheels.	5. The sizes of tires are nominal and vary according to exact size (and shape) of the mold as well as tire design and construction. The same size of tire from two different manufacturers can often differ in diameter and width. While the differences should be slight, many vehicles are extremely sensitive to these small differences, and poor vehicle handling, torque steer, and pulling could result if different brands of tires are used.
6. Purchase fresh tires. Tires that are older may have been stored in a hot warehouse, where oxygen can attack rubber and cause deterioration.	6. Look at the tire build date code (the last three numbers of the DOT code). TRY to purchase four tires with the same or similar date codes.

CAUTION: If changing tire sizes or styles beyond the recommendations as stated here, consult a knowledgeable tire store representative for help in matching wheel and tire combinations to your vehicle.

NOTE: Some tires may be five or more years old when purchased. Always check the date code!



FIGURE 109–23 The size of the wheel is usually cast or stamped into the wheel. This wheel is 7 inches wide. The letter "J" refers to the contour of the bead seat area of the wheel.

WHEELS

TERMINOLOGY

The concept of a wheel has not changed in the last 5,000 years, but the style and materials used have changed a lot. Early automotive wheels were constructed from wood with a steel band as the tire.

Today's wheels are constructed of steel or aluminum alloy. The center section of the wheel that attaches to the hub is called the **center section** or **spider** because early wheels used wooden spokes that resembled a spider's web. The rubber tire attaches to the rim of the wheel. The rim has two *bead flanges* where the bead of the tire is held against the wheel when the tire is inflated. The shape of this flange is very important and is designated by Tire and Rim Association letters. For example, a wheel designated 14 × 6JJ means that the diameter of the wheel is 14 in. and the wheel is 6 in. wide measured from inside to inside of the flanges. The letters JJ indicate the *exact* shape of the flange area. ● **SEE FIGURE 109–23.** This flange area shape and the angle that the rim drops down from the flange are important because of the following:

- They permit a good seal between the rim and the tire.
- They help retain the tire on the rim in the event of loss of air. This is the reason why modern wheels are called "safety rim wheels." ● **SEE FIGURE 109–24.**
- Run-flat tires (tires that are designed to operate without air for a limited distance without damage) often require a specific wheel rim shape.

WHEEL OFFSET

Offset is a very important variable in wheel design. If the center section (spider) is centered on the outer rim, the offset is zero. Wheel offset is often referred to as ET, which stands for *Einpress Tieffe* in German. ● **SEE FIGURE 109–25.**

POSITIVE OFFSET

The wheel has a positive offset if the center section is outward from the wheel centerline. Front-wheel-drive vehicles commonly use positive-offset wheels to improve the loading on the front wheels and to help provide for a favorable scrub radius.

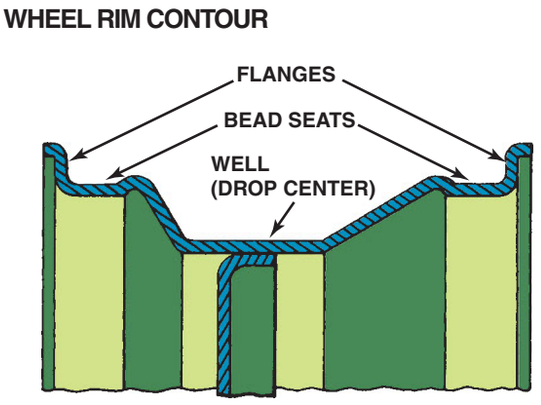


FIGURE 109–24 The wheel rim well provides a space for the tire to fit during mounting; the bead seat provides a tire-to-wheel sealing surface; the flange holds the beads in place.

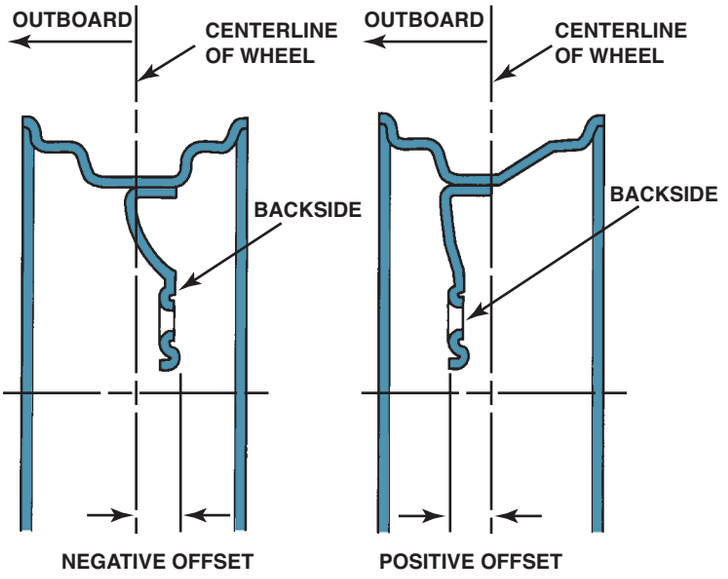


FIGURE 109–26 Offset is the distance between the centerline of the wheel and the wheel mounting surface.

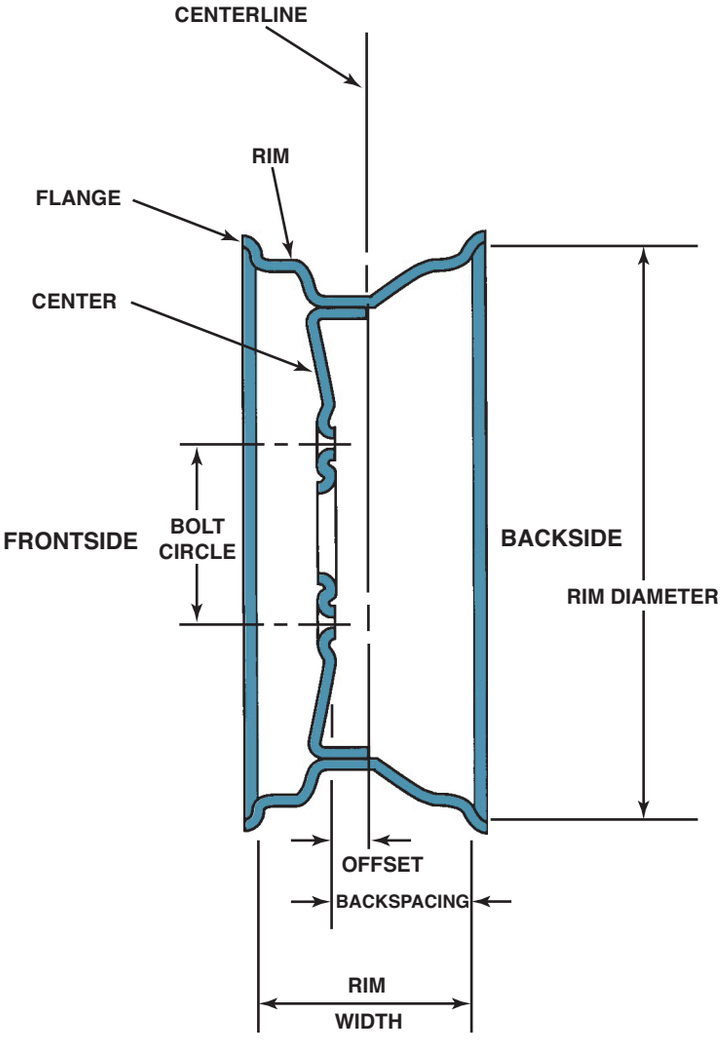


FIGURE 109–25 A cross section of a wheel showing part designations.

NEGATIVE OFFSET

The wheel has a negative offset if the center section is inboard (or "dished") from the wheel centerline. ● **SEE FIGURE 109–26.** Avoid using replacement wheels that differ from the original offset.

BACK SPACING

Back spacing, also called *rear spacing* or *backside setting,* is the distance between the back rim edge and the wheel center section mounting pad. **This is not the same as offset.** Back spacing can be measured directly with a ruler, as shown in ● **FIGURE 109–27.**

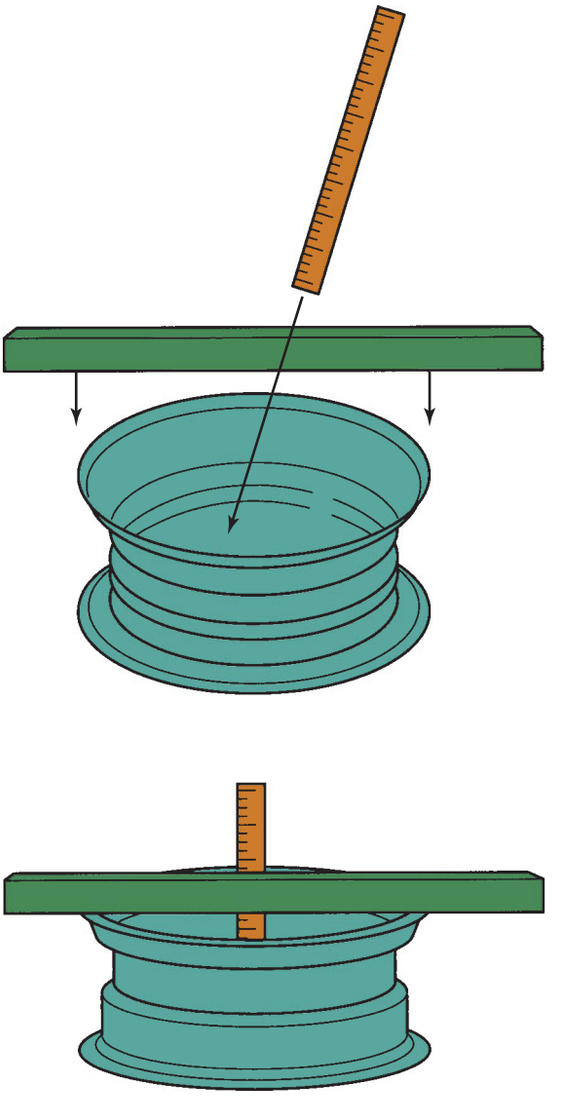


FIGURE 109–27 Back spacing (rear spacing) is the distance from the mounting pad to the edge of the rim. Most custom wheels use this measurement method to indicate the location of the mounting pad in relation to the rim.

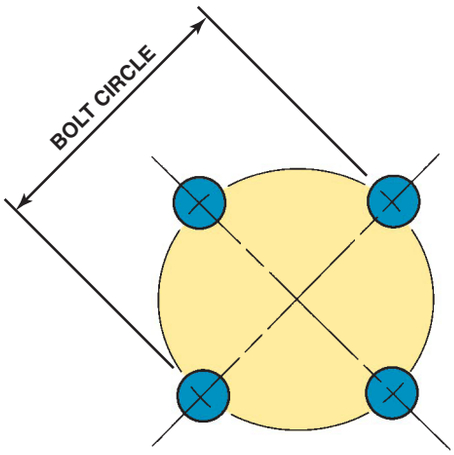


FIGURE 109–28 Bolt circle is the diameter of a circle that can be drawn through the center of each lug hole or stud. The bolt circle is sometimes referred to as PCD for pitch circle diameter.

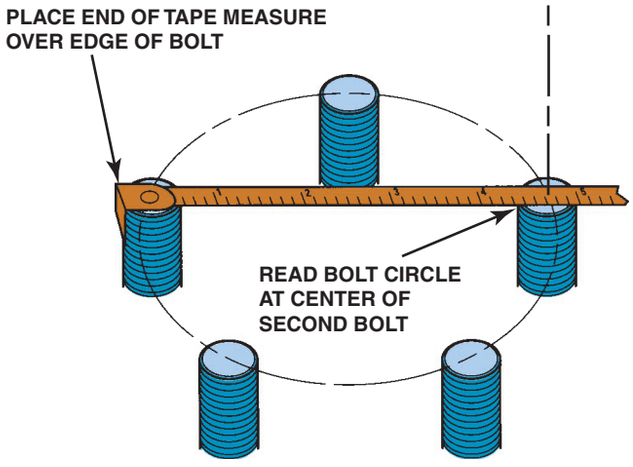


FIGURE 109–29 Measuring the bolt circle on a five lug wheel is difficult, but a quick and easy way includes measuring as shown to determine the approximate bolt circle of a five-lug wheel.

DETERMINING BOLT CIRCLE

On four-lug axles and wheels, the **bolt circle** measurement is simply taken from center to center on opposite studs or holes, as shown in ● **FIGURE 109–28.**

On five-lug axles and wheels, it is a little harder to determine bolt circle. One method is to measure from the far edge of one bolt hole to the center of the hole two over from the first, as shown in ● **FIGURE 109–29.** Another method for a five-lug wheel is to measure from center to center between two adjacent studs and convert this measurement into bolt circle diameter, as in the following chart. ● **SEE FIGURE 109–30.**

Center-to-Center Distance	Bolt Circle Diameter
2.645 in.	41/2-in. bolt circle
2.792 in.	43/4-in. bolt circle
2.939 in.	5-in. bolt circle
3.233 in.	51/2-in. bolt circle

STEEL WHEELS

Steel is the traditional wheel material. A steel wheel is very strong due to its designed shape and the fact that it is *work hardened* during manufacturing. In fact, most of the strength of a steel wheel is due to its work hardening. Painting and baking cycles also increase the strength of a steel wheel. Steel wheels are formed from welded hoops that are flared and joined to stamped spiders.

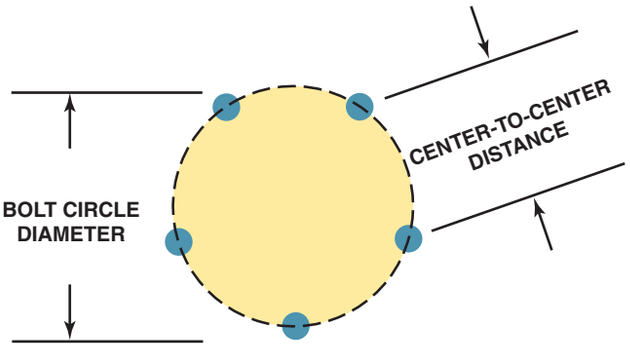


FIGURE 109–30 Measure center-to-center distance and compare the distance to the figures in the chart in the text to determine the diameter for a five-lug bolt circle.

? FREQUENTLY ASKED QUESTION

What Does This Mark in a Wheel Mean?

The symbol **JWL,** for the Japan Wheel Light Metal Standard Mark, means that the wheel meets the technical standards for passenger-car light-alloy wheels. See the mark in ● **FIGURE 109–31.**

The manufacturer is responsible for conducting the inspections set forth in the technical standard, and the JWL mark is displayed on those products that pass the inspection.

ALUMINUM WHEELS

Forged and cast aluminum wheels are commonly used on cars and trucks. *Forged* means that the aluminum is hammered or forged under pressure into shape. A forged aluminum wheel is much stronger than a *cast* aluminum wheel.

A cast aluminum wheel is constructed by pouring liquid (molten) aluminum into a mold. After the aluminum has cooled, the cast aluminum wheel is removed from the mold and machined. Aluminum wheels are usually thicker than steel wheels and require special wheel weights when balancing. Coated or covered wheel weights should be used when balancing aluminum wheels to prevent galvanic corrosion damage to the wheel. Most aluminum wheels use an alloy of aluminum. Aluminum can be combined (alloyed) with copper, manganese, silicon, or other elements to achieve the physical strength and characteristics for the exact product. Aluminum ally wheels are often called alloy wheels.

Some racing wheels are made from a lighter-weight metal called magnesium. These wheels are called *mag* wheels (an abbreviation for *magnesium*). True magnesium wheels are not practical for production wheels because their cost and corrosion are excessive compared with steel or aluminum alloy wheels. The term *mag wheel,* however, is still heard when referring to alloy (aluminum) wheels.

NOTE: If purchasing replacement aftermarket wheels, check that they are certified by the SFI. SFI is the Specialty Equipment Manufacturers Association (SEMA) Foundation, Incorporated. SEMA and SFI are nongovernment agencies that were formed by the manufacturers themselves to establish standards for safety.



FIGURE 109–31 A typical JWL symbol for the Japan Wheel Light Metal standard mark.

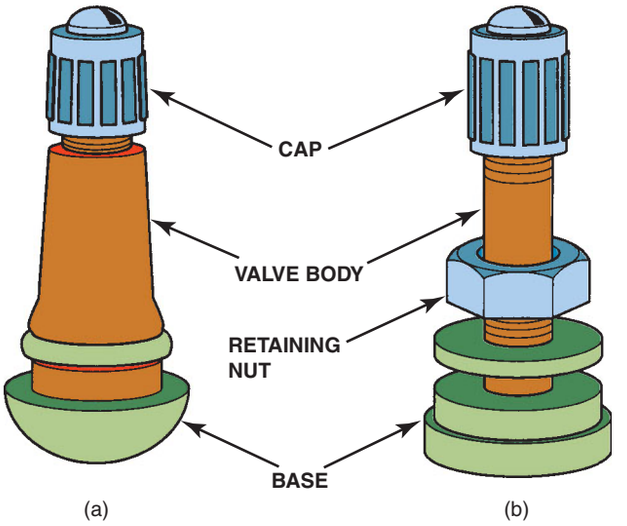


FIGURE 109–32 (a) A rubber snap-in style tire valve assembly. (b) A metal clamp-type tire valve assembly used on most high-pressure (over 60 PSI) tire applications such as is found on many trucks, RVs, and trailers. The internal Schrader valve threads into the valve itself and can be replaced individually, but most experts recommend replacing the entire valve assembly every time the tires are replaced to help prevent air loss.

TIRE VALVES

All tires use a tire valve, called a **Schrader valve,** to hold air in the tire. The Schrader valve was invented in New York in 1844 by August Schrader for the Goodyear Brothers: Charles, Henry, and Nelson. Today, Schrader valves are used not only as valves in tires but on fuel-injection systems, air-conditioning systems, and air shock (ride control) systems. Most tire experts agree that the valve stem (which includes the Schrader valve) should be replaced whenever tires are replaced–tires can last four or more years, and in that time the valve stem can become brittle and crack. A defective or leaking valve stem is a major cause of air loss. Low tire pressure can cause the tire to become overheated. Replacement valve stems are therefore a wise investment whenever purchasing new tires. Aluminum (alloy) wheels often require special metal valve stems that use a rubber washer and are actually bolted to the wheel. ● **SEE FIGURE 109–32.**

UNSPRUNG WEIGHT

The lighter the wheel and tire assembly, the faster it can react to bumps and dips in the road surface and thus the better the ride. The chassis and the body of any vehicle are supported by some sort of spring suspension system. It is the purpose of the suspension system to isolate the body of the vehicle from the road surface. Also, for best handling, all four tires must remain in contact with the road. After all, a tire cannot grip the road if it leaves the ground after hitting a bump. The wheel and tire are **unsprung weight** because they are not supported by the vehicle's springs. If heavy wheels or tires are used, every time the vehicle hits a bump, the wheel is forced upward. The heavy mass of the wheel and tire would transmit this force through the spring of the vehicle and eventually to the driver and passengers. Obviously, a much lighter wheel and tire assembly reacts faster to bumps and dips in the road surface. The end result is a smoother-riding vehicle with greater control.

An aluminum wheel is *generally* lighter than the same-size stamped steel wheel. This is not always the case, however, so before purchasing aluminum wheels, check their weight!

NOTE: Putting oversized tires on an off-road-type vehicle is extremely dangerous. The increased unsprung weight can cause the entire vehicle to leave the ground after hitting a bump in the road. The increased body height necessary to clear the larger tires seriously affects driveshaft angles and wheel alignment angles, making the vehicle very difficult to control.

LUG NUTS

PURPOSE AND FUNCTION **Lug nuts** are used to hold a wheel to the brake disc, brake drum, or wheel bearing assembly. Most manufacturers use a stud in the brake or bearing assembly with a lug nut to hold the wheel. Some models of VW, Audi, and Mazda use a lug *bolt* that is threaded into a hole in the brake drum or bearing assembly.

NOTE: Some aftermarket manufacturers offer a stud conversion kit to replace the lug bolt with a conventional stud and lug nut.

Typical lug nuts are tapered so that the wheel stud will center the wheel onto the vehicle. Another advantage of the taper of the lug nut and wheel is to provide a suitable surface to prevent the nuts from loosening. The taper, usually 60 degrees, forms a wedge that helps ensure that the lug nut will not loosen. Steel wheels are deformed slightly when the lug nut is torqued down against the wheel mounting flange; be certain that the taper is *toward* the vehicle.

TYPES Many alloy wheels use a *shank-nut*-type lug nut that has straight sides without a taper. This style of nut must be used with wheels designed for this nut type. If replacement wheels are used on any vehicle, check with the wheel manufacturer as to the proper

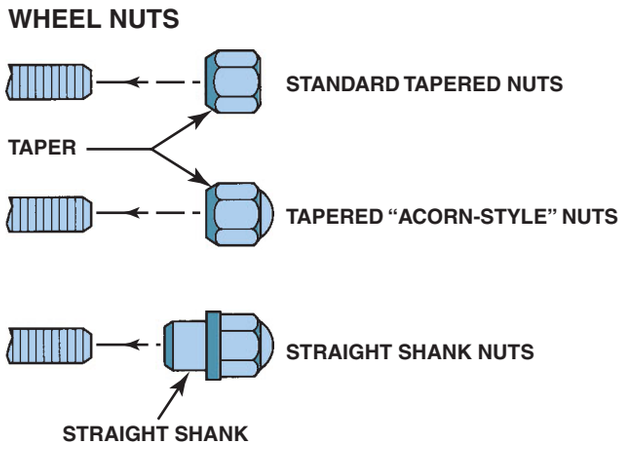


FIGURE 109–33 Various styles of lug nuts.

type and style of lug nut. ● **FIGURE 109–33** shows several of the many styles of lug nuts that are available.

SIZE Lug nuts are sized to the thread size of the stud onto which they screw. The diameter and the number of threads per inch are commonly stated. Since some vehicles use left-hand threads, RH and LH are commonly stated, indicating "right-hand" and "left-hand" threads. A typical size is 7/16-20RH, where the 7/16 indicates the diameter of the wheel stud and 20 indicates that there are 20 threads per inch. Another common fractional size is 1/2 × 20. Metric sizes such as M12 × 1.5 use a different sizing method.

M	metric
12	12-mm diameter of stud
1.5	1.5-mm distance from one thread peak to another

Other commonly used metric lug sizes include M12 × 1.25 and M14 × 1.5. Obviously, metric wheel studs require metric lug nuts.

LUG STUDS Lug studs are usually installed in hubs or drums using a press fit. Serrations on the shoulder of the stud provide support. Most studs are replaceable and should be replaced if the treads are damaged.

TIRE INSPECTION



1 Check the tire information placard, usually located on the driver's door or door jamb, for the specified tire size and inflation pressure.



2 Visually check the tires for abnormal wear or damage.



3 Remove the tire valve cap and visually check the condition of the valve stem.



4 Check inflation pressure by pushing the tire pressure gauge straight onto the end of the tire valve. If a "hissing" sound is heard, then the reading will not be accurate.



5 Read the pressure and compare to specifications. Use an analog or digital gauge if possible which have been proven to be more accurate than a mechanical pencil-type gauge.



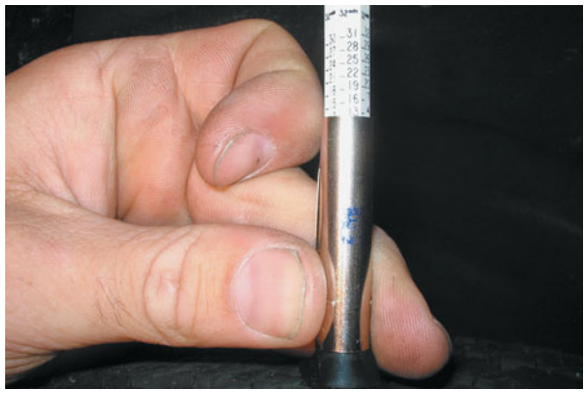
6 A typical tire tread depth gauge.

CONTINUED ▶

TIRE INSPECTION (CONTINUED)



7 The blade of the tire tread depth gauge is pushed down into the groove of the tire at the lowest part.



8 Remove the gauge from the tire and read the tread depth at the metal housing. Tread depth is usually measured in 1/32's of an inch.



9 If the top of Lincoln's head is visible, then the tread depth is lower than 2/32 in., the legal limit in many states.

REVIEW QUESTIONS

1. List the various parts of a tire and explain how a tire is constructed.
2. What is the aspect ratio?
3. List the factors that should be considered when purchasing tires.
4. Explain the three major areas of the Uniform Tire Quality Grading System.
5. How is the proper tire inflation pressure determined?

CHAPTER QUIZ

1. The part of the tire that is under just the tread of a radial tire is called the _____.
   - **a.** Bead
   - **b.** Body (carcass) ply
   - **c.** Belt
   - **d.** Inner liner
2. The aspect ratio of a tire means _____.
   - **a.** Its width to diameter of a wheel ratio
   - **b.** The ratio of height to width
   - **c.** The ratio of width to height
   - **d.** The ratio of rolling resistance

3. A tire is labeled 215/60R × 15 92T; the T indicates _____.
   a. Its speed rating
   b. Its tread wear rating
   c. Its load rating
   d. Its temperature resistance rating
4. The 92 in the tire designation in question 3 refers to the tire's _____.
   a. Speed rating
   b. Tread wear rating
   c. Load rating
   d. Temperature resistance rating
5. Radial tires can cause a vehicle to pull to one side while driving. This is called "radial tire pull" and is often due to _____.
   a. The angle of the body (carcass) plies
   b. Tire conicity
   c. Tread design
   d. Bead design
6. Tire inflation is very important to the safe and economical operation of any vehicle. Technician A says that the pressure should never exceed the maximum pressure imprinted on the sidewall of the tire. Technician B says to inflate the tires to the pressures recommended on the tire information decal or placard on the driver's door. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. When purchasing replacement tires, do not change tire width from the stock size by more than _____.
   a. 10 mm
   b. 15 mm
   c. 20 mm
   d. 25 mm
8. What do the letters JJ mean in a wheel designation size labeled 14 × 7JJ?
   a. The offset of the rim
   b. The bolt circle code
   c. The back spacing of the rim
   d. The shape of the flange area
9. Technician A says that a PAX run-flat tire uses a special wheel. Technician B says that a standard tire can be used to replace a PAX run-flat tire. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. Wheel back spacing is also called _____.
   a. Rear spacing
   b. Positive offset
   c. Negative offset
   d. Offset

chapter 110 TIRE PRESSURE MONITORING SYSTEMS

OBJECTIVES: **After studying Chapter 110, the reader will be able to:** • Explain why a tire-pressure monitoring system is used. • Describe how an indirect tire pressure monitoring system works. • Describe how a direct tire pressure monitoring system works. • Discuss the TREAD Act. • List the two types of TPMS sensors. • Describe how to program or relearn TPMS sensors. • List the tools needed to service a tire-pressure monitoring system.

KEY TERMS: Active mode 1265 • Alert mode 1265 • Cold placard inflation pressure 1262 • Delta pressure method 1267 • Initialization 1263 • Relearn 1263 • Sleep mode 1265 • Storage mode 1266 • Tire-pressure monitoring system (TPMS) 1261 • Transmitter ID 1267 • TREAD Act 1263

NEED FOR TIRE PRESSURE MONITORING

BACKGROUND A **tire-pressure monitoring system (TPMS)** is a system that detects a tire that has low inflation pressure and warns the driver. A tire-pressure monitoring system was first used when run-flat tires were introduced in the 1990s. A driver was often not aware that a tire had gone flat after a puncture. Because a run-flat tire is designed to be driven a limited distance and at limited speed after it loses air pressure, a method of alerting the driver had to be found. There were two systems used, indirect and direct, until the 2008 model year when the use of direct-reading pressure systems was required by law.



FIGURE 110–1 The tire pressure placard (sticker) on the driver's side door or door jamb indicates the specified tire pressure.

TEMPERATURE	TIRE PRESSURE (PSI)	CHANGE FROM COLD PLACARD INFLATION PRESSURE
120°F (49°C)	37	+5
110°F (43°C)	36	+4
100°F (38°C)	35	+3
90°F (32°C)	34	+2
80°F (27°C)	33	+1
70°F (21°C)	32	0
60°F (16°C)	31	−1
50°F (10°C)	30	−2
40°F (4°C)	29	−3
30°F (−1°C)	28	−4
20°F (−7°C)	27	−5
10°F (−12°C)	26	−6
0°F (−18°C)	25	−7
−10°F (−23°C)	24	−8
−20°F (−29°C)	23	−9

CHART 110–1

The effects of outside temperature on tire inflation, assuming a placard pressure of 32 PSI.

LOW TIRE PRESSURE EFFECTS

Low-tire inflation pressures have led to all of the following:

- Reduces fuel economy due to increased rolling resistance of the tires—3 PSI below specifications results in an increase of 1% in fuel consumption
- Reduces tire life—3 PSI below specifications results in a decrease of 10% of tire life
- Increases the number of roadside faults, which have been estimated to be 90% related to tire issues
- Reduces handling and braking efficiency
- Hundreds of deaths and thousands of personal injuries are due to problems associated with low-tire inflation pressure.

COLD PLACARD INFLATION PRESSURE

The term **cold placard inflation pressure** is used in service information to indicate the specified tire inflation pressure. The "placard" is the driver's side door jamb sticker that shows the tire size and the specified tire inflation pressure. The pressure stated is measured when the tires are cold or at room temperature, which is about 70°F (21°C). ● **SEE FIGURE 110–1.**

The tires become warmer while the vehicle is being driven, so tires should be checked before the vehicle has been driven or allowed to cool after being driven. Tire inflation pressure changes 1 PSI for every 10 degrees. ● **SEE CHART 110–1.**

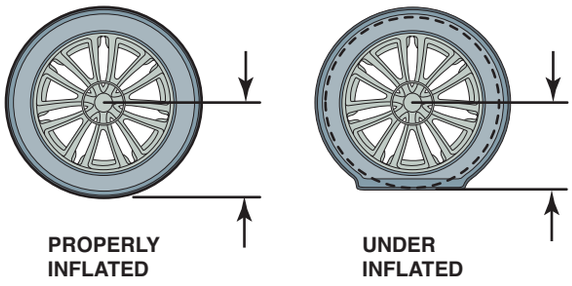


FIGURE 110–2 A tire with low inflation will have a shorter distance (radius) between the center of the wheel and the road and will therefore rotate faster than a tire that is properly inflated.

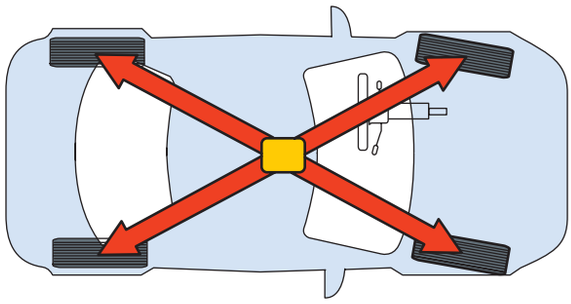


FIGURE 110–3 The speeds of the diagonally opposed wheels are added together and then compared to the other two wheels to check if one tire is rotating faster.

INDIRECT TPMS

PURPOSE AND FUNCTION

Indirect tire-pressure monitoring systems do not measure the actual tire pressure. Instead, the system uses the wheel speed sensors to detect differences in the speed of the wheels. The indirect system uses the wheel speed sensors to check the rolling speed of each of the tires. If a tire is underinflated, the following occurs:

- A tire that is underinflated will have a smaller diameter than a properly inflated tire. ● **SEE FIGURE 110–2.**
- An underinflated tire will rotate faster than a properly inflated tire.

COMPENSATION FOR CORNERING

When a vehicle turns a corner, the outside wheels rotate faster than the inside wheels. To compensate for this normal change in wheel rotation speed, the indirect tire-pressure monitoring system checks the diagonally opposed wheels. ● **SEE FIGURE 110–3.**

If the calculation of the diagonal wheel speed indicates that one of the wheels is rotating faster than the other, the TPMS warning light is illuminated.

ADVANTAGES Advantages for using the indirect system include:

- This system does not require additional components, such as tire-pressure sensors.
- This system is easily added to existing vehicles that were equipped with four-wheel speed sensors.
- It is low cost.

DISADVANTAGES Disadvantages for using the indirect system include:

- System cannot detect if all four tires are underinflated.
- Use of a space-saver spare tire may trigger the warning light.
- Cannot detect if more than one tire is low.
- Does not meet the Federal Highway Traffic Safety Standard (FMVSS) 138, which requires the system to be able to detect if any tire is underinflated by 25%.

DIAGNOSIS OF INDIRECT TPMS The diagnosis of an indirect tire-pressure monitoring system includes the following steps:

STEP 1 Verify the fault.
- If the TPMS warning light is on but not flashing, this indicates that the system has detected a tire with low inflation pressure.
- If the TPMS warning light flashes, this indicates that the system has detected a fault. Check service information for the specified steps to follow.

STEP 2 If the system has detected low tire pressure, check and adjust the tire pressure to that listed on the door pillar placard or factory specifications as stated in the owner's manual or service information.

STEP 3 Determine and correct the cause of the underinflated tire.

RELEARN (RESET) PROCEDURES After checking that all four tires are the same size and condition, the system may require resetting, also called **relearn** or **initialization.** Check service information for the exact steps to follow, which could include driving the vehicle over an extended period of time. The procedure usually includes the following:

- Inflate all four tires to the placard inflation pressure.
- Depress and hold the reset switch for 3 seconds. **SEE FIGURE 110–4.** The TPMS warning lamp should flash three times.
- Drive the vehicle so the ABS controller can learn the new "good" values. Typical driving times include:
  - Ford—20 minutes of driving
  - Toyota—30 to 60 minutes of driving
  - General Motors—60 minutes of driving

Check service information for the exact procedure to follow. Many service technicians ask the vehicle owner to drive the vehicle instead of taking the technician's time.

DIRECT TPMS

PURPOSE AND FUNCTION Direct tire pressure monitoring systems use a pressure sensor in each wheel that detects and transmits the tire pressure to a TPMS controller. This system means that the controller can notify the driver if any one or all of the tires are under-inflated. While some vehicles used the direct system for many years especially those vehicles equipped with run-flat tires such as the Chevrolet Corvettes, it was not until 2008 when all vehicles sold in the United States were required to be equipped with a direct tire pressure monitoring system.

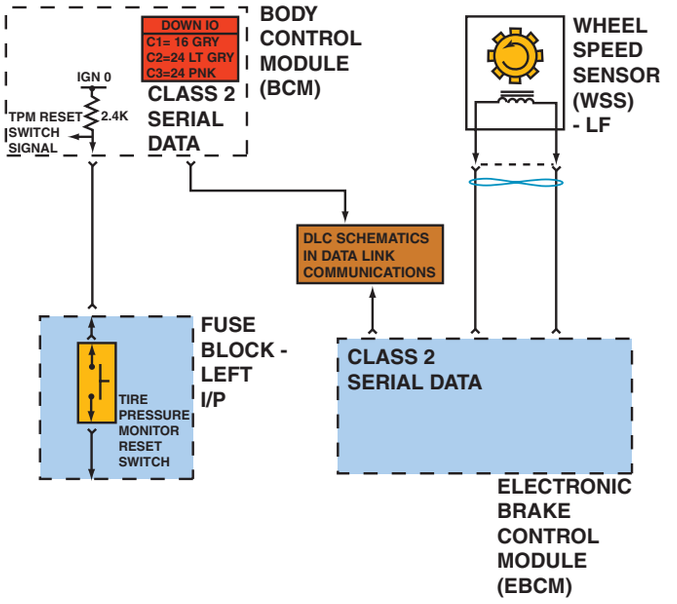


FIGURE 110–4 The indirect tire-pressure monitoring system has a reset switch that should be depressed after rotating or replacing tires.

TREAD ACT The **Transportation Recall Enhancement, Accountability and Documentation (TREAD) Act** requires that all vehicles be equipped with a tire-pressure monitoring system that will warn the driver in the event of an underinflated tire. This act was passed due to many accidents that were caused at least in part to underinflated tires. These accidents resulted in many deaths.

Congress passed the TREAD Act on November 1, 2000. The National Highway Traffic Safety Administration (NHTSA) requires the installation of tire-pressure monitoring systems (TPMSs) in passenger vehicles and light trucks manufactured after September 1, 2007 (2008 model year).

The NHTSA ruling is part one of a two-part final ruling.

- Part one establishes a new Federal Motor Vehicle Safety Standard (FMVSS) 138 that requires tire-pressure monitoring systems be installed in passenger vehicles and light trucks to warn the driver when a tire is 25% below the cold placard pressure.
- Part two includes the requirement to equip vehicles with a tire-pressure monitoring system that was phased-in starting in 2004. The phase-in included:
  - 20% from October 5, 2005 to August 31, 2006
  - 70% from September 1, 2006 to August 31, 2007
  - 100% from September 1, 2007 (2008 model year vehicles)

FMVSS 138 requires all cars, trucks, and vans with a gross vehicle weight rating (GVWR) of 10,000 pounds or less to illuminate a warning lamp within 10 minutes when the inflation pressure drops 25% or more from the vehicle manufacturer's specified cold tire inflation pressure as printed on the door placard.

WARNING LAMP The FMVSS 138 specifies that the driver must be warned of a low-tire inflation pressure by turning on an amber warning lamp. The warning lamp must also come on during a bulb check. The spare tire is not required to be monitored, but many vehicle manufacturers do equip full-size spare tires with a pressure sensor.

COLD PLACARD INFLATION PRESSURE (PSI)	WARNING LIGHT PRESSURE (−25%)	PSI LOW
40	30.0	10.0
39	29.3	9.7
38	28.5	9.5
37	27.8	9.2
36	27.0	9.0
35	26.3	8.7
34	25.5	8.5
33	24.8	8.2
32	**24**	**8.0**
31	23.3	7.7
30	22.5	7.5
29	21.8	7.2
28	21	7.0

CHART 110–2

Placard inflation pressure compared with the pressure when the TPMS triggers a warning light.



FIGURE 110–5 A clear plastic valve-stem tire-pressure monitoring sensor, showing the round battery on the right and the electronic sensor and transistor circuits on the left.

TECH TIP

Check Tire Pressure and Do Not Rely on the Warning Light

Industry experts think that 25% is too low and that this generally means that a tire has to be lower by about 8 PSI to trigger a warning light. All experts agree that tire pressure should be checked at least every month and kept at the specified cold placard inflation pressure.

- If the TPMS warning lamp is on at start-up, the system has detected a tire with low inflation pressure.
- If the TPMS warning lamp is flashing for 60 to 90 seconds, a system fault has been detected.

TWENTY-FIVE PERCENT RULE The TREAD Act specifies that the driver be warned if any tire inflation pressure drops by 25% or more from the cold placard pressure. ● **SEE CHART 110–2.**

IDENTIFYING A VEHICLE WITH TPMS

All vehicles sold in the United States since the 2008 model year must be equipped with a tire-pressure sensor. If the tire/wheel assembly has a tire-pressure monitoring system (TPMS) valve-type sensor, it can usually be identified by the threaded portion of the valve stem. ● **SEE FIGURE 110–5.**

RUBBER TIRE VALVE STEMS Some TPMS sensors are black rubber like a conventional valve core but it uses a tapered brass section and a longer cap. ● **SEE FIGURE 110–6.** If the cap is short then it does not have a stem-mounted tire-pressure sensor. However, the wheel may be equipped with a wheel-mounted sensor, so care should still be taken to avoid damaging the sensor during service.

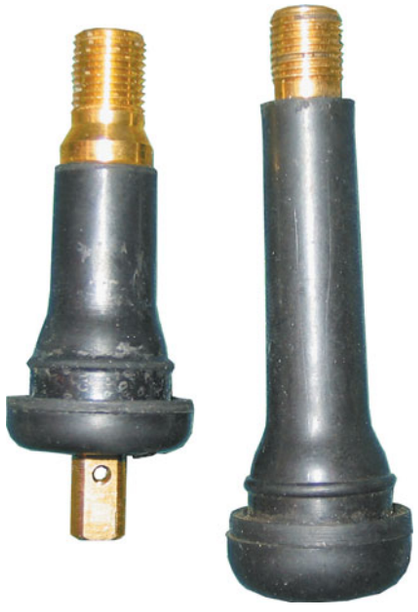


FIGURE 110–6 A conventional valve stem is on the right compared with a rubber TPMS sensor stem on the left. Notice the tapered and larger brass stem. The rubber TPMS sensor also uses a longer cap that makes it easy for a technician to spot that this is not a conventional rubber valve stem.

ALUMINUM TIRE VALVE STEMS If the vehicle has an aluminum tire valve stem, it is equipped with a direct tire-pressure monitoring system. The valve stem itself is the antenna for the sensor.

TPMS PRESSURE SENSORS

TYPES All direct TPMS sensors transmit tire inflation pressure to a module using a radio frequency (RF) signal. There are two basic designs used in direct pressure-sensing systems.



FIGURE 110–7 The three styles of TPMS sensors most commonly found include the two stem-mounted (rubber and aluminum, left and top), and the banded style (right).



FIGURE 110–8 A typical tire-pressure monitoring system tester. The unit should be held near the tire and opposite the valve stem if equipped with a wheel-mounted sensor, and near the valve stem if equipped with a valve-stem-type sensor.

TECH TIP

Use TPMS-Friendly Replacement Tires

Some replacement tires use steel body plies and could therefore block the low-level radio frequency signal sent from the tire-pressure sensor. Before installing replacement tires, check that the tires are safe and recommended for use on vehicles equipped with a direct-type tire-pressure monitoring system.

These sensors are manufactured by a variety of manufacturers, including:

- Beru
- Lear
- Pacific
- Schrader
- Siemens
- TRW

Each sensor uses a 3-volt lithium ion battery that has a service life of 7 to 10 years.

1. **Valve stem-mounted sensor**—This type of sensor uses the valve stem as the transmitter. The correct (nickel plated) valve core *must* be used in the aluminum valve stem. If a conventional brass valve is used, moisture in the air will cause corrosion between the two different metals.
2. **Banded sensor**—Banded sensors are installed in the drop well of the wheel and banded or clamped to keep them secure. Early banded sensors, such as those used in Corvettes equipped with run-flat tires, were piezoelectric and did not require a battery. All newer banded sensors include a battery.

   ● **SEE FIGURE 110–7.**

MODES OF OPERATION Tire-pressure sensors operate in three modes of operation:

1. **Active mode**—When the sensor inside detects that the vehicle is traveling above 20 mph (32 km/h), the sensor transmits once every minute.

TECH TIP

Check the TPMS Sensors Before and After Service

It is wise to check that all of the tire-pressure monitoring system sensors are working before beginning service work. For example, if the tires need to be rotated, the sensors will have to be reprogrammed for their new location. If a tire-pressure monitoring sensor is defective, the procedure cannot be performed. Use an aftermarket or original equipment tire-pressure monitoring sensor tester, as shown in ● **FIGURE 110–8.**

Then the tire-pressure sensors should be checked again after the service to make sure that they are working correctly before returning the vehicle to the customer.

2. **Sleep mode**—When the vehicle is stopped, the sensor "goes to sleep" to help improve battery life. In this mode, the transmitter still will broadcast tire inflation information every hour or every 6 hours, depending on the sensor.
3. **Alert mode**—Alert mode is triggered if a rapid change in inflation pressure is detected. In alert (or rapid mode), the tire inflation pressure is sent about every second (every 800 milliseconds on some sensors).

TPMS SENSOR OPERATION

Depending on the type and manufacturer, tire-pressure monitoring sensors can be any of several different designs. The TREAD Act does not specify the type or operation of the pressure sensors, only that the system must be capable of measuring tire inflation pressure and light the TPMS warning lamp. The types of sensors include:

- **Continuous-wave-type sensor**—designed to signal a tester when exposed to 5 to 7 seconds of continuous 125 KHz wave signal.



FIGURE 110–9 Some vehicles display the actual measured tire pressure for each tire on a driver information display.

FREQUENTLY ASKED QUESTION

Does a TPMS Sensor Work before Being Installed?

No. New tire-pressure warning sensors (transmitters) are shipped in **storage mode.** This mode prevents the battery from becoming discharged while in storage. When the transmitter is installed in a wheel/tire assembly and the tire is inflated to more than 14 PSI (97 kPa), the transmitter automatically cancels storage mode. Once a transmitter has canceled storage mode, it cannot enter this mode again. Therefore, once a sensor has been installed and the tire inflated above 14 PSI, the clock is ticking on battery life.

- **Magnetically-triggered-type sensor**—designed to trigger a tester if exposed to a powerful magnetic force.
- **Pulse-width-modulated-type sensor**—designed to be triggered when exposed to modulated wave 125 KHz signal.

The sensor also can vary according to the frequency at which it transmits tire-pressure information to the receiver in the vehicle. The two most commonly used frequencies are:

- 315 MHz
- 433.92 MHz (commonly listed as 434 MHz)

TPMS RECEIVER

The wireless TPMS receiver is housed in one of the following locations, depending on the vehicle:

- Remote keyless entry (RKE) receiver
- Body control module (BCM)
- Door module
- Individual antennas near each wheel well. These individual antennas then transmit tire-pressure information to the driver information center. ● **SEE FIGURE 110–9.**

DIRECT TPMS DIAGNOSIS

WARNING LIGHT ON If the TPMS warning light is on and not flashing, the system has detected a tire that has low inflation pressure. ● **SEE FIGURE 110–10.**

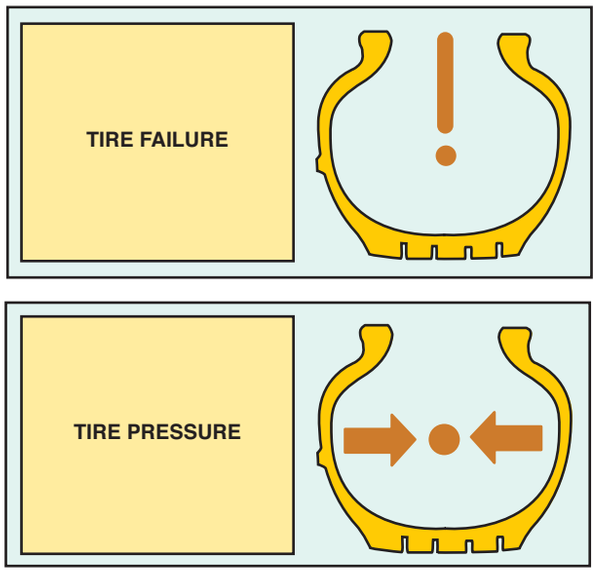


FIGURE 110–10 A tire-pressure warning light can vary depending on the vehicle, but includes a tire symbol.

If the TPMS light is on, perform the following steps:

STEP 1 Check the door placard for the specified tire inflation pressure.

STEP 2 Check all tires using a known-accurate tire-pressure gauge.

STEP 3 Inflate all tires to the specified pressure.

NOTE: Some systems will trigger the TPMS warning light if a tire is overinflated. An overinflated tire is also a safety-related problem.

WARNING LIGHT FLASHING If the TPMS warning lamp is flashing on and off, the system has detected a fault in the system. Faults could include:

- Defective wheel sensors, such as a sensor with a dead battery.
- A fault in the receiver, such as in the remote keyless entry module.

Check service information for the exact procedure to follow if the TPMS warning lamp is flashing. Always follow the specified diagnostic and service procedures.

INSTALLING A NEW PRESSURE SENSOR

When installing a new pressure sensor either because it failed or was damaged, the new sensor has to be relearned. This process is usually done with either:

- A scan tool
- A TPMS tester

The identification number on each sensor must be recorded before being installed, so it can register to a specific location on the vehicle. All four sensor identification numbers usually have to be entered into the tool within 300 seconds (5 minutes). On some vehicles, all four sensors must be relearned even if only one sensor is replaced.

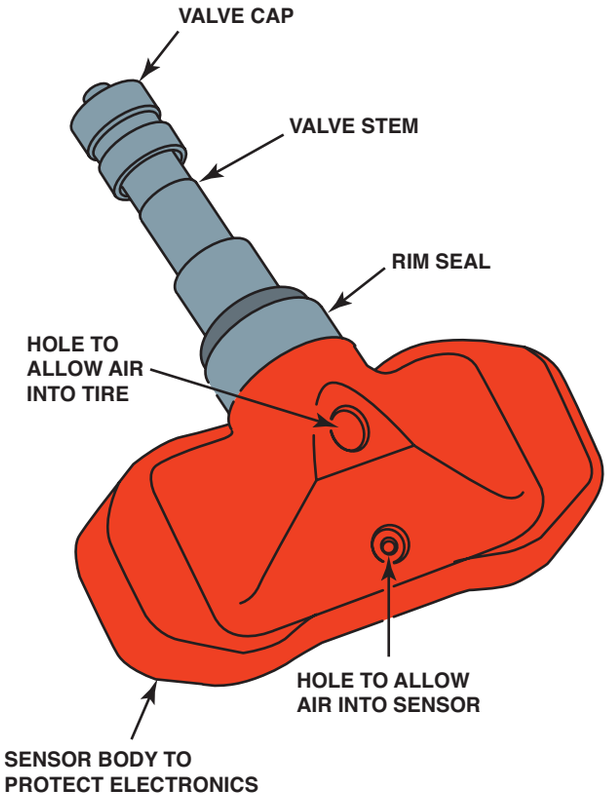


FIGURE 110–11 The parts of a typical stem-mounted TPMS sensor. Notice the small hole used to monitor the inflation pressure. The use of stop-leak can easily clog this small hole.

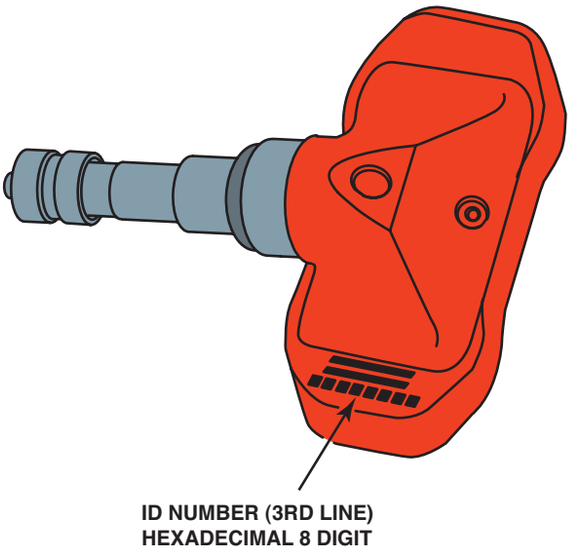


FIGURE 110–12 When replacing a TPMS sensor, be sure to record the sensor ID because this needs to be entered into the system through the use of a tester or scan tool.



FIGURE 110–13 A magnet is placed around the valve stem to reprogram some stem-mounted tire-pressure sensors.

TECH TIP

Check the Spare Tire

Many vehicles equipped with a full-size spare tire also have a TPMS sensor. If the inflation pressure decreases enough, the system will trigger the TPMS warning light. This is confusing to many vehicle owners who have checked all four tires and found them to be properly inflated. This fault often occurs during cold weather when the tire inflation pressure drops due to the temperature change. Most 2008 and newer vehicles equipped with a full size spare tire will come equipped with a TPMS sensor in the spare.

TPMS DIAGNOSTIC TOOLS

SCAN TOOLS Scan tools can be used for TPMS service if the scan tool is an original equipment tool for the vehicle make or if an aftermarket scan tool has original equipment-compatible software to access the chassis or body functions of the vehicle. A scan tool is used to perform the following functions:

1. **Register TPMS sensors**—A replacement TPMS transmitter has an 8-digit number, called the **transmitter ID,** on each valve/transmitter assembly. ● **SEE FIGURE 110–11.**
2. **Perform initialization**—This step assigns a transmitter ID to the correct position on the vehicle, such as right front (RF). ● **SEE FIGURE 110–12.**
3. **Monitor sensor values**—TPMS transmitters send information to the controller including:
   - Sensor identification
   - Tire inflation pressure
   - Tire air temperature (some sensors)
   - Sensor battery voltage (some sensors)

TPMS SENSOR ACTIVATIONS

ACTIVATING THE SENSOR A tire-pressure monitoring system sensor needs to be activated to verify that the sensor actually works. This should be performed before any tire or wheel service is performed. There are three methods used to activate a TPMS sensor to cause it to send a signal that can be captured to verify proper operation. These activation methods include:

1. **Using a magnet** (aluminum wheels and stem-mounted sensors only) ● **SEE FIGURE 110–13.**
2. **Changing inflation pressure** (usually requires lowering the inflation pressure by 5 to 10 PSI) This method is called the **delta pressure method.** The term *delta* refers to a change and is named for the Greek letter delta (Δ).



FIGURE 110–14 Always use an accurate, known-good tire-pressure gauge. Digital gauges are usually more accurate than mechanical gauges.

3. **Triggered by a handheld TPMS tester** that transmits a signal to wake up the sensor. There are two formats used, depending on the sensor. They include:
   - 125 KHz constant or continuous pulse
   - 125 KHz pulse-width-modulated pulse

HANDHELD TESTERS Several manufacturers produce handheld testers to reset the sensors. These tools are used to perform the following functions:

- TPMS sensor activation
- TPMS sensor relearn
- To program a new TPMS sensor

Tools are available from the following companies:

- OTC (http://www.otctools.com)
- Bartec (http://www.bartecusa.com)
- Snap-on (http://www.snapon.com)

TPMS RELEARN PROCEDURE

The following procedure will allow the service technician to reprogram the TPMS after tire rotation on a General Motors vehicle without using a scan tool.

1. With KOEO (key on, engine off), the "lock" and "unlock" buttons on the key fob should be simultaneously pressed and held. The horn will chirp within 10 seconds, indicating the receiver is in programming mode. The programming procedure must now be completed within five minutes, with no more than one minute between programming.

   NOTE: If the horn does not chirp at the start of this procedure, the TPMS option has not been enabled. A scan tool is needed to enable the system.

2. At the left front wheel, the special magnet tool must be held over the valve stem to force the sensor to transmit its code. The horn will chirp once, indicating the system has recognized the sensor. The next sensor must be programmed within one minute.
3. The remaining sensors should be programmed in the following order: RF, RR, LR. The horn will chirp once when each sensor has been detected. It will chirp twice to indicate completion of the programming process.

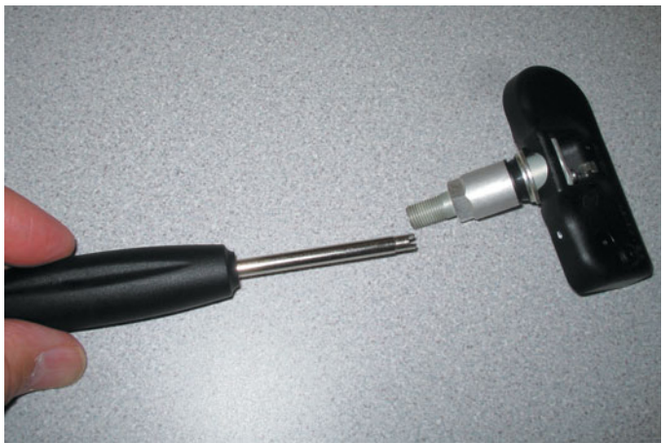


FIGURE 110–15 A clicker-type valve core tool ensures that the valve core is tightened to factory specifications.

TECH TIP

All TPMS Sensors Will Fail

All TPMS pressure sensors will fail because they contain a battery that has a service life of 7 to 10 years. What does this mean to the service technician? This means that if new tires are being installed on a 5- or 6-year-old vehicle equipped with tire-pressure sensors, then the customer should be notified that the TPMS sensors could fail almost anytime.

TPMS SENSOR SERVICE TOOLS

ITEMS NEEDED Whenever servicing a tire/wheel assembly that has a direct TPMS system, certain items are needed. When a stem-mounted sensor is removed, the following items are needed:

1. **Information**—Check service information for the exact procedure to follow for the vehicle being serviced. Vehicles and sensors are different for different vehicles.
2. **Digital tire-pressure gauge**—Many mechanical tire-pressure gauges are not accurate. An old mechanical gauge may be used to ensure that all tires are inflated to the same pressure, but the pressure may not be accurate. ● **SEE FIGURE 110–14.**
3. **Tire valve core torque wrench**—This calibrated tool ensures that the valve core is tightened enough to prevent air loss, but not too tight to cause harm. The recommended torque is 3 to 5 inch-pounds (0.34 to 0.56 N.m). ● **SEE FIGURE 110–15.**
4. **Tire valve nut torque wrench**—Most are 11 or 12 mm in size and the torque ranges from 30 to 90 in.-lb (4.25 to 10.0 N.m).
5. **Sensor service kit**—If a pressure sensor is going to be reused, the following service parts must be replaced:
   - Cap
   - Valve core (nickel plated only)
   - Nut
   - Grommet

   These parts are usually available individually or in an assortment package. Pressure sensor and kit information can be found at the following websites:

- http://www.schrader-bridgeport.com
- http://www.myerstiresupply.com
- http://www.rubber-inc.com

● **SEE FIGURE 110–16.**

? **FREQUENTLY ASKED QUESTION**

Can TPMS sensors be switched to new wheels?

Maybe. It depends on the style of the new or replacement wheels as to whether the sensors will fit or not. Some vehicles are designed to allow for a second set of sensors such as for winter tires. Many Lexus vehicles can be programmed to use set #1 or set #2. It is best to check before purchasing new wheels. Another set of TPMS sensors could be a major added expense.



FIGURE 110–16 An assortment of service parts that include all of the parts needed to service a stem-mounted TPMS sensor being installed after removal for a tire replacement or repair.

REVIEW QUESTIONS

1. How does the use of wheel speed sensors detect a tire with low inflation pressure?
2. What is the difference between faults when the TPMS warning lamp is on compared with when it is flashing?
3. What is the percentage of vehicles that each vehicle manufacturer must equip with TPMS?
4. TPMS pressure sensors can be made by what manufacturer?
5. What are the three modes of sensor operation?
6. What information is sent to the TPMS controller from the sensor?
7. After removing a stem-type pressure sensor to replace a tire or perform a tire repair, what should be replaced?

CHAPTER QUIZ

1. A tire with lower than specified inflation pressure could lead to what condition?
   a. Reduced fuel economy
   b. Reduced tire life
   c. Increased chances of roadside faults or accidents
   d. All of the above
2. Which tire inflation information should be checked to determine the proper tire inflation pressure?
   a. Cold placard inflation pressure
   b. The maximum pressure as stated on the sidewall of the tire
   c. 32 PSI in all tires
   d. Any of the above
3. Two technicians are discussing tire pressure and temperature. Technician A says that tire pressure will drop 1 PSI for every 10-degree drop in temperature. Technician B says that the tire pressure will increase as the vehicle is being driven. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. Two technicians are discussing the indirect tire-pressure monitoring system. Technician A says that it was used by some vehicle manufacturers on vehicles before the 2008 model year. Technician B says that it uses the speeds of the RF and LR tires and compares the rotating speeds of the LF and RR tires to detect a low tire. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
5. The FMVSS 138 law requires that the driver be notified if the tire inflation pressure drops how much?
   a. 30% **c.** 20%
   b. 25% **d.** 15%
6. The two basic types of direct TPMS sensors include _____.
   a. Rubber stem and aluminum stem
   b. Beru and Schrader
   c. Stem-mounted and banded
   d. Indirect and direct
7. What mode does a direct pressure sensor enter when the vehicle is stopped?
   a. Sleep mode **c.** Alert mode
   b. Storage mode **d.** Active mode
8. To activate or learn a direct pressure sensor, what does the service technician need to do?
   a. Enter learn mode and use a magnet
   b. Enter learn mode and decrease inflation pressure
   c. Use a handheld tester
   d. Any of the above depending on the vehicle and system
9. What does the “delta pressure method” mean?
   a. Change the inflation pressure
   b. Activate the sensor so it broadcasts the pressure to the scan tool
   c. Inflating the tire to the specified pressure
   d. Using a handheld tester to read the pressure as reported by the sensor
10. What type of valve core is used in stem-mounted sensors?
    a. Brass **c.** Steel
    b. Nickel plated **d.** Aluminum

chapter 111

TIRE AND WHEEL SERVICE

OBJECTIVES: After studying Chapter 111, the reader will be able to: • Prepare for ASE Suspension and Steering (A4) certification test content area "E" (Wheel and Tire Diagnosis and Repair). • Discuss the need for proper inflation pressure. • Explain the purpose of nitrogen inflation. • Discuss proper tire mounting procedures. • Describe recommended tire rotation methods. • Discuss how to properly balance a tire. • Describe tire repair procedures. • Explain wheel and tire safety precautions.

KEY TERMS: Dynamic balance 1278 • Lateral runout 1277 • Match mounting 1272 • Modified X 1275 • Radial force variation 1277 • Radial runout 1276 • Shimmy 1277 • Static balance 1278 • Tire rotation 1274 • Tramp 1276 • Wheel mounting torque 1273

INTRODUCTION

Proper tire service is extremely important for the safe operation of any vehicle. Premature wear can often be avoided by checking and performing routine service, such as frequent rotation and monthly inflation checks. Avoid overloading the vehicle and have any leaks repaired as soon as possible. ● **SEE FIGURE 111–1.**

TIRE INFLATION

Tires should always be inflated to the pressure indicated on the driver's door or pillar sticker. Tires should be checked when cold, before the vehicle has been driven, because driving on tires increases the temperature and therefore the pressure of the tires. Proper tire inflation is important for the following reasons:

- **Inflation pressure carries the load of the vehicle.** If the pressure is low, the load capacity of the tire is decreased. ● **SEE FIGURE 111–2.**



FIGURE 111–1 Using soapy water from a spray bottle is an easy method to find the location of an air leak from a tire.

- **Inflation pressure varies with temperature.** Tires lose 1 PSI for every 10-degree drop in temperature. This means that as the sensors change and the temperature changes, so does the inflation pressure inside the tires. For example, if tires were inflated to 35 PSI on the first day of summer (June 21) when the temperature was 90°F (32°C), then the following pressures would occur, assuming no air loss at all:

  Summer (June 21) 90°F—35 PSI

  Fall (September 21) 80°F—34 PSI

  Winter (December 21) 30°F—29 PSI

  Therefore, it is very important to check and correct inflation pressures regularly.
- **Tire inflation affects fuel economy.** A drop in inflation pressure from 30 PSI to 23 PSI can result in a drop of fuel economy from 20 miles per gallon to 18 miles per gallon. ● **SEE FIGURE 111–3.**
- **Tire inflation affects tire life.** Even a slight drop in air pressure can have a major effect on the life of a tire. If, for example, the inflation pressure dropped 10 PSI, the life of the tire would be reduced by 40%. ● **SEE FIGURE 111–4.**
- **The TREAD Act specifies that the driver be notified if the inflation of a tire drops by 25%.** However, 25% represents a loss of air pressure of about 8 PSI. A drop of 8 PSI means an approximate 2-mpg decrease in fuel economy as well as about a 25% reduction in tread wear.

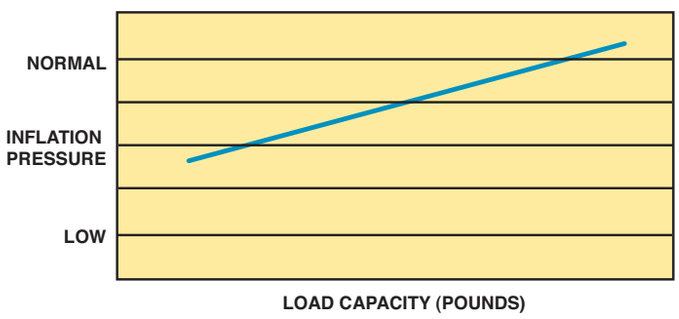


FIGURE 111–2 This chart shows the relationship between tire inflation pressure and load capacity of the tire.

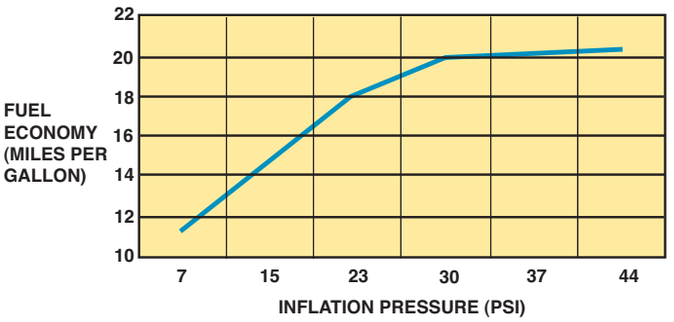


FIGURE 111–3 This chart shows that a drop in inflation pressure has a major effect on fuel economy.

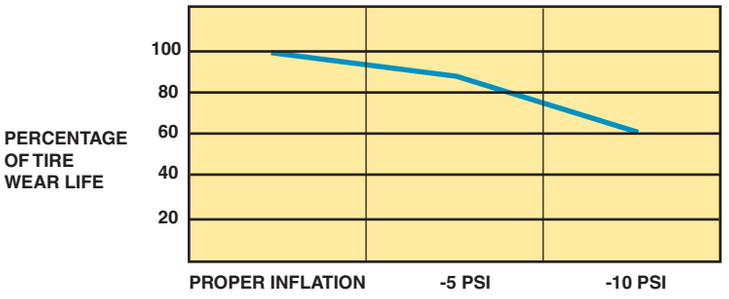


FIGURE 111–4 Notice that if a tire is underinflated by 10 PSI, the life expectancy is reduced by 40%.

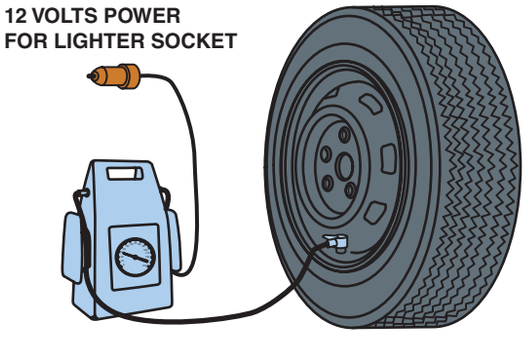


FIGURE 111–5 A temporary inflation pump that uses 12 volts from the cigarette lighter to inflate the tire.

FREQUENTLY ASKED QUESTION

What Is a "Temporary Mobility Kit"?

A temporary mobility kit is a system to inflate a flat tire supplied by the vehicle manufacturer instead of a spare tire. A temporary mobility kit can include:

- A compressor powered by the cigarette lighter. ● **SEE FIGURE 111–5.**
- An aerosol spray can that provides inflation and sealer. ● **SEE FIGURE 111–6.**

Either type can be found in many vehicles because such devices save weight, increase trunk space, and cost less than a conventional spare tire and jack. However, these kits are designed to be a temporary repair only because the cause of the low tire was never determined. If the tire appears to be fixed, many vehicle owners may think that the tire has been repaired. However, the tire should be carefully inspected inside and out for damage and properly repaired.

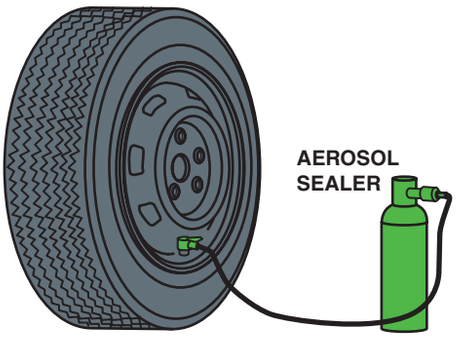


FIGURE 111–6 Many vehicle manufacturers include an aerosol can of sealer on vehicles that are not equipped with a conventional spare tire.



FIGURE 111–7 Most shops that use nitrogen inflation install a green tire value cap to let others know that nitrogen, rather than air has been used to inflate the tire.

NITROGEN INFLATION

PURPOSE Some shops recommend and inflate tires using nitrogen instead of using compressed air. Compressed air contains about 78% nitrogen, 21% oxygen, and 1% other gases. If air already contains mostly nitrogen, why use pure nitrogen? There are several reasons, including:

- The nitrogen molecule is slightly larger than the oxygen molecule so the tire will lose pressure faster if air is used instead of nitrogen.
- Compressed nitrogen contains less moisture than compressed air. When the tire heats up, moisture in the tire vaporizes and expands, causing the pressure inside the tire to increase. Even small changes in tire pressure can noticeably affect the handling of the vehicle.
- Race teams use nitrogen because they already come to the track with a cylinder of nitrogen to power the air tools.
- Race teams also have more control over how much the pressure will increase when the tires heat up, because nitrogen has less tendency to change pressure with temperature change.
- Some oxygen in the tires could, over a long period of time, cause the oxidation of the inner liner of the tire and the corrosion of the wheel. ● **SEE FIGURE 111–7.**

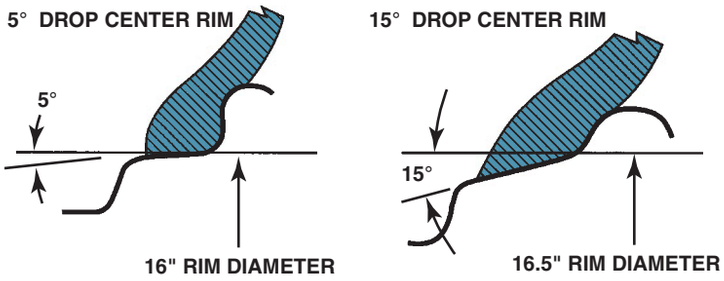


FIGURE 111–8 Note the difference in the shape of the rim contour of the 16-in. and 16 1/2-in. diameter wheels. While it is possible to mount a 16-in. tire on a 16 1/2-in. rim; it cannot be inflated enough to seat against the rim flange. If an attempt is made to seat the tire bead by overinflating (over 40 PSI), the tire bead can break, resulting in an explosive force that could cause serious injury or death.

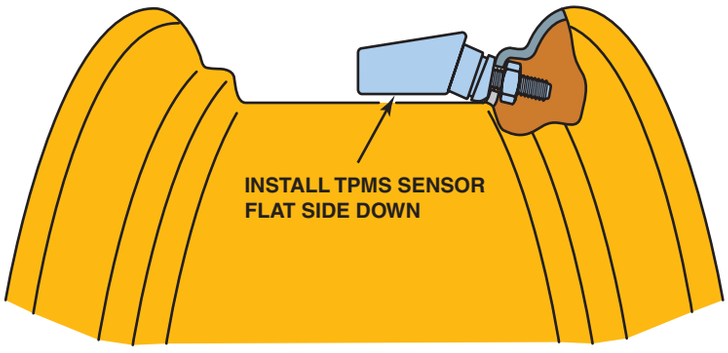


FIGURE 111–9 When installing a tire-pressure monitoring system sensor, be sure that the flat part of the sensor is parallel to the center section of the rim.

TIRE MOUNTING RECOMMENDATIONS

1. When removing a wheel from a vehicle for service, mark the location of the wheel and lug stud to ensure that the wheel can be replaced in exactly the same location. This ensures that tire balance will be maintained if the tire/wheel assembly was balanced on the vehicle.
2. Make certain that the wheel has a good, clean metal-to-metal contact with the brake drum or rotor. Rust, grease, oil, or dirt between these two surfaces could cause the wheel lug nuts to loosen while driving.
3. Always check the rim size. For example, simply by looking it is hard to distinguish a 16-in. wheel from a 16.5-in. wheel used on some trucks. ● **SEE FIGURE 111–8.** The rim size is marked on the sidewall of the tire, and the rim's diameter and width are stamped somewhere on the wheel.
4. Remove the tire from the rim following the instructions of the tire change machine adhering to all safety precautions.
5. Install a new tire valve or the tire-pressure monitoring system (as shown in ● **FIGURE 111–9**).

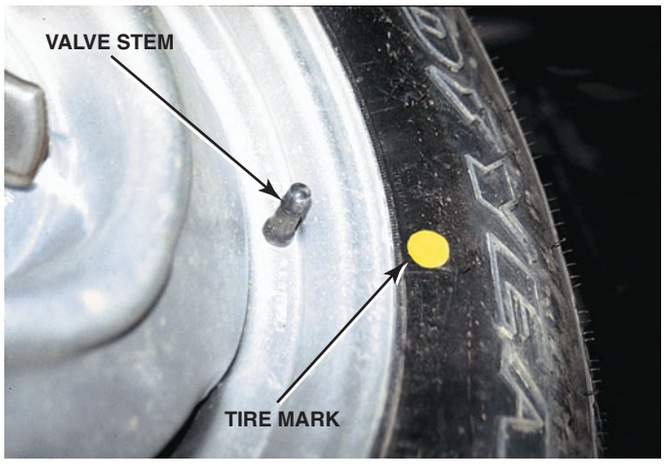


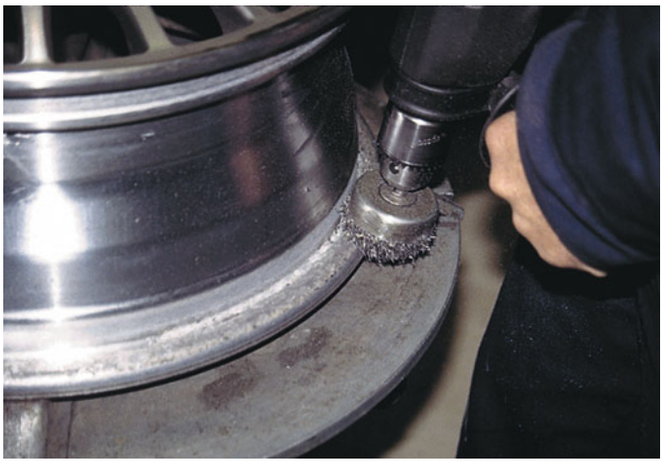
FIGURE 111–10 This tire on a new vehicle has been match mounted at the factory. The yellow sticker is placed at the largest diameter of the tire. The valve core hole in the wheel is usually drilled at the smallest diameter of the wheel. The best way to make sure the assembly is as round as possible and to reduce the number of wheel weights needed to balance the tire is to align the sticker with the valve core.

6. Many tires have been marked with a paint dot or sticker, as shown in ● **FIGURE 111–10.** This mark represents the largest diameter (high point) and/or stiffest portion of the tire. This variation is due to the overlapping of carcass and belt fabric layers, as well as tread and sidewall rubber splices. The tire should be mounted to the rim with this mark lined up with the valve stem. The valve stem hole is typically drilled at the smallest diameter (low point) of the wheel. Mount the tires on the rim with the valve stem matched to (lined up next to) the mark on the tire. This is called **match mounting.**
7. Never use more than 40 PSI (275 kPa) to seat a tire bead.
8. Rim flanges must be free of rust, dirt, scale, or loose or flaked rubber build-up prior to mounting the tire. ● **SEE FIGURE 111–11.**
9. When mounting new tires, do *not* use silicone lubricant on the tire bead. Use special lubricant such as rendered (odorless) animal fat or rubber lubricant to help prevent tire rotation on the rim. This rubber lube is a water-based soap product that is slippery when wet (coefficient of friction when less than 0.3) and acts almost as an adhesive when dry (coefficient of friction when dry of over 0.5 for natural products and over 1.0 for synthetic products). ● **SEE FIGURE 111–12.** If the wrong lubricant is used, the rubber in the bead area of the tire can be softened or weakened. Also, most other lubricants do not increase in friction when they dry like rubber lubricant does. The result can be the rotation of the tire on the rim (wheel), especially during rapid acceleration or braking.

NOTE: Many experts recommend that when a new tire is installed the vehicle should be driven at less than 50 mph (80 km/h) for the first 50 miles (80 km) to allow the tires to adhere to the rim. During this break-in period, the rubber lube used to mount the tire is drying and the tire is becoming fully seated on the rim. By avoiding high speeds, rapid acceleration, and fast braking, the driver is helping to prevent the tire from rotating on the rim.



(a)



(b)

FIGURE 111–11 (a) Cleaning the bead area of an aluminum (alloy) wheel using a handheld wire brush. The technician is using the tire changer itself to rotate the wheel as the brush is used to remove any remnants of the old tire. (b) Using an electric or air-powered wire brush speeds the process, but care should be exercised not to remove any of the aluminum itself. (Remember, steel is harder than aluminum and a steel wire brush could cause recesses to be worn into the aluminum wheel, which would prevent the tire from proper seating in the bead area.) The bead seat area on steel wheels should also be cleaned to prevent air leaks at the rim.

TECH TIP

Spin the Tires

When performing a vehicle inspection and the vehicle has been hoisted on a frame-type lift, check the tires by rotating them by hand. The tires on the nondrive wheels should spin freely.

- On front-wheel-drive vehicles, rear wheels should rotate easily.
- On rear-wheel-drive vehicles, front wheels should rotate easily.
- On all-wheel-drive vehicles, all four wheels may require effort to rotate.

What to Look For:

- When rotating the wheels, look at the tires from the front or rear and check that the tread of the tires does not change or look as if the tread is moving inward or outward. If the tread is moving, this indicates an internal fault with the tire and it should be replaced. This type of fault can cause a vibration even though the tire/wheel assembly has been correctly balanced.
- Look from the side of the vehicle as the wheel/tire assembly is being rotated. Look carefully at the tread of the tire and see if the tire is round. If the tire is out-of-round, the tread will appear to move up and down as the tire is being rotated.

WHEEL MOUNTING TORQUE

For **wheel mounting torque,** make certain that the wheel studs are clean and dry, and torqued to the manufacturer's specifications.

CAUTION: Most manufacturers warn that the wheel studs should not be oiled or lubricated with grease; this can cause the wheel lug nuts to loosen while driving. Always follow the vehicle manufacturers' recommended service procedures.

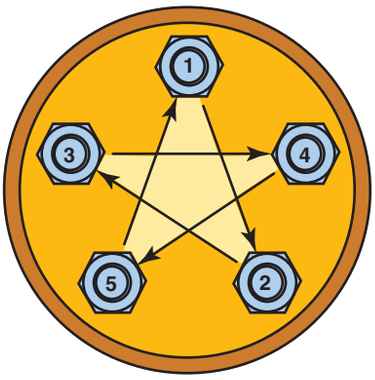


FIGURE 111–12 Rendered (odorless) animal fat is recommended by some manufacturers of tire changing equipment for use as a rubber lubricant.

Always tighten lug nuts gradually in the proper sequence—star pattern (tighten one nut, skip one, and tighten the next nut). This helps prevent warping the brake drums or rotors, or bending a wheel. ● **SEE FIGURE 111–13.**

Tire lug nuts should always be torqued to factory specifications. If the exact torque value is not available, use the following chart as a guide for the usual value based on the size (diameter) of the lug studs.

Stud Diameter	Torque (lb-ft)
3/8 in.	35–45
7/16 in.	55–65
1/2 in.	75–85
9/16 in.	95–115
5/8 in. (usually only trucks)	125–150
12 mm	70–80
14 mm	85–95



TORQUE SEQUENCE

FIGURE 111–13 Always tighten wheel lug nuts (or studs) in a star pattern to ensure even pressure on the axle flange, brake rotors or drums, and the wheel itself.

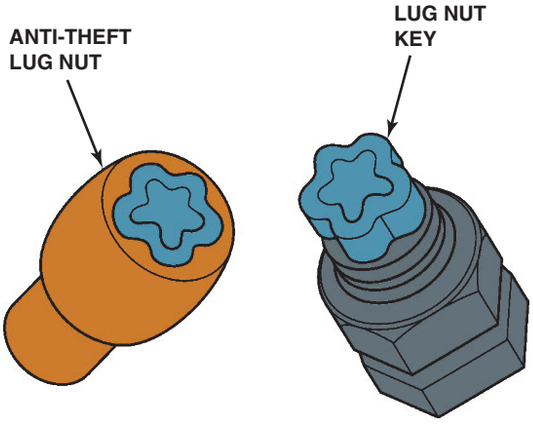


FIGURE 111–14 Most manufacturers recommend using hand tools rather than an air impact wrench to remove and install lock-type lug nuts to prevent damage. If either the key or the nut is damaged, the nut may be very difficult to remove.

Many factory-installed and aftermarket wheels use anti-theft wheel lug nuts, as shown in ● **FIGURE 111–14,** usually on only one wheel stud. When removing or installing a locked lug nut, be sure the key is held square to the lug nut to prevent damaging either the nut or the key.

Whenever you install a brand new set of aluminum wheels, re-torque the wheels after the first 25 miles. The soft aluminum often compresses slightly, loosening the torque on the wheels.

NOTE: The use of torque-absorbing adapters (torque-limiting shank sockets or torque sticks) on lug nuts with an air impact wrench properly set has proved to give satisfactory results. ● SEE FIGURE 111–15 for a photo of a torque-absorbing adapter.

TIRE ROTATION

To ensure long life and even tire wear, **tire rotation** is essential. It is important to rotate each tire to another location. Some rear-wheel-drive vehicles, for example, may show premature tire wear

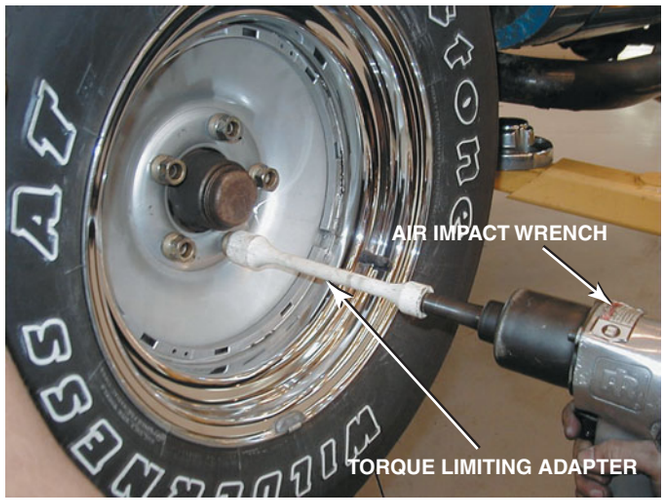


FIGURE 111–15 A torque-limiting adapter (torque stick) for use with an air impact wrench still requires care to prevent overtightening. The air pressure to the air impact should be limited to 125 PSI (860 kPa) in most cases, and the proper adapter must be selected for the vehicle being serviced. The torque adapter absorbs any torque beyond its designed rating. Most adapters are color coded for easy identification as to the size of lug nut and torque value.

TECH TIP

Fine-Tune Handling with Tire-Pressure Changes

The handling of a vehicle can be changed by changing tire pressures between the front and rear tires.

Understeer—A term used to describe how a vehicle handles when cornering where additional steering input is needed to maintain the corner, or resisting turning into a corner. This is normal handling for most vehicles.

Oversteer—A term used to describe handling where correction while cornering is often necessary because the rear tires lose traction before the front tires.

Tire Pressure	To Decrease Understeer	To Decrease Oversteer
Front tire inflation pressure	Increase	Decrease
Rear tire inflation pressure	Decrease	Increase

CAUTION: Do not exceed the maximum inflation pressure as imprinted on the tire sidewall.

REAL WORLD FIX

I Thought the Lug Nuts Were Tight!

Proper wheel nut torque is critical, as one technician discovered when a customer returned complaining of a lot of noise from the right rear wheel. ● **SEE FIGURE 111–16** for a photo of what the technician discovered. The lug (wheel) nuts had loosened and ruined the wheel.

CAUTION: Most vehicle manufacturers also specify that the wheel studs/nuts should not be lubricated with oil or grease. The use of a lubricant on the threads could cause the lug nuts to loosen.



FIGURE 111–16 This wheel was damaged because the lug nuts were not properly torqued.

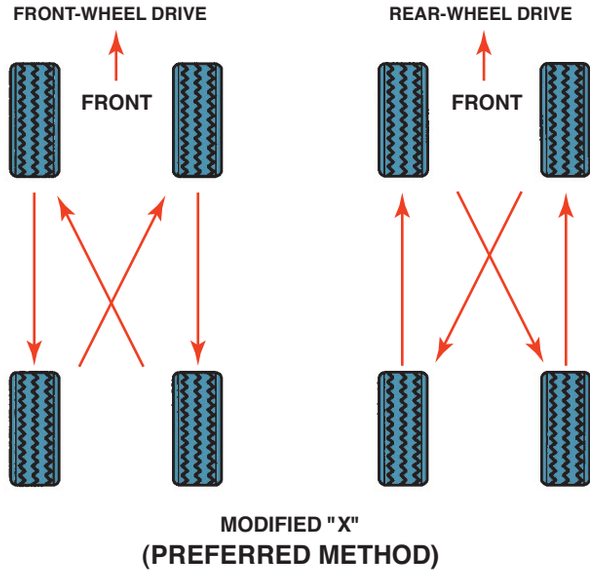


FIGURE 111–17 The method most often recommended is the modified X method. Using this method, each tire eventually is used at each of the four wheel locations. An easy way to remember the sequence, whether front wheel drive or rear wheel drive, is to say to yourself, "Drive wheels straight, cross the nondrive wheels."

TECH TIP

Tire Rotation

Tire rotation should be done at every *other* oil change. Most manufacturers recommend changing the engine oil every 6,000 miles (9,500 km) or every six months so this means that a tire rotation is recommended every year or every 12,000 miles (19,000 km).

on the front tires. The wear usually starts on the outer tread row. This wear usually appears as a front-to-back (high and low) wear pattern on individual tread blocks. These *blocks of tread* rubber are deformed during cornering, stopping, and turning. This type of tread block wear can cause tire noise and/or tire roughness. While some shoulder wear on front tires is normal, it can be reduced by proper inflation, alignment, and tire rotation. For best results, tires should be rotated every 6,000 miles or every six months. ● **SEE FIGURE 111–17** for suggested methods of rotation, such as the **modified X.**

NOTE: Radial tires can cause a radial pull due to their construction. If wheel alignment is correct, attempt to correct a pull by rotating the tires front to rear or, if necessary, side to side.

Some tire manufacturers do not recommend rotating the tires on front-wheel-drive vehicles because the front tires often wear three times as fast as the rear. They recommend replacing just front tires, because the rear tires often last over 90,000 miles (145,000 km).

CAUTION: General Motors also warns that the wheels on many vehicles such as the Pontiac Trans Am and the newer Grand Prix cannot be rotated front to rear because the wheels and tires are different sizes. Always check service information as to the specified tire rotation procedure to follow on the vehicle being serviced.

TECH TIP

All-Wheel-Drive Tire Concerns

It is very important that all-wheel-drive vehicles be equipped with tires that are all the same outside diameter. If, for example, the vehicle has 20,000 miles and the tires are half worn, all of the tires should be replaced in the event of a problem requiring replacement of only one tire.

Most vehicle manufacturers specify that all tires must be within 2/32 in. of tread depth without causing a constant strain on the drive train.



FIGURE 111–18 Tire showing excessive shoulder wear resulting from underinflation and/or high-speed cornering.

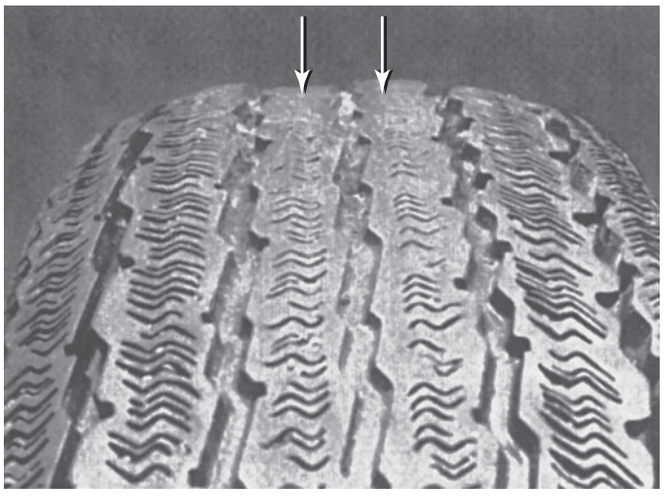


FIGURE 111–19 Tire showing excessive wear in the center, indicating overinflation or heavy acceleration on a drive wheel.

TIRE INSPECTION

All tires should be carefully inspected for faults in the tire itself or for signs that something may be wrong with the steering or suspension systems of the vehicle. ● **SEE FIGURES 111–18 THROUGH 111–20** for examples of common problems.

RADIAL RUNOUT

Even though a tire has no visible faults, it can be the cause of vibration. If vibration is felt above 45 mph, regardless of the engine load, the cause is usually an out-of-balance or a defective out-of-round tire. Both of these problems cause a **tramp** or *up-and-down*-type vibration. If the vibration is seen in the hood of the vehicle or felt in the steering wheel, then the problem is usually the *front* tires. If the vibration is felt throughout the entire vehicle or in the seat of your pants, then the rear tires (or drive shaft, in rear-wheel-drive vehicles) are the problem. This can be checked by using a runout gauge and checking for **radial runout.** ● **SEE FIGURES 111–21** and **111–22.**



FIGURE 111–20 Wear on the outside shoulder only is an indication of an alignment problem.

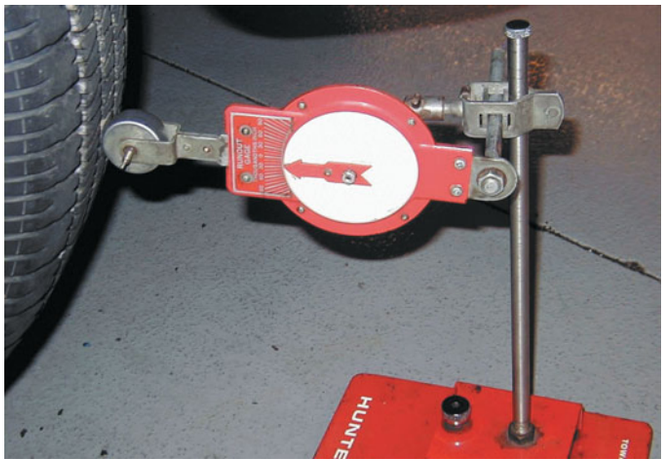


FIGURE 111–21 A tire runout gauge being used to measure the radial runout of a tire.

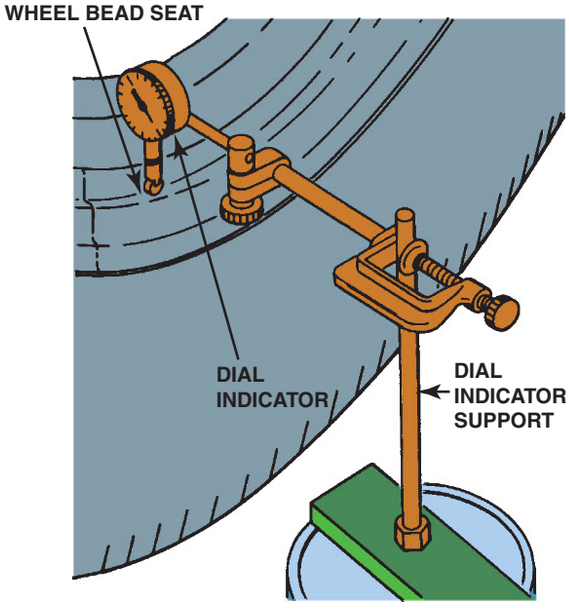


FIGURE 111–22 To check wheel radial runout, the dial indicator plunger tip rides on a horizontal surface of the wheel, such as the bead seat.

FREQUENTLY ASKED QUESTION

I Thought Radial Tires Couldn't Be Rotated!

When radial tires were first introduced by American tire manufacturers in the 1970s, rotating tires side-to-side was *not* recommended because of concerns about belt or tread separation. Since the late 1980s, most tire manufacturers throughout the world, including the United States, have used tire-building equipment specifically designed for radial-ply tires. These newer radial tires are constructed so that the tires can now be rotated from one side of the vehicle to the other without fear of causing a separation by the resulting reversal of the direction of rotation.

To check radial runout (checking for out-of-round) and lateral runout (checking for side-to-side movement), follow these steps:

1. Raise the vehicle so that the tires are off the ground approximately 2 in. (5 cm).
2. Place the runout gauge against the tread of the tire in the center of the tread and, while rotating the tire, observe the gauge reading.
3. Note that maximum radial runout should be less than 0.060 in. (1.5 mm). Little, if any, tramp will be noticed with less than 0.030 in. (0.8 mm) runout. If the reading is over 0.125 in. (3.2 mm), replacement of the tire is required.
4. Check all four tires.

CORRECTING RADIAL RUNOUT Excessive radial runout may be corrected by one of several methods:

1. Try relocating the wheel on the mounting studs. Mark one stud and remount the wheel two studs away from its original position. Excessive wheel hole and/or stud tolerance may be the cause. If the radial runout is now satisfactory, re-mark the stud and wheel to prevent a future occurrence of the problem.
2. Remount the tire on the wheel 180 degrees from its original location. This can solve a runout problem, especially if the tire was not match mounted to the wheel originally.
3. If runout is still excessive, remove the tire from the wheel and check the runout of the *wheel.* If the wheel is within 0.035 in. (0.9 mm), yet the runout of the tire/wheel assembly is excessive, the problem has to be a defective tire and it should be replaced.

Sometimes a problem within the tire itself can cause a vibration, and yet not show up as being out-of-round when tested for radial runout. A condition called **radial force variation** can cause a vibration even if correctly balanced.

NOTE: Some tire balancers are equipped with a roller that is pressed against the tread of the tire to measure radial force variations. Follow the instructions as shown on the balancer display to correct for excessive radial force variations.

LATERAL RUNOUT

Another possible problem that tires can cause is a type of vibration called **shimmy.** This *rapid back-and-forth motion* can be transmitted through the steering linkage to the steering wheel.

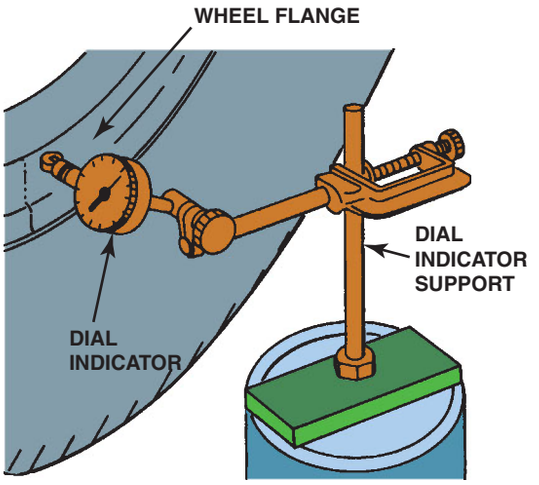


FIGURE 111–23 To check lateral runout, the dial indicator plunger tip rides on a vertical surface of the wheel, such as the wheel flange.

FREQUENTLY ASKED QUESTION

Is the Age of a Tire Important?

Yes. The National Highway Traffic Safety Administration (NHTSA) recommends that any tire six years old or older should be replaced regardless of tread depth. This means that tires that look almost like new but are six years old or older should be replaced because the NHTSA determined that age, not tread depth, was a major factor in tire failures.

Excessive runout is usually noticeable by the driver of the vehicle as a side-to-side vibration, especially at low speeds between 5 and 45 mph (8 and 72 km/h). Shimmy can be caused by an internal defect of the tire or a bent wheel. This can be checked using a runout gauge on the side of the tire or wheel to check for **lateral runout.**

Place the runout gauge against the side of the tire and rotate the wheel. Observe the readings. The maximum allowable reading is 0.045 in. (1.1 mm). If close to or above 0.045 in. (1.1 mm), check on the edge of the wheel to see if the cause of the lateral runout is due to a bent wheel, as shown in ● **FIGURE 111–23.**

Most manufacturers specify a maximum lateral runout of 0.035 in. (0.9 mm) for alloy wheels and 0.045 in. (1.1 mm) for steel wheels. ● **SEE FIGURE 111–24.**

CORRECTING LATERAL RUNOUT Excessive lateral runout may be corrected by one of several methods:

1. Re-torque the wheel in the proper star pattern to the specified torque. Unequal or uneven wheel torque can cause excessive lateral runout.
2. Remove the wheel and inspect the wheel mounting flange for corrosion or any other reason that could prevent the wheel from seating flat against the brake rotor or drum surface.
3. Check the condition of the wheel or axle bearings. Looseness in the bearings can cause the wheel to wobble.

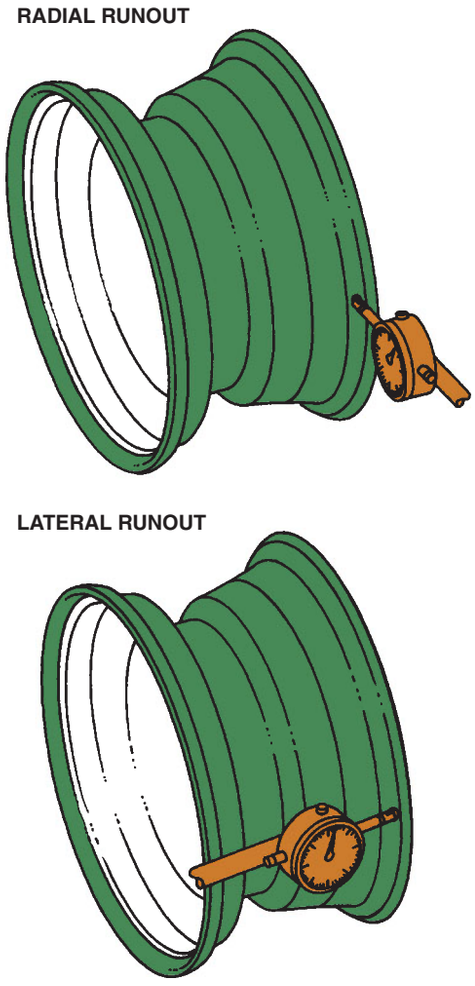


FIGURE 111–24 The most accurate method of measuring wheel runout is to dismantle the tire and take dial indicator readings on the inside of the wheel rim.

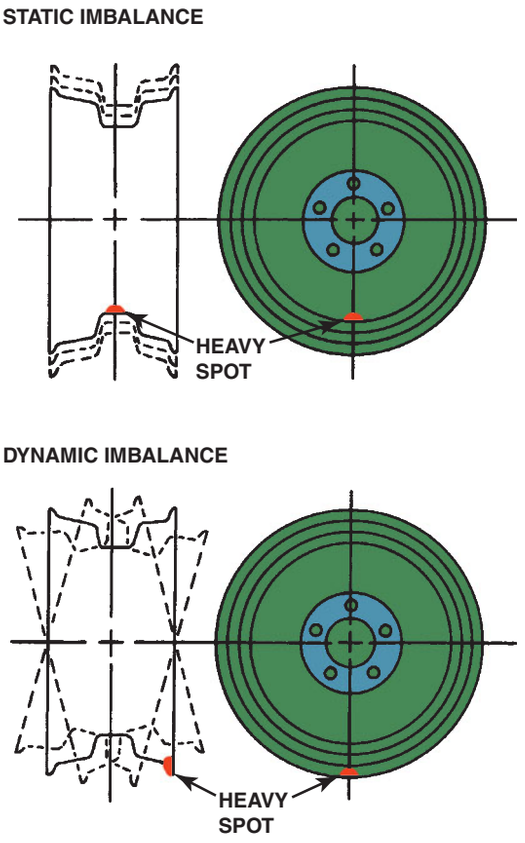


FIGURE 111–25 A wheel balancer detects heavy spots on the wheel and tire, and indicate where to place weight to offset both static and dynamic imbalance.

REAL WORLD FIX

The Greased Wheel Causes a Vibration

Shortly after an oil change and a chassis lubrication, a customer complained of a vibration at highway speed. The tires were checked for excessive radial runout to be certain the cause of the vibration was not due to a defective out-of-round tire. After removing the wheel assembly from the vehicle, excessive grease was found on the inside of the rim. Obviously, the technician who greased the lower ball joints had dropped grease on the rim. After cleaning the wheel, it was checked for proper balance on a dynamic computer balancer and found to be properly balanced. A test-drive confirmed that the problem was solved.

TIRE BALANCING

Proper tire balance is important for tire life, ride comfort, and safety. Tire balancing is needed because of the lack of uniform weight and stiffness (due to splices) and a combination of wheel runout and tire runout. Balancing a tire can compensate for most of these conditions. However, if a tire or wheel is excessively out of round or bent, then replacement of the wheel or tire is required.

STATIC BALANCE The term **static balance** means that the weight mass is evenly distributed around the axis of rotation.

1. For example, if a wheel is spun and stops at different places with each spin, then the tire is statically balanced.
2. **If the static balance is not correct, wheel tramp-type (vertical shake) vibration and uneven tire wear can result.**
3. Static balance can be tested with the tire stationary or while being spun to determine the heavy spot (sometimes called *kinetic balance*).

DYNAMIC BALANCE The term **dynamic balance** means that the centerline of weight mass is in the same plane as the centerline of the wheel. ● **SEE FIGURE 111–25.**

1. Dynamic balance must be checked while the tire and the wheel are rotated, to determine side-to-side as well as up-and-down out of balance.
2. **Incorrect dynamic balance causes shimmy.** Shimmy-type vibration causes the steering wheel to shake from side to side.

PREBALANCE CHECKS Before attempting to balance any tire, the following should be checked and corrected to ensure good tire balance:

1. Check the wheel bearing adjustment for looseness or wear.
2. Check the radial runout.
3. Check the lateral runout.



FIGURE 111–26 An assortment of wheel weights designed to fit different shaped rims.



FIGURE 111–27 Liquid tire stop leak was found in all four tires. This liquid caused the tires to be out of balance.

4. Remove stones from the tread.
5. Remove grease or dirt buildup on the inside of the wheel.
6. Check for dragging or misadjusted brakes.
7. Check for loose or backward lug nuts.
8. Check for proper tire pressures.
9. Remove all of the old weights.
10. Check for bent or damaged wheel covers.

WHEEL WEIGHTS A weight equal to and placed 180 degrees opposite from the heavy spot of the tire/wheel assembly is used for static balancing. In other words, tire balancing is actually counter-balancing a heavy spot with a weight. For dynamic balancing, the tire balancing machine calculates how far out and 180 degrees opposite the heavy spot from centerline of the out-of-balance section. Wheel weights are available in a variety of styles and types, including the following:

1. Clip-on lead weights for standard steel rims.
2. Clip-on weights for alloy (aluminum) wheels. ● **SEE FIGURE 111–26.**
   a. Uncoated—generally *not* recommended by wheel or vehicle manufacturers because corrosion often occurs where the lead weight contacts the alloy wheel surface.
   b. Coated—lead weights that are painted or coated in a plastic material are usually the *recommended* type of weight to use on alloy wheels.

   Weights are usually coated with a nylon or polyester-type material that often matches the color of the aluminum wheels.
3. Steel or zinc wheel weights are being sold to replace weights made from lead. Some states have outlawed lead weights due to environmental concerns of lead on the ground from lost wheel weights.
4. Adhesive (stick on) wheel weights are used on the inside of the rim where they do not show. Stick-on weights come with an adhesive backing that is most often used on alloy wheels. ● **SEE FIGURE 111–28.**



FIGURE 111–28 Stick-on weights are used from the factory to balance the alloy wheels of this Prowler.

REAL WORLD FIX

The Vibrating Ford Van

A technician was asked to solve a vibration problem on a rear-wheel-drive Ford van. During a test-drive, the vibration was felt everywhere—the dash, the steering wheel, the front seat, the shoulder belts; everything was vibrating! The technician balanced all four tires on a computer balancer. Even though wheel weights were put on all four wheels and tires, the vibration was even worse than before. The technician rebalanced all four wheels time after time, but the vibration was still present. The shop supervisor then took over the job of solving the mystery of the vibrating van. The supervisor balanced one wheel/tire assembly and then tested it again after installing the weights. The balance was way off! The supervisor broke the tire down and found about 1 quart (1 liter) of liquid in the tire! Liquid was found in all four tires. No wonder the tires couldn't be balanced! Every time the tire stopped, the liquid would settle in another location.

The customer later admitted to using a tire stop-leak liquid in all four tires. Besides stop leak, another common source of liquid in tires is water that accumulates in the storage tank of air compressors, which often gets pumped into tires when air is being added. All air compressor storage tanks should be drained of water regularly to prevent this from happening. ● **SEE FIGURE 111–27.**



FIGURE 111–29 Wheel weight pliers are specially designed to remove and install wheel weights.

TECH TIP

Stop Leak Can Damage TPMS Sensors

Stop leak should never be used in a tire that is equipped with the TPMS sensor because the sensor can be damaged.

FREQUENTLY ASKED QUESTION

How Much Is Too Much Weight?

Whenever balancing a tire, it is wise to use as little amount of weight as possible. For most standard-size passenger vehicle tires, most experts recommend that no more than 5.5 oz of weight be added to correct an imbalance condition. If more than 5.5 oz total weight is needed, remove the tire from the wheel (rim) and carefully inspect for damage to the tire or the wheel. If the tire still requires more than 5.5 oz and the wheel is not bent or damaged, replace the tire.

Most wheel weights come in 1/4 ounce (0.25-oz) increment (oz × 28 = grams).

0.25 oz = 7 gm	1.75 oz = 49 gm
0.50 oz = 14 gm	2.00 oz = 56 gm
0.75 oz = 21 gm	2.25 oz = 63 gm
1.00 oz = 28 gm	2.50 oz = 70 gm
1.25 oz = 35 gm	2.75 oz = 77 gm
1.50 oz = 42 gm	3.00 oz = 84 gm

Use a wheel weight pliers to help ensure proper installation and removal of wheel weights. ● **SEE FIGURE 111–29.**

BUBBLE BALANCER This type of static balancer is commonly used and is accurate, if calibrated and used correctly. A bubble balancer is portable and can be easily stored away when not in use. It is also easy to use and is relatively inexpensive.

COMPUTER BALANCER The most popular type of tire balancer is the computer dynamic balancer. Most computer balancers are designed to balance wheels and tires off the vehicle. Computer dynamic balancers spin the tire at a relatively slow speed (approximately 20 mph). Sensors attached to the spindle of the balancer determine the amount and location of weights necessary to balance the tire dynamically. All computer balancers must be programmed with the actual rim size and tire location for the electronic circuits to calibrate the required weight locations. Some computer balancers can perform loaded radial force and lateral force variation testing on the tire/wheel assembly and display corrective actions. ● **SEE FIGURE 111–30.**



FIGURE 111–30 A tire balancer that can also detect radial and lateral force variation and instruct the operator where to rotate the tire to achieve the best ride, or indicate a bent wheel.

FREQUENTLY ASKED QUESTION

Are the Brake Drums and Rotors Balanced?

Whenever an off-the-vehicle computer balancer is used, a question often asked by beginning technicians is, "What about the balance of the brake drums and rotors?" Brake drums and rotors are balanced at the factory, usually to within 0.5 oz-in. Imbalance measured in oz-in. means that any imbalance force is measured in ounces, then multiplied by the distance from the center measured in inches. This means that at a distance of 1 in. from the center of the drum or rotor, it is within 0.5 ounce of being perfectly balanced. Being within 0.5 ounce-inch also means that at 5 inches from the center, the imbalance is only 0.1 ounce.

What this means to the technician is that most drums and rotors are balanced well enough not to be a problem when using off-the-vehicle balancers. However, the smart technician should look for evidence that weights have been removed from brake drums to permit aluminum wheels to fit, or other cases where the factory balance of the drums and rotors has been changed.

Most computer balancers will be accurate to within 1/4 oz (0.25 oz), while some are accurate to within 1/8 oz (0.125 oz). (Most drivers can feel an out-of-balance of 1 oz or more, but few can feel a vibration caused by just 1/4 oz.) For sensitive drivers or vehicles used for high speeds, such as racing, most computer balancers can be programmed to balance within 1/8 oz (0.125 oz). Refer to the manufacturer's instructions for the exact capabilities and procedures for your computer balancer.

Most vehicle manufacturers specify that no more than 5.5 oz (150 gm) be used to balance any tire, with no more than 3.5 oz (100 gm) used per side of each wheel.

REPLACEMENT WHEELS

Whenever a replacement wheel is required, the same offset should be maintained. If wider or larger-diameter wheels are to be used, consult a knowledgeable wheel or tire salesperson to determine the correct wheel for your application.

CAUTION: Never remove the weights that are welded to the surface of the brake drum facing the wheel. ● **SEE FIGURE 111–31.** **If replacement wheels do not fit without removing these weights, either replace the brake drum (one without a weight) or select another brand or style of wheel. Removing the weights from a brake drum can cause severe vibration at highway speeds.**

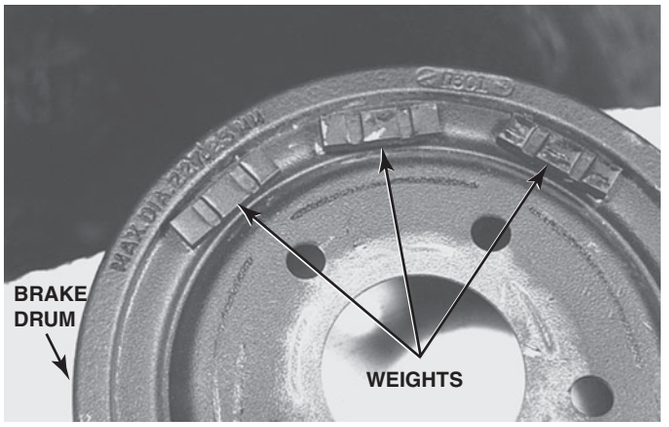


FIGURE 111–31 Most brake drums do not have this much attached weight.

REAL WORLD FIX

It Happened to Me—It Could Happen to You

During routine service, I rotated the tires on a Pontiac Trans Am. Everything went well and I even used a torque wrench to properly torque all of the lug nuts. Then, when I went to drive the car out of the service stall, I heard a horrible grinding sound. When I hoisted the car to investigate, I discovered that the front wheels were hitting the outer tie rod ends. ● **SEE FIGURE 111–32.** The 16-in. wheels had a different back spacing front and rear, and therefore these wheels could not be rotated. Always check replacement or aftermarket wheels for proper fit before driving the vehicle.

FREQUENTLY ASKED QUESTION

What Are Hubcentric Wheels?

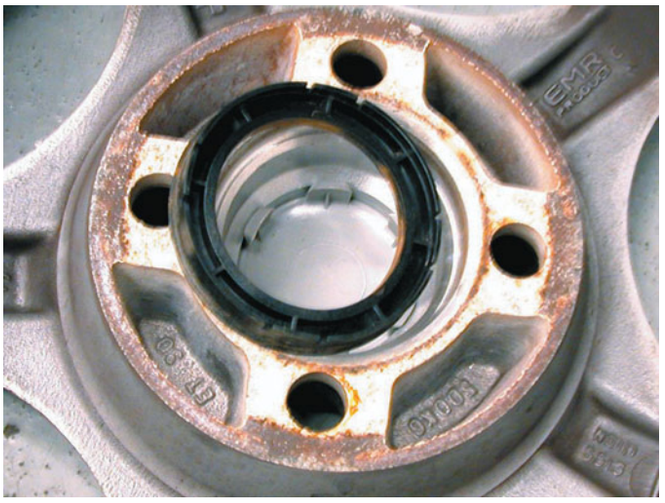
Most wheels are designed to fit over and be supported by the axle hub. This type of wheel is called a hubcentric type wheel. Some wheels use an enlarged center hub section and rely on the wheel studs for support and to keep the wheel centered on the axle. Some aftermarket wheels may be designed to fit several different vehicles. As a result, the wheel manufacturers use plastic hubcentric adapter rings. ● **SEE FIGURE 111–33.**

TIRE REPAIR

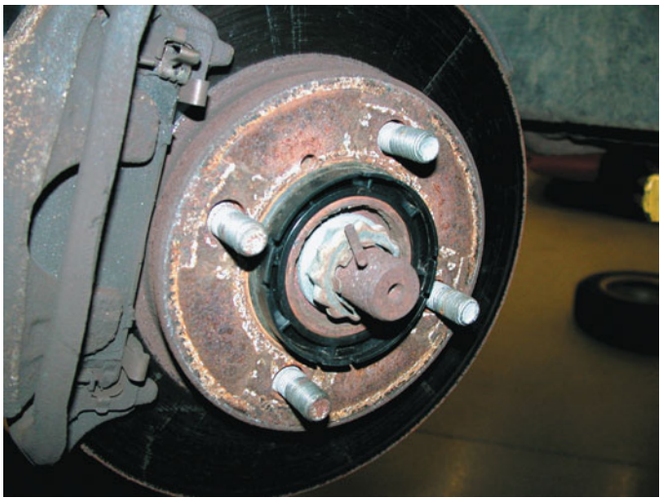
Tread punctures, nail holes, or cuts up to 1/4 in. (2.6 mm) can be repaired. Repairs should be done from the inside of the tire using plugs or patches. The tire should be removed from the rim to make the



FIGURE 111–32 Notice that the rim touches the tie rod end.



(a)



(b)

FIGURE 111–33 (a) A hubcentric plastic ring partially removed from an aftermarket wheel. (b) A hubcentric plastic ring left on the hub when removing a wheel.

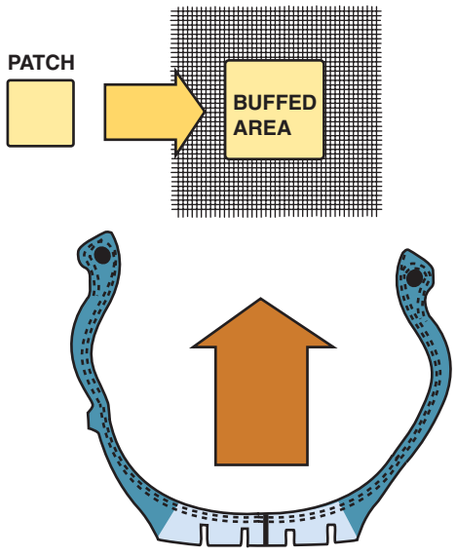


FIGURE 111–34 The area of the repair should be buffed slightly larger than the patch to be applied.

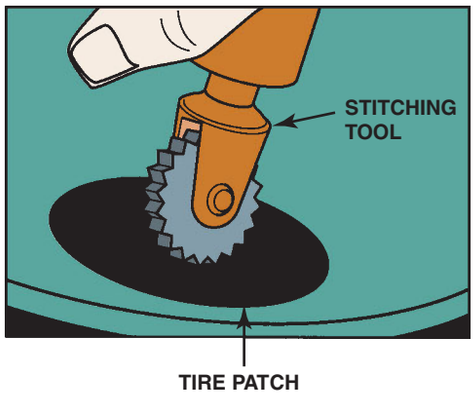


FIGURE 111–35 A stitching tool being used to force any trapped air out from under the patch.

repair. With the tire off the wheel, inspect the wheel and the tire for hidden damage. The proper steps to follow for a tire repair are as follows:

1. Mark the location of the tire on the wheel.
2. Dismount the tire; inspect and clean the punctured area with a prebuff cleaner. DO NOT USE GASOLINE!
3. Buff the cleaned area with sandpaper or a tire-buffing tool until the rubber surface has a smooth, velvet finish. ● **SEE FIGURE 111–34.**
4. Ream the puncture with a fine reamer from the inside. Cut and remove any loose wire material from the steel belts.
5. Fill the puncture with contour filling material, and cut or buff the material flush with the inner liner of the tire.
6. Vacuum and clean the area. Then apply chemical vulcanizing cement and allow to dry.
7. Apply the patch and use a stitching tool from the center toward the outside of the patch to work any air out from between the patch and the tire. ● **SEE FIGURE 111–35.** Another excellent tire repair procedure uses a rubber plug. Pull the stem through the hole in the tire, as shown in ● **FIGURE 111–36.**
8. Remount the tire on the rim, aligning the marks made in step 1. Inflate to the recommended pressure and check for air leaks.

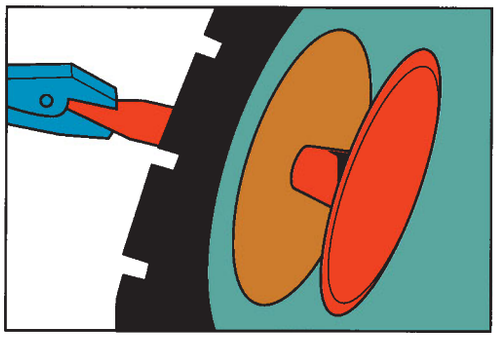


FIGURE 111–36 A rubber plug being pulled through a hole in the tire. The stem is then cut off flush with the surface of the tire tread.

TECH TIP

Dispose of Old Tires Properly

Old tires cannot be thrown out in the trash. They must be disposed of properly. Tires cannot be buried because they tend to come to the surface. They also trap and hold water, which can be a breeding ground for mosquitoes. Used tires should be sent to a local or regional recycling center where the tires will be ground up and used in asphalt paving or other industrial uses. Because there is often a charge to dispose of old tires, it is best to warn the customer of the disposal fee.

WARNING

Most experts agree that tire repairs should be done from the inside. Many technicians have been injured and a few killed when the tire they were repairing exploded as a steel reamer tool was inserted into the tire. The reamer can easily create a spark as it is pushed through the steel wires of a steel-belted tire. This spark can ignite a combustible mixture of gases inside the tire caused by using stop leak or inflator cans. Since there is no way a technician can know if a tire has been inflated with a product that uses a combustible gas, always treat a tire as if it could explode.

TECH TIP

Open-End Wrenches Make It Easier

Tire repair is made easier if two open-end wrenches are used to hold the beads of the tire apart. See step 4 in the tire repair photo sequence.

NOTE: Most vulcanizing (rubber) cement is highly flammable. Use out of the area of an open flame. Do not smoke when making a tire repair.

There are many tire repair products on the market. Always follow the installation and repair procedures exactly per the manufacturer's instructions.



1 A typical tire-changing machine showing the revolving table and movable arm used to remove a tire from the wheel.



2 The foot-pedal controls allow the service technician to break the tire bead, damp the wheel (rim) to the machine, rotate the tire/wheel assembly, and still have both hands free.



3 Using a tire valve removal tool, unscrew the valve core using extreme caution and wear eye protection because the valve is under pressure and can be forced outward and cause personal injury.



4 The valve core removed from the tire valve. Allow all of the air in the tire to escape.



5 A bead breaker is being used to separate the tire from the bead seat of the wheel. Repeat as needed to break the bead on both sides of the wheel.



6 After breaking the beads from both sides of the tire, install the wheel/tire assembly flat onto the machine and, using the foot-pedal control, lock the wheel to the changer.

CONTINUED ▶



7 To remove the tire from the wheel, position the arm of the changer against the rim of the wheel and lock in position.



8 The tire tool (flat bar) is placed between the bead of the tire and the wheel. Using tire lubricant can help prevent damage to the tire.



9 The foot pedal that causes the table to rotate is depressed and the tire is removed from the wheel.



10 Reposition the tire tool to remove the lower bead of the tire from the wheel.



11 As the table of the tire changer is rotated, the tire is released from the wheel and can be lifted off the wheel.



12 Before installing a tire, inspect and clean the bead seat.



13 Before installing a new tire, most experts recommend replacing the tire valve, being installed here, using a tool that pulls the valve through the hole in the wheel.



14 Apply tire soap or rubber lubricant to both beads of the tire.



15 Rotate the tire on the wheel and position the arm so that the tire will be guided onto the rim as the wheel is rotated.



16 Repeat for the upper bead.



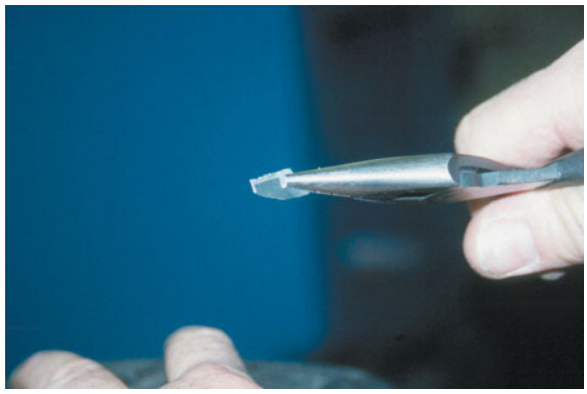
17 Inflate the tire, being careful to not exceed 40 PSI. Experts suggest that a tire be in a cage during the initial bead seating inflation to help prevent personal injury if the wheel or tire fails.



18 Install the tire valve core and inflate the tire to specifications.



1 The source of the leak was detected by spraying soapy water on the inflated tire. Needle-nose pliers are being used to remove the object that caused the flat tire.



2 A part of a razor blade was found to be the cause of the flat tire.



3 A reamer is being used to clean the puncture hole.



4 This technician is using two open-end wrenches to hold the tire beads apart if a tire bead spreader is not available.



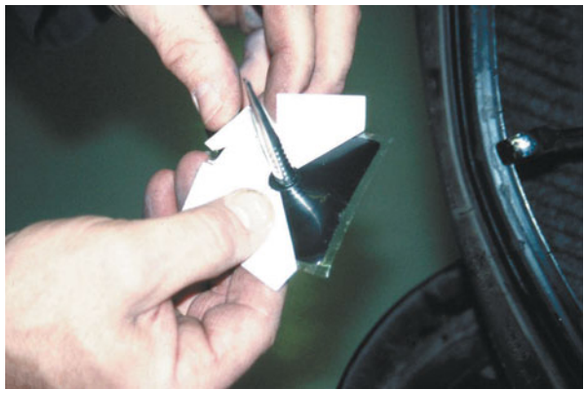
5 The surrounding area is being buffed using an air-powered die grinder equipped with a special buffing tool specifically designed for this process.



6 After using a vacuum on all debris and rubber after buffing, apply rubber cement to the area.



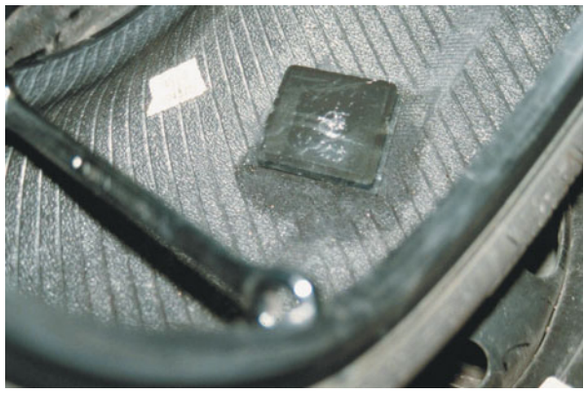
7 The brush included with the rubber cement makes the job easy. Be sure to cover the entire area around the puncture.



8 Peel off the paper from the adhesive on the patch. Insert the tip of the patch through the puncture from the inside of the tire.



9 Use a pair of pliers to pull the plug of the patch through the puncture.



10 This view of the patch is from the inside of the tire.



11 To be assured of an airtight patch, the adhesive of the patch should be “stitched” to the inside of the tire using a serrated roller called a stitching tool.



12 A view of the plug from the outside of the tire after metal covering used to pierce the puncture is removed from the patch plug. The plug can be trimmed to the level of the tread using side cutters or a knife.

REVIEW QUESTIONS

1. List the precautions and recommendations regarding tire selection and maintenance.
2. Determine the proper wheel mounting torque for your vehicle from the guidelines provided.
3. Describe how to check for lateral and radial runout of the wheels and tires.
4. Describe the difference between static and dynamic balance.

CHAPTER QUIZ

1. A tire is worn excessively on both edges. The most likely cause of this type of tire wear is _____.
   a. Overinflation **c.** Excessive radial runout
   b. Underinflation **d.** Excessive lateral runout
2. When seating a bead of a tire, never exceed _____ PSI.
   a. 30 **c.** 50
   b. 40 **d.** 60
3. For best tire life, most vehicle and tire manufacturers recommend tire rotation every _____.
   a. 3,000 miles **c.** 9,000 miles
   b. 6,000 miles **d.** 12,000 miles
4. What lubricant should be used when mounting a tire?
   a. Silicone spray **c.** Water-based soap
   b. Grease **d.** SAE 10W-30 engine oil
5. Using the modified X-method of tire rotation on a front-wheel-drive vehicle, where should the left front wheel be placed?_____
   a. Right front **c.** Left rear
   b. Right rear **d.** Kept at the left front
6. Which statement is *false?*
   a. Excessive radial runout can cause a tramp-type vibration.
   b. Excessive lateral runout can cause a tramp-type vibration.
   c. A tire out of balance dynamically can cause a shimmy-type vibration.
   d. A tire out of balance statically can cause a tramp-type vibration.
7. The recommended type of wheel weight to use on aluminum (alloy) wheels is _____.
   a. Lead with plated spring steel clips
   b. Coated (painted) or stick-on lead weights
   c. Lead weights with longer-than-normal clips
   d. Aluminum weights
8. Most vehicle and tire manufacturers recommend that no more than _____ ounces of balance weight be added to a wheel/tire assembly.
   a. 2.5 **c.** 4.5
   b. 3.5 **d.** 5.5
9. A vehicle vibrates at highway speed. Technician A says that water in the tire(s) could be the cause. Technician B says that an out-of-round tire could be the cause. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
10. Proper tire inflation pressure information is found _____.
    a. On the driver's door or post **c.** On the sidewall of the tire
    b. In the owner's manual **d.** Both a and b

chapter 112

SUSPENSION SYSTEM PRINCIPLES AND COMPONENTS

OBJECTIVES: **After studying Chapter 112, the reader will be able to:** • Prepare for ASE Suspension and Steering (A4) certification test content area "B" (Suspension System Diagnosis and Repair). • List various types of suspensions and their component parts. • Explain how coil, leaf, and torsion bar springs work. • Describe how suspension components function to allow wheel movement up and down and provide for turning. • Describe how shock absorbers control spring forces.

KEY TERMS: Air spring 1306 • Anti-dive 1299 • Anti-squat 1299 • Ball joints 1300 • Bulkhead 1290 • Bump stop 1308 • Center bolt 1295 • Coil springs 1291 • Composite leaf spring 1296 • Control arms 1299 • Cradle 1289 • Full frame 1289 • GVW 1290 • Hooke's Law 1291 • Independent suspension 1290 • Insulators 1294 • Kingpin 1299 • Ladder frame 1289 • Lateral links 1298 • Leaf springs 1295 • Load-carrying ball joint 1300 • Mono leaf 1296 • Non-load-carrying ball joint 1300 • Perimeter frame 1289 • Platforms 1290 • Rebound clips 1296 • Shackles 1296 • Shock absorbers 1302 • Space frame 1290 • Spring pocket 1294 • Spring rate 1291 • Springs 1291 • Sprung weight 1290 • Stabilizer bars 1301 • Steering knuckles 1299 • Stress riser 1295 • Strut rod 1301 • Struts 1306 • Stub-type frame 1289 • Torsion bar 1297 • Unit-body 1290 • Unsprung weight 1290 • Wheel rate 1294

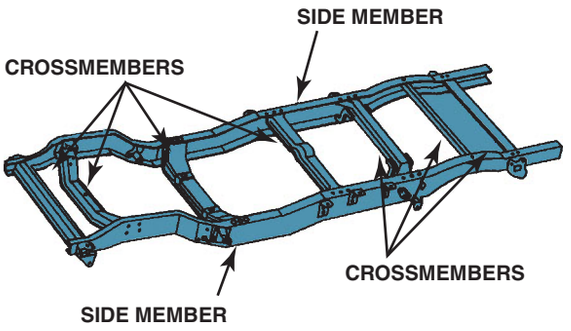


FIGURE 112–1 A typical truck frame is an excellent example of a ladder-type frame. The two side members are connected by a crossmember.

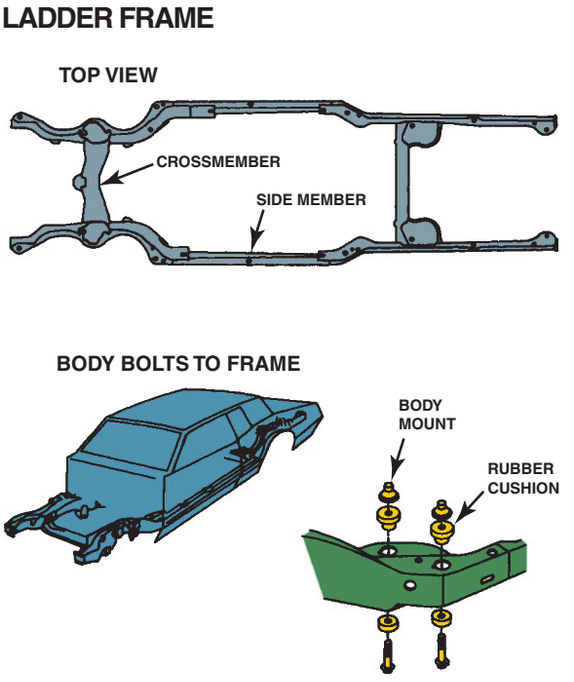


FIGURE 112–2 Rubber cushions used in body or frame construction isolate noise and vibration from traveling to the passenger compartment.

INTRODUCTION

PURPOSE AND FUNCTION Street-driven cars and trucks use a suspension system to keep the tires on the road and to provide acceptable riding comfort. A vehicle with a solid suspension, or no suspension, would bounce off the ground when the tires hit a bump. If the tires are off the ground, even for a fraction of a second, loss of control is possible. The purpose of the suspension is to provide the vehicle with the following:

1. A smooth ride
2. Accurate steering
3. Responsive handling
4. Support for the weight of the vehicle
5. Maintenance of acceptable tire wear

FRAME CONSTRUCTION

TERMINOLOGY Frame construction usually consists of channel-shaped steel beams welded and/or fastened together. The frame of a vehicle supports all the "running gear" of the vehicle, including the engine, transmission, rear axle assembly (if rear-wheel drive), and all suspension components.

This frame construction, referred to as **full frame,** is so complete that most vehicles can usually be driven without the body. Most trucks and larger rear-wheel-drive cars use a full frame.

LADDER FRAME A **ladder frame** is a common name for a type of perimeter frame where the transverse (lateral) connecting members are straight across. ● **SEE FIGURES 112–1 AND 112–2.** When viewed with the body removed, the frame resembles a ladder. Most pickup trucks are constructed with a ladder-type frame.

PERIMETER FRAME A **perimeter frame** consists of welded or riveted frame members around the entire perimeter of the body. This means that the frame members provide support underneath the sides as well as for the suspension and suspension components.

STUB-TYPE FRAMES A **stub-type frame** is a partial frame often used on unit-body vehicles to support the power train and suspension components. It is also called a **cradle** on many front-wheel-drive vehicles. ● **SEE FIGURE 112–3.**

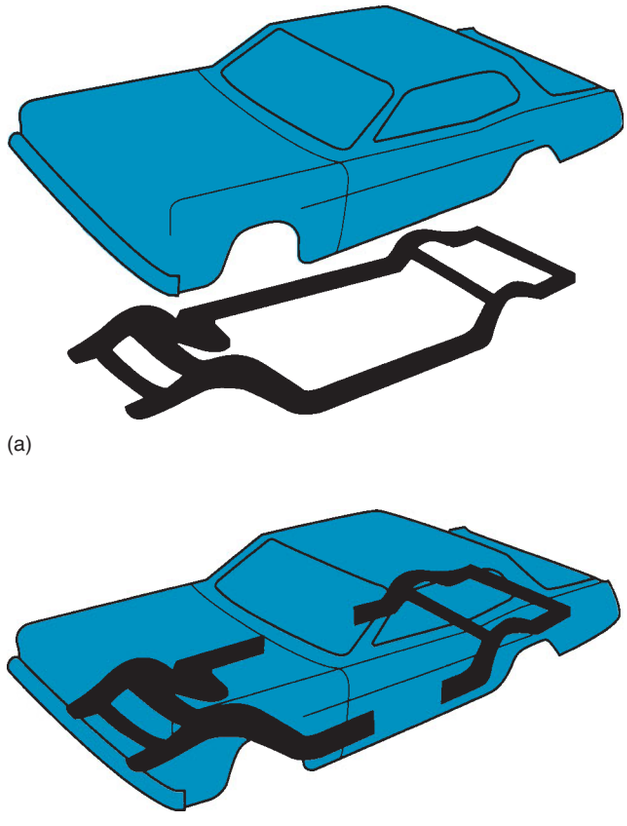


FIGURE 112–3 (a) Separate body and frame construction; (b) unitized construction: the small frame members are for support of the engine and suspension components. Many vehicles attach the suspension components directly to the reinforced sections of the body and do not require the rear frame section.

UNIT-BODY CONSTRUCTION

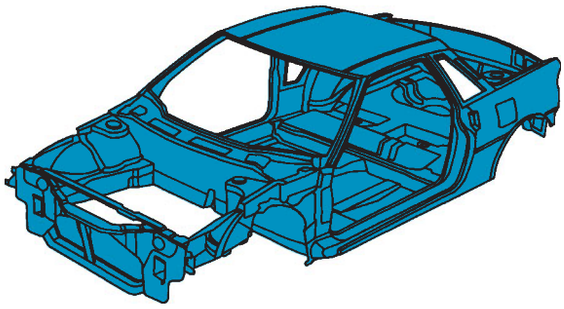


FIGURE 112–4 Welded metal sections create a platform that combines the body with the frame using unit-body construction.

UNIT-BODY CONSTRUCTION

Unit-body construction (sometimes called *unibody*) is a design that combines the body with the structure of the frame. The body supports the engine and drive line components, as well as the suspension and steering components. The body is composed of many individual stamped-steel panels welded together.

The strength of this type of construction lies in the *shape* of the assembly. The typical vehicle uses 300 separate and different stamped steel panels that are spot-welded to form a vehicle's body. ● **SEE FIGURE 112–4.**

NOTE: A typical vehicle contains about 10,0000 individual parts.

SPACE FRAME CONSTRUCTION

Space frame construction consists of formed sheet steel used to construct a framework for the entire vehicle. The vehicle is drivable without the body, which uses plastic or steel panels to cover the steel framework.

PLATFORMS

TERMINOLOGY

The **platform** of any vehicle is its basic size and shape. Various vehicles of different makes can share the same platform, and therefore many of the same drive train (engine, transmission, and final drive components) and suspension and steering components.

A platform of a unit-body vehicle includes all major sheet-metal components that form the load-bearing structure of the vehicle, including the front suspension and engine-supporting sections. The area separating the engine compartment from the passenger compartment is called the **bulkhead.** The height and location of this bulkhead panel to a large degree determines the shape of the rest of the vehicle.

TRACK AND WHEELBASE

Other components of vehicle platform design that affect handling and ride are the track and wheelbase of the vehicle. *The track of a vehicle is the distance between the wheels, as viewed from the front or rear.* A wide-track vehicle is a vehicle with a wide wheel stance; this increases the stability of the vehicle, especially when cornering. *The wheelbase of a vehicle is the distance between the center of the front wheel and the center of the rear wheel, as viewed from the side.* A vehicle with a long wheelbase tends to ride smoother than a vehicle with a short one.

Examples of common platforms include the following:

1. Chevrolet Impala and Pontiac Grand Prix
2. Toyota Camry and Lexus ES 350
3. Buick Lucerne and Cadillac DTS

? FREQUENTLY ASKED QUESTION

What Does GVW Mean?

GVW, gross vehicle weight, is the weight of the vehicle plus the weight of all passengers the vehicle is designed to carry (× 150 lb [68 kg] each), plus the maximum allowable payload or luggage load. *Curb weight* is the weight of a vehicle when *wet,* meaning with a full tank of fuel and all fluids filled, but without passengers or cargo (luggage). *Model weight* is the weight of a vehicle wet and with passengers.

The GVW is found stamped on a plate fastened to the doorjamb of most vehicles. A high GVW rating does not mean that the vehicle itself weighs a lot more than other vehicles. For example, a light truck with a GVW of 6,000 lbs (2,700 kg) will not ride like an old 6,000-lb luxury car. In fact, a high GVW rating usually requires stiff springs to support the payload; these stiff springs result in a harsh ride. Often technicians are asked to correct a harsh-riding truck that has a high GVW rating. The technician can only check that everything in the suspension is satisfactory and then try to convince the owner that a harsher-than-normal ride is the result of a higher GVW rating.

UNSPRUNG WEIGHT

A suspension system has to be designed to allow the wheels to move up and down quickly over bumps and dips without affecting the entire weight of the car or truck. In fact, the lighter the total weight of the components that move up and down, the better the handling and ride. This weight is called **unsprung weight.** The idea of very light weight resulted in magnesium wheels for racing cars, which are very light yet strong. Aftermarket wheels that resemble racing car wheels are often referred to as *mag* wheels. For best handling and ride, the unsprung weight should be kept as low as possible.

Sprung weight is the term used to identify the weight of the car or truck that does *not* move up and down and is supported or *sprung* by the suspension.

TYPES OF SUSPENSIONS

Early suspension systems on old horse wagons, buggies, and older vehicles used a solid axle for front and rear wheels. ● **SEE FIGURE 112–5.** If one wheel hit a bump, the other wheel was affected, as shown in ● **FIGURE 112–6.**

Most vehicles today use a separate control-arm-type of suspension for each front wheel, which allows for movement of one front wheel without affecting the other front wheel. This type of front suspension is called **independent suspension.** ● **SEE FIGURE 112–7.**

Many rear suspensions also use independent-type suspension systems. Regardless of the design type of suspension, all suspensions use springs in one form or another.

SPRINGS A suspension **spring** serves two purposes. First, it acts as a buffer between the suspension and frame to absorb vertical wheel and suspension movement without passing it on to the frame. Second, each spring transfers part of the vehicle weight to the suspension component it rests on, which transfers it to the wheels.

The basic method by which springs absorb road shocks varies according to the type of spring. Simply stated, leaf springs flatten, coil springs and air springs compress, and torsion bars twist. What all springs have in common is that they somehow give way to absorb the vertical force of the moving wheel during jounce, then release that force during rebound as they return to their original shape and position.

SPRING MATERIALS. Most springs are made of a tempered steel alloy known as spring steel, consisting of chrome silicon or chrome-vanadium alloy. Tempering is a process of heating and cooling metal under controlled conditions, which increases the resilience of the metal. Resilience is the ability of the metal to return to, or spring back to, its original shape after being twisted or compressed.

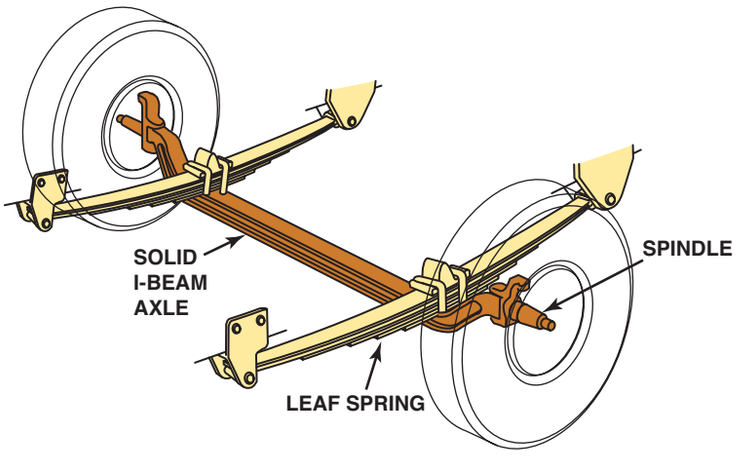


FIGURE 112–5 Solid I-beam axle with leaf springs.

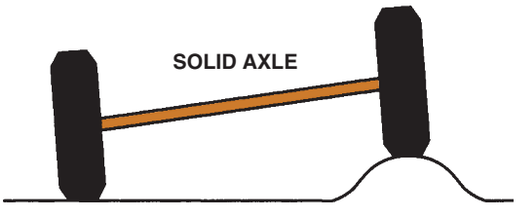


FIGURE 112–6 When one wheel hits a bump or drops into a hole, both left and right wheels are moved. Because both wheels are affected, the ride is often harsh and feels stiff.

HOOKE'S LAW

Regardless of type, all suspensions use springs that share a common characteristic described by **Hooke's Law.** Robert Hooke (1635–1703), an English physicist, discovered the force characteristics of springs: *The deflection (movement or deformation) of a spring is directly proportional to the applied force.*

What this means is that when a coil spring (for example) is depressed 1 in., it pushes back with a certain force (in pounds), such as 400 pounds. If the spring is depressed another inch, the force exerted by the spring is increased by another 400 pounds. The **spring rate** or force constant for this spring is therefore "400 lb per inch," usually symbolized by the letter K. Since the force constant is the force per unit of displacement (movement), it is a measure of the stiffness of the spring. The higher the spring rate (K), the stiffer the spring. ● **SEE FIGURE 112–8.**

COIL SPRINGS

Coil springs are made of special round spring steel wrapped in a helix shape. The strength and handling characteristics of a coil spring depend on the following:

1. Coil diameter
2. Number of coils

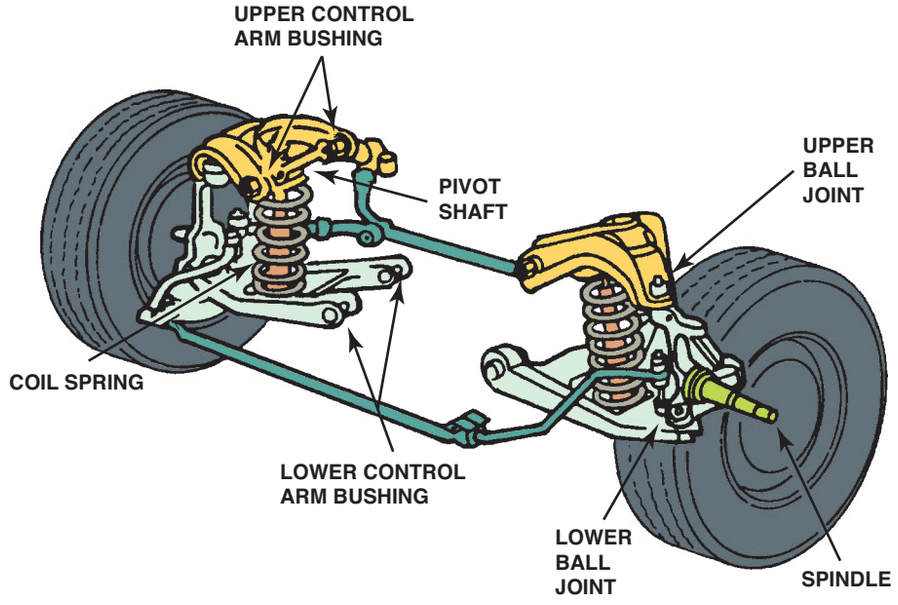


FIGURE 112–7 A typical independent front suspension used on a rear-wheel-drive vehicle. Each wheel can hit a bump or hole in the road independently without affecting the opposite wheel.

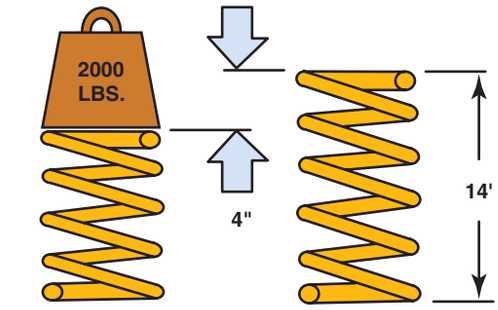


FIGURE 112–8 This spring was depressed 4 inches due to a weight of 2,000 lb. This means that this spring has a spring rate (K) of 500 lb per inch (2000 ÷ 4 in. = 500 lb./in.).

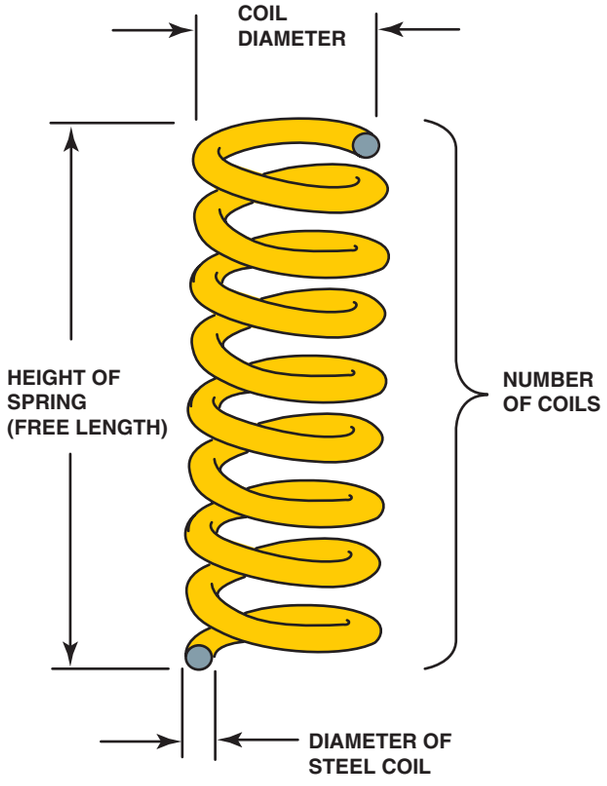


FIGURE 112–9 The spring rate of a coil spring is determined by the diameter of the spring and the diameter of the steel used in its construction plus the number of coils and the free length (height).

3. Height of spring
4. Diameter of the steel coil that forms the spring. ● **SEE FIGURE 112–9**.

The spring rate (K) for coil springs is expressed by the formula:

$$K = \frac{Gd4}{8ND3}$$

where

G = 11,250,000 (constant for steel)
d = diameter of wire
N = number of coils
D = diameter of the coil

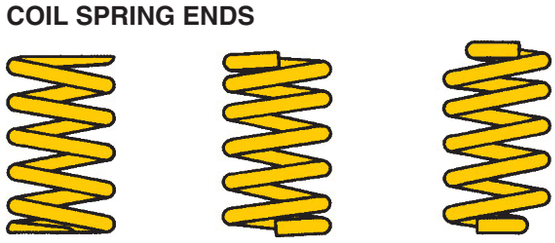


FIGURE 112–10 Coil spring ends are shaped to fit the needs of a variety of suspension designs.

Coil springs are used in front and/or rear suspensions.

- The larger the diameter of the steel, the "stiffer" the spring.
- The shorter the height of the spring, the stiffer the spring.
- The fewer the coils, the stiffer the spring.

Springs are designed to provide desired ride and handling and come in a variety of spring ends, as shown in ● **FIGURE 112–10.**

CAUTION: The use of spacers between the coils of a coil spring is *not* recommended because the force exerted by the spacers on the springs can cause spring breakage. When a spacer is installed between the coils, the number of coils is reduced and the spring becomes stiffer. The force exerted on the coil spring at the contact points of the spacer can cause the spring to break.

SPRING RATE

Spring rate, also called *deflection rate,* is a value that reflects how much weight it takes to compress a spring a certain amount. Generally, spring rate is specified in pounds per inch, which is the weight in pounds it takes to compress the spring 1 inch. In other words, if a 100-pound weight causes a spring to compress 1 inch, the spring has a spring rate of 100 pounds.

A constant-rate spring continues to compress at the same rate throughout its complete range of deflection. For example, if a constant-rate spring compresses 1 inch under a 100-pound load, it will compress 2 inches under a 200-pound load, and so on. ● **SEE FIGURE 112–11.** Many automotive suspension springs, both coil and leaf, compress at a variable rate. That is, they become stiffer and exert more force the farther they compress. For example, a variable-rate spring may compress 1 inch under a 100-pound load, but only compress an additional 1/2 inch under a 200-pound load. Variable-rate springs offer a soft, comfortable ride under normal circumstances but will not bottom out as quickly when adverse road conditions compress them farther. ● **SEE FIGURE 112–12.**

Before a spring is installed on a vehicle or any load is placed on it, it is at its uncompressed length, or free length. Once installed, the weight of the corner of the vehicle resting on the spring is called its *static load.* The static load constantly compresses the spring. Therefore, the uncompressed length and the spring rate must be such that the spring has room to compress and keep the vehicle at the correct ride height *after* the static load is applied. ● **SEE FIGURE 112–13.**

Typical Front-Wheel-Drive Sedan Springs

	Force @ Height	Spring Rate
LF	1,343 lbs. @ 7.6 in.	256 lb. in.
RF	1,300 lbs. @ 7.6 in.	254 lb. in.
LR	638 lbs. @ 9.38 in.	200 lb. in.
RR	610 lbs. @ 9.38 in.	195 lb. in.

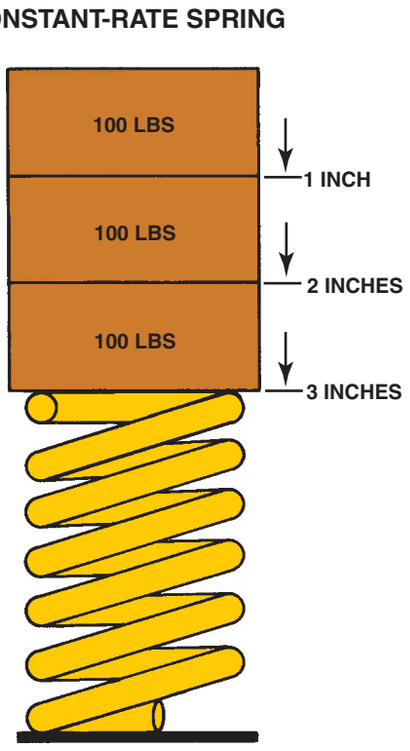


FIGURE 112–11 A constant-rate spring compresses at the same rate regardless of the amount of weight that is applied.

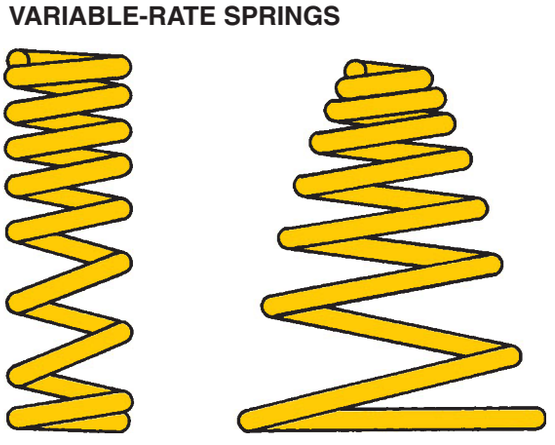


FIGURE 112–12 Variable-rate springs come in a variety of shapes and compress more slowly as weight is applied.

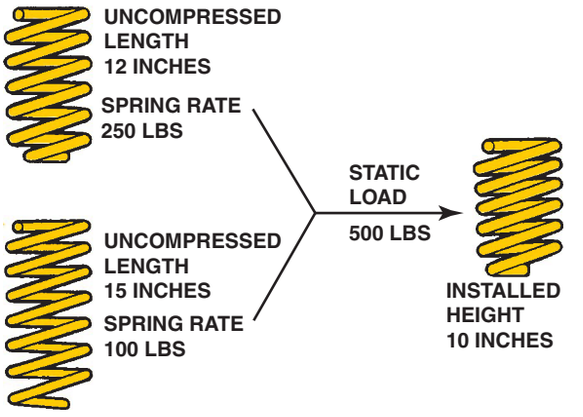


FIGURE 112–13 Two springs, each with a different spring rate and length, can provide the same ride height even though the higher-rate spring will give a stiffer ride.

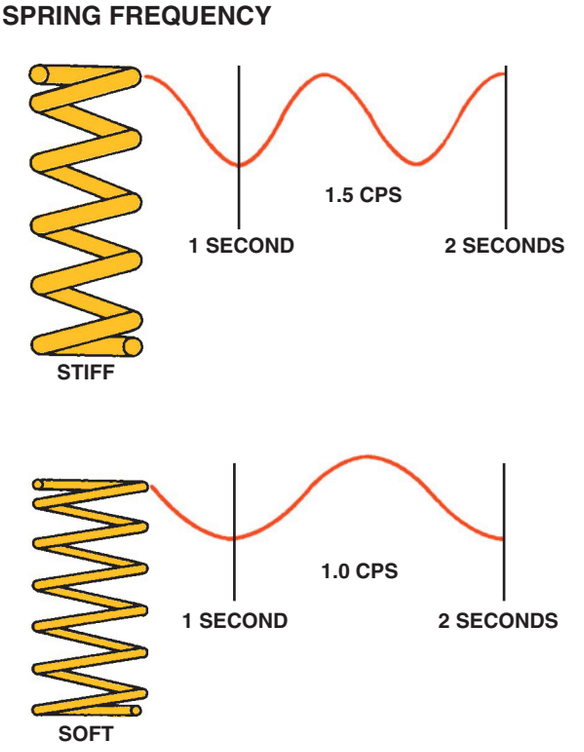


FIGURE 112–14 Stiffer springs bounce at a higher frequency than softer springs.

Notice that each of the four coil springs used on this vehicle is unique. The higher spring rate on the left is used to help support the weight of the driver. Because each spring is designed for each location on the vehicle, they should be marked if they are removed from a vehicle during service.

SPRING FREQUENCY Spring frequency is a value that reflects the speed at which a spring oscillates, or bounces, after it is released from compression or extension. Frequency is typically measured in cycles per second (CPS) or hertz (Hz). ● **SEE FIGURE 112–14.** There is a direct correlation between spring rate and spring frequency: the higher the spring rate, the higher the spring frequency. This means that stiffer springs bounce at a higher frequency, while softer springs bounce more slowly.

? FREQUENTLY ASKED QUESTION

Does the Spring Rate Change as the Vehicle Gets Older?

No, the spring rate of a spring does not change, but the spring load can change due to fatigue. The spring rate is the amount of force it takes to compress the spring 1 inch. The spring load is the amount of weight that a spring can support at any given compressed height. When a spring fatigues, the spring's load capacity decreases and the vehicle will sag.

WHEEL RATE Depending on the suspension design, springs are installed a certain distance away from the wheel, which determines the ratio of wheel travel to spring travel, or **wheel rate.** ● **SEE FIGURE 112–15.** For example, if a coil spring is mounted on the midpoint of a control arm, or halfway between the center of the wheel and the arm pivot points, it compresses approximately 1 inch when the wheel travels vertically 2 inches. On a strut-type suspension, the coil spring has a more direct ratio because it is closer to the wheel, so when the wheel of a strut travels vertically 2 inches, the spring also compresses 2 inches. This means that a coil spring used on a strut-type suspension is less than half the spring rate of a coil spring used on suspensions that use control arms.

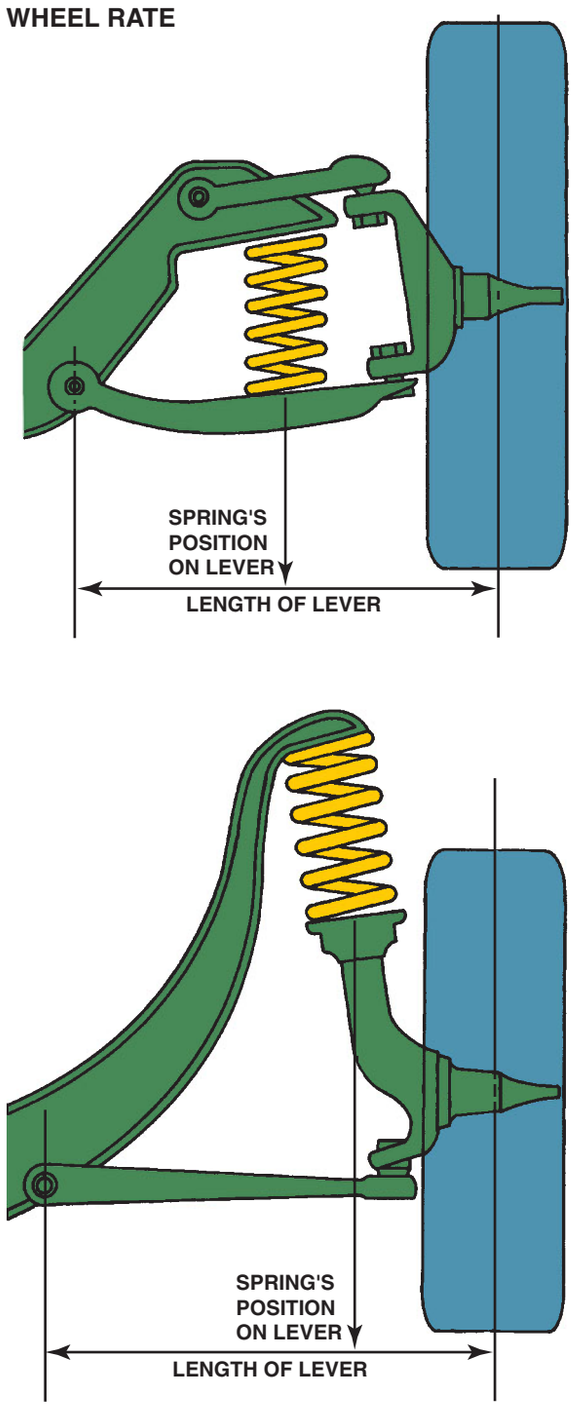


FIGURE 112–15 The wheel and arm act as a lever to compress the spring. The spring used on the top picture must be stiffer than the spring used on the strut-type suspension shown on the bottom because the length of the lever arm is shorter.

COIL SPRING MOUNTING Coil springs are usually installed in a **spring pocket** or spring seat. Hard rubber or plastic cushions or **insulators** are usually mounted between the coil spring and the spring seat. ● **SEE FIGURE 112–16.** The purpose of these insulators is to isolate and dampen road noise and vibration from the

TECH TIP

Don't Cut Those Coil Springs!

Chassis service technicians are often asked to lower a vehicle. One method is to remove the coil springs and cut off half or more coils from the spring. While this *will* lower the vehicle, this method is generally *not* recommended for the following reasons:

1. A coil spring could be damaged during the cutting-off procedure, especially if a torch is used to do the cutting.
2. The spring will get stiffer when shortened, often resulting in a very harsh ride.
3. The amount the vehicle is lowered is *less* than the amount cut off from the spring. This is because as the spring is shortened, it becomes stiffer. The stiffer spring will compress less than the original.

Instead of cutting springs to lower a vehicle, several preferable methods are available if the vehicle *must* be lowered:

1. There are replacement springs designed specifically to lower that model vehicle. A change in shock absorbers may be necessary because the shorter springs change the operating height of the stock (original) shock absorbers. Consult spring manufacturers for exact installation instructions and recommendations. ● **SEE FIGURE 112–17.**
2. There are replacement spindles designed to *raise* the location of the wheel spindle, thereby lowering the body in relation to the ground. Except for ground clearance problems, this is the method recommended by many chassis service technicians. Replacement spindles keep the same springs, shock absorbers, and ride, while lowering the vehicle without serious problems.

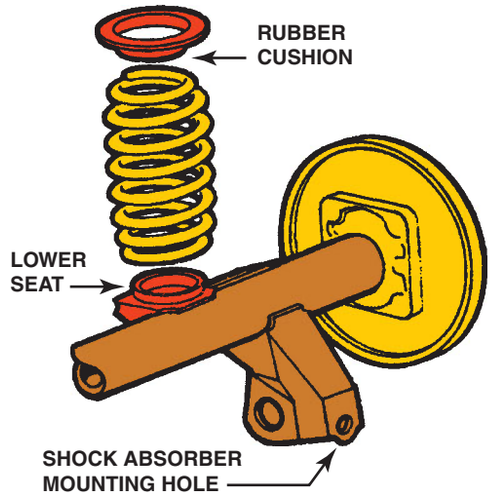


FIGURE 112–16 The spring cushion helps isolate noise and vibration from being transferred to the passenger compartment. *(Courtesy of Cooper Automotive Company)*



FIGURE 112–17 This replacement coil spring is coated to prevent rust and corrosion and colored to help identify the spring and/or spring manufacturer.

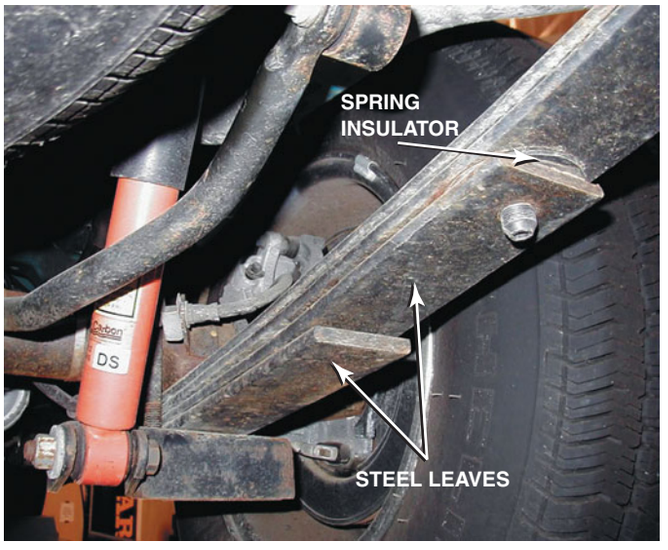


FIGURE 112–18 A typical leaf spring used on the rear of a pickup truck showing the plastic insulator between the leaves, which allows the spring to move without creating wear or noise.

vehicle body. The type of end on the coil spring also varies and determines the style of the spring mount.

SPRING COATINGS All springs are painted or coated with epoxy to help prevent breakage. A scratch, nick, or pit caused by corrosion can cause a **stress riser** that can lead to spring failure. The service technician should be careful not to remove any of the protective coating. Whenever a service operation requires the spring to be compressed, always use a tool that will not scratch or nick the surface of the spring.

LEAF SPRINGS

Leaf springs are constructed of one or more strips of long, narrow spring steel. These metal strips, called leaves, are assembled with plastic or synthetic rubber insulators between the leaves, allowing for freedom of movement during spring operation. ● **SEE FIGURE 112–18.**

The ends of the longest spring leaf are rolled or looped to form eyes. Rubber bushings are installed in the eyes of the spring and act as noise and vibration insulators. ● **SEE FIGURE 112–19.**

The leaves are held together by a **center bolt,** also called a *centering pin.* ● **SEE FIGURE 112–20.**

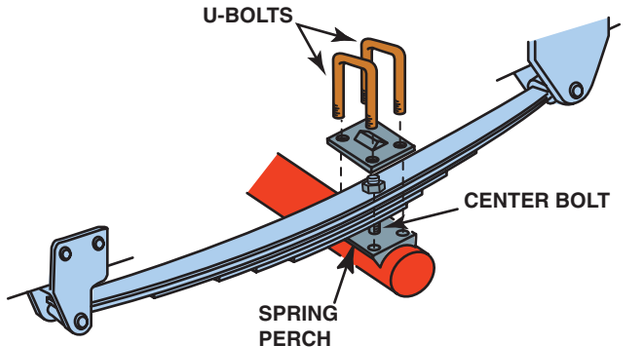


FIGURE 112–20 All multileaf springs use a center bolt to not only hold the leaves together but also help retain the leaf spring in the center of the spring perch.

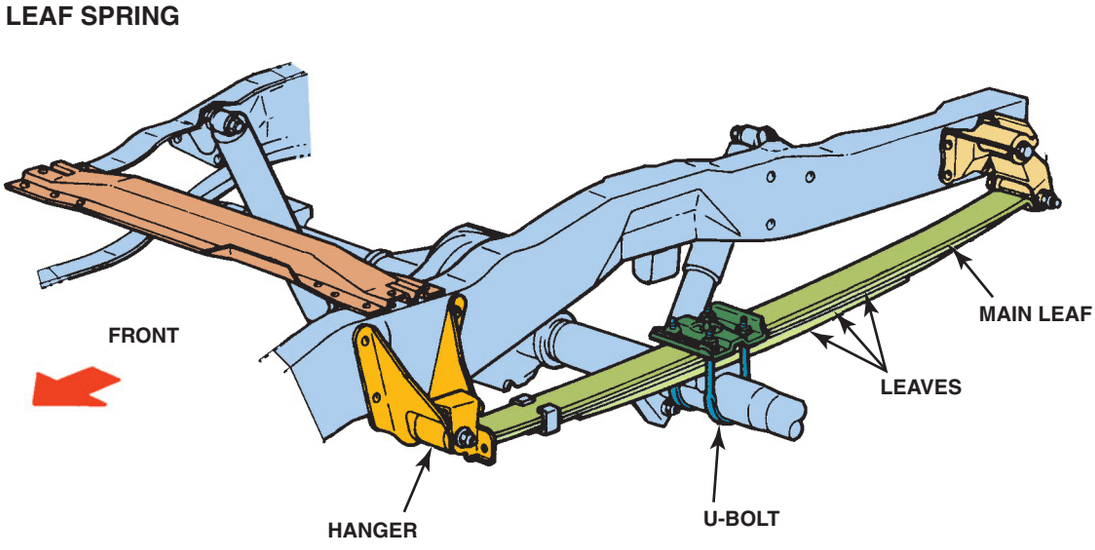


FIGURE 112–19 A typical leaf spring installation. The longest leaf, called the *main leaf,* attaches to the frame through a shackle and a hanger.

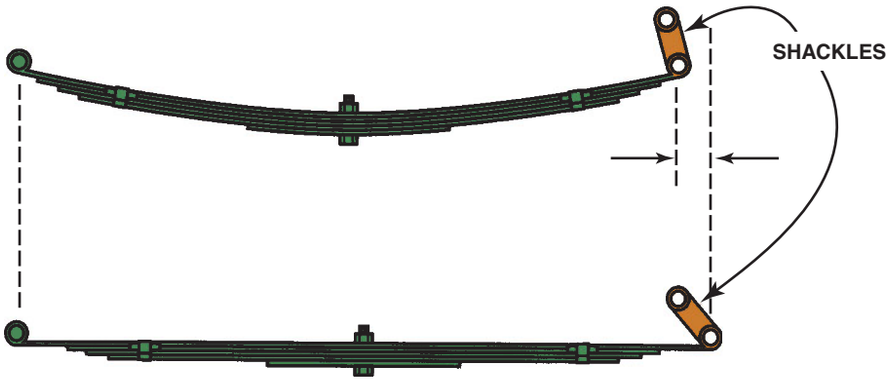


FIGURE 112–21 When a leaf spring is compressed, the spring flattens and becomes longer. The shackles allow for this lengthening. Rubber bushings are used in the ends of the spring and shackles to help isolate road noise from traveling into the passenger compartment.

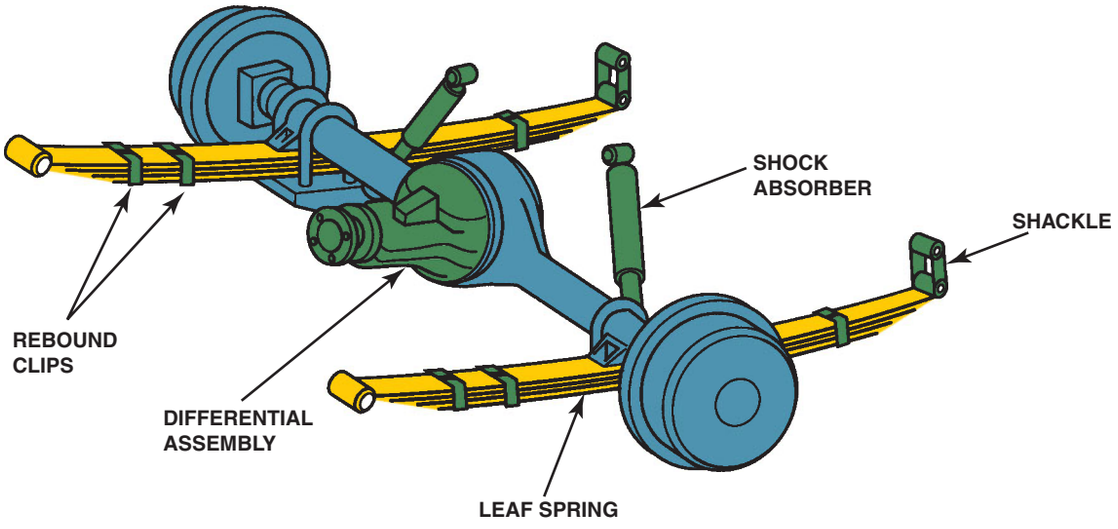


FIGURE 112–22 Typical rear leaf-spring suspension of a rear-wheel-drive vehicle.

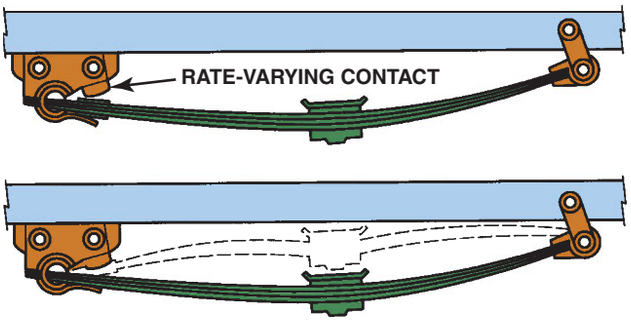


FIGURE 112–23 As the vehicle is loaded, the leaf spring contacts a section of the frame. This shortens the effective length of the spring, which makes it stiffer.

One end of a leaf spring is mounted to a hanger with a bolt and rubber bushings directly attached to the frame. The other end of the leaf spring is attached to the frame with movable mounting hangers called **shackles.** ● **SEE FIGURE 112–21.**

The shackles are necessary because as the spring hits a bump, the slightly curved spring (semi-elliptical) becomes longer and straighter, and the shackles allow for this rearward movement. **Rebound clips,** or spring alignment clips, help prevent the leaves from separating whenever the leaf spring is rebounding from hitting a bump or rise in the roadway. ● **SEE FIGURE 112–22**.

Single leaf steel springs, called **mono leaf,** are used on some vehicles. A single or mono leaf spring is usually tapered to produce a variable spring rate. Leaf springs are used for rear suspensions on cars and many light trucks. A variable rate can be accomplished with a leaf spring suspension by providing contacts on the mount that effectively shorten the spring once it is compressed to a certain point. This provides a smoother ride when the load is light and still provides a stiffer spring when the load is heavy. ● **SEE FIGURE 112–23**.

To provide additional load-carrying capacity, especially on trucks and vans, auxiliary or *helper* leaves are commonly used. This extra leaf becomes effective only when the vehicle is heavily loaded. ● **SEE FIGURE 112–24** on page 1297.

Leaf springs are used on the front suspension of many four-wheel-drive trucks, especially medium and heavy trucks.

COMPOSITE LEAF SPRINGS Since the early 1980s, fiberglass-reinforced epoxy plastic **composite leaf springs** have been used on production vehicles. They save weight: An 8-pound spring can replace a conventional 40-pound steel leaf spring. The secret to making a strong plastic leaf spring is the glass fibers

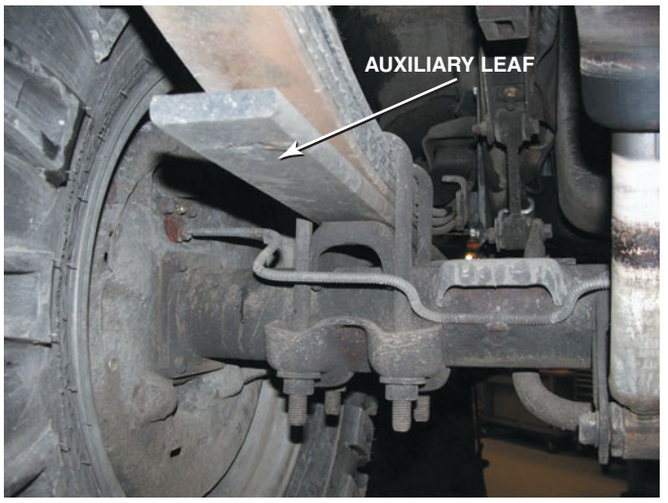


FIGURE 112–24 Many pickup trucks, vans, and sport utility vehicles (SUVs) use auxiliary leaf springs that contact the other leaves when the load is increased.

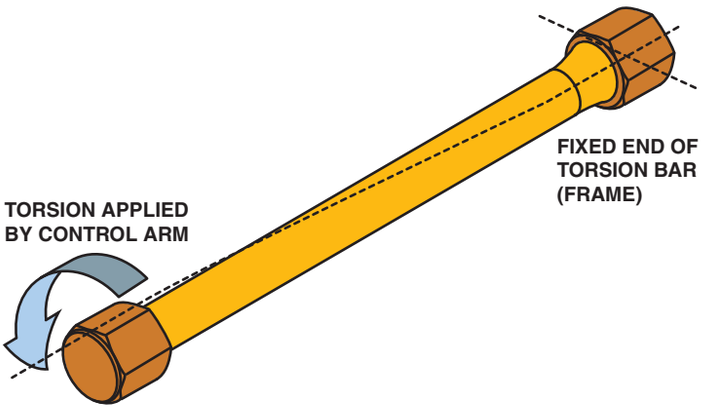
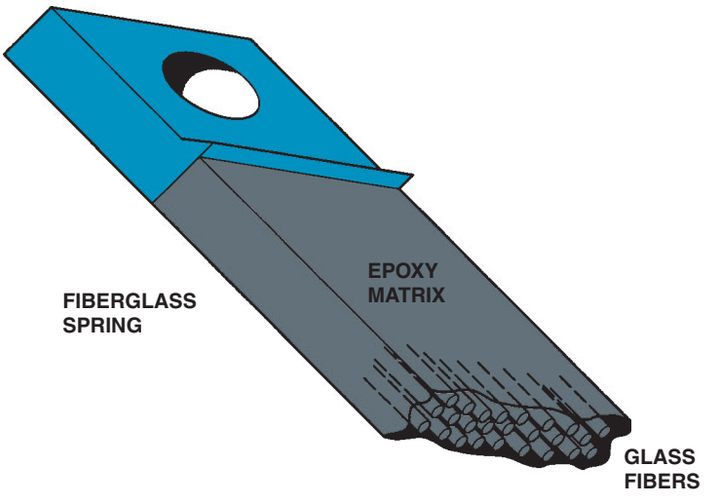
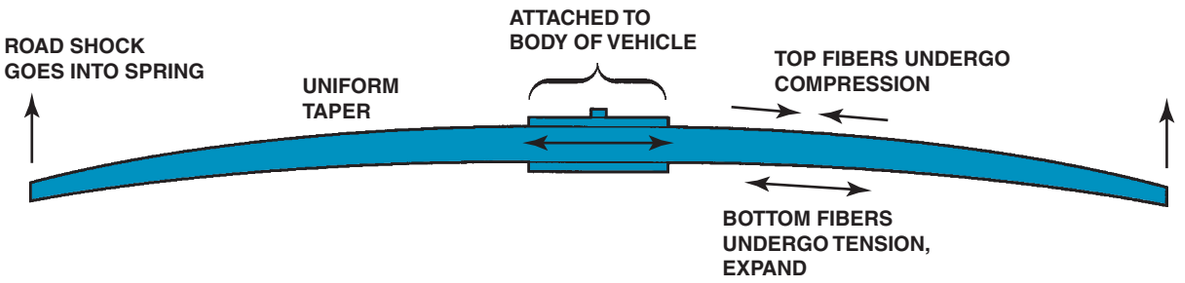


FIGURE 112–26 A torsion bar resists twisting and is used as a spring on some cars and many four-wheel-drive pickup trucks and sport utility vehicles. The larger the diameter, or the shorter the torsion bar, the stiffer the bar. A torsion bar twists very little during normal operation and about a 1/16 of a revolution during a major suspension travel event.

FIGURE 112–25 (a) A fiberglass spring is composed of long fibers locked together in an epoxy (resin) matrix. (b) When the spring compresses, the bottom of the spring expands and the top compresses. Composite leaf springs are used and mounted transversely (side-to-side) on Chevrolet Corvettes and at the rear on some other General Motors vehicles.



(a)



(b)

running continuously from one end of the spring to the other, and the use of 70% fiberglass with 30% epoxy composite. The single-leaf composite spring helps isolate road noise and vibrations. It is more efficient than a multileaf spring because it eliminates the interleaf friction of the steel leaves and requires less space. ● **SEE FIGURE 112–25**.

Leaf spring rate increases when the thickness increases, and decreases as the length increases.

TORSION BARS

A **torsion bar** is a spring that is a long, *round,* hardened steel bar similar to a coil spring except that it is a *straight* bar. ● **SEE FIGURE 112–26**.

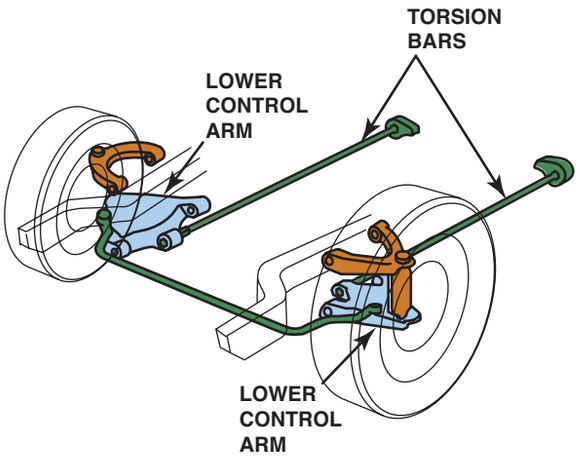


FIGURE 112–27 Longitudinal torsion bars attach at the lower control arm at the front and at the frame at the rear of the bar.

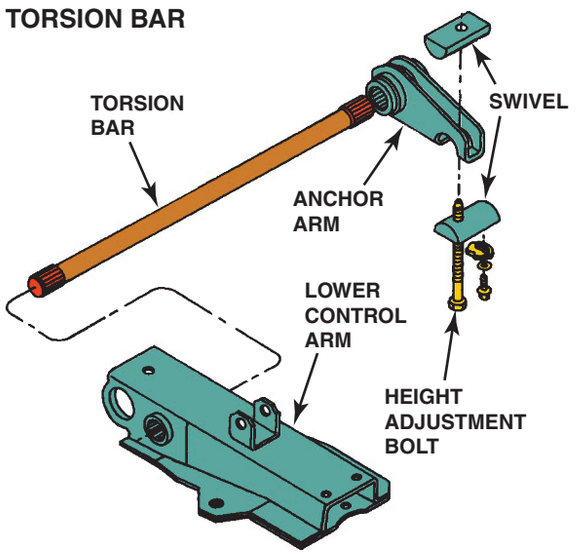


FIGURE 112–28 One end of the torsion bar attaches to the lower control arm and the other to an anchor arm that is adjustable.

One end is attached to the lower control arm of a front suspension and the other end to the frame. When the wheels hit a bump, the bar twists and then untwists. General Motors pickup trucks use torsion-bar front suspension longitudinally. ● **SEE FIGURE 112–27**.

Many manufacturers of pickup trucks currently use torsion-bar-type suspensions, especially on their four-wheel-drive models. Torsion bars allow room for the front drive axle and constant velocity joint and still provide for strong suspension.

As with all automotive springs, spring action is controlled by the shock absorbers. Unlike other types of springs, torsion bars may be adjustable for correct ride height. ● **SEE FIGURE 112–28.**

Most torsion bars are labeled *left* or *right,* usually stamped into the end of the bars. The purpose of this designation is to make sure that the correct bar is installed on the original side of the vehicle. Torsion bars are manufactured without any built-in direction or preload. However, after being in a vehicle, the bar takes a set; reversing the side the torsion bar is used on causes the bar to be twisted in the opposite direction. Even though the bars are usually interchangeable, proper ride height can be accomplished even if the bars were installed on the side opposite from the original. But because the bar is being "worked" in the opposite direction, it can weaken and break. If a torsion bar breaks, the entire suspension collapses; this can cause severe vehicle damage, as well as a serious accident.

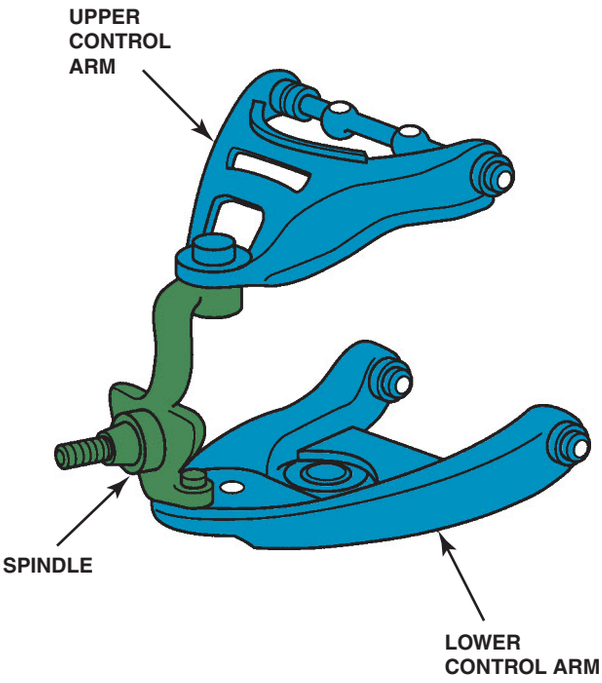


FIGURE 112–29 The spindle supports the wheels and attaches to the control arm with ball-and-socket joints called ball joints. The control arm attaches to the frame of the vehicle through rubber bushings to help isolate noise and vibration between the road and the body. (*Courtesy of Cooper Automotive Company*)

SUSPENSION PRINCIPLES

Suspensions use various links, arms, and joints to allow the wheels to move freely up and down; front suspensions also have to allow the front wheels to turn. All suspensions must provide for the following supports:

1. **Transverse (or side-to-side) wheel support.** As the wheels of the vehicle move up and down, the suspension must accommodate this movement and still keep the wheel from moving away from the vehicle or inward toward the center of the vehicle. ● **SEE FIGURE 112–29**. The control arm pivots on the vehicle frame. The wheels attach to a spindle that attaches to the ball joint at the end of the control arm. Transverse links are also called **lateral links.**
2. **Longitudinal (front-to-back) wheel support.** As the wheels of the vehicle move up and down, the suspension must allow for this movement and still keep the wheels from moving backward whenever a bump is hit. Note in ● **FIGURE 112–29** how the separation of the pivot points, where the control arm meets the frame, provides support to prevent front-to-back wheel movement.

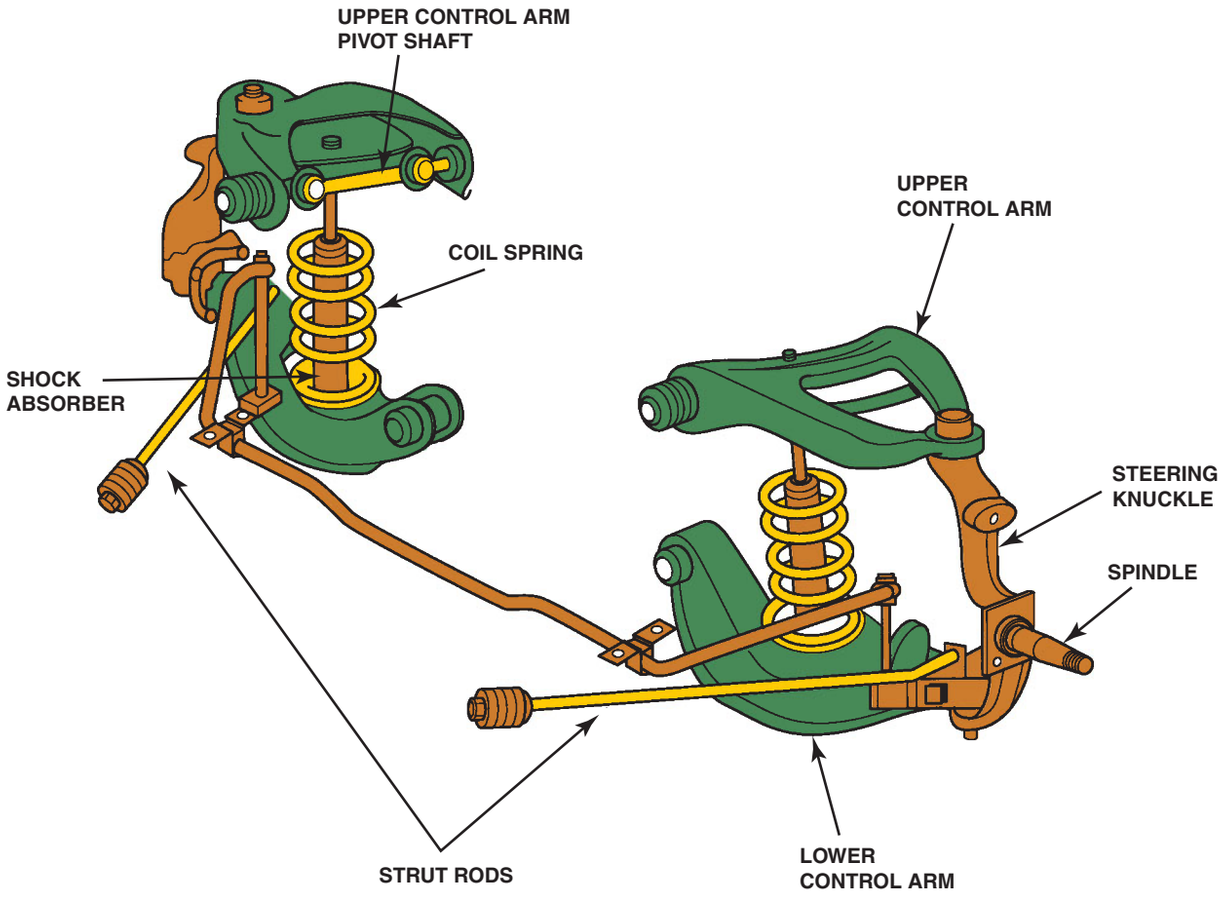


FIGURE 112–30 The strut rods provide longitudinal support to the suspension to prevent forward or rearward movement of the control arms.

At least two suspension links or arms are required in order to provide for freedom of movement up or down, and to *prevent* any in–out or forward–back movement. Some suspension designs use an additional member to control forward–back movement. ● **SEE FIGURE 112–30.**

The design of the suspension and the location of the suspension mounting points on the frame or body are critical to proper vehicle handling. Two very important design factors are called **anti-squat** and **anti-dive.**

1. **Anti-squat.** Anti-squat refers to the reaction of the body of a vehicle during acceleration. It is normal in most designs for the vehicle to squat down at the rear while accelerating. Most drivers feel comfortable feeling this reaction, even on front-wheel-drive vehicles. Anti-squat refers to the degree to which this normal force is neutralized. If 100% anti-squat were designed into the suspension system, the vehicle would remain level while accelerating.
2. **Anti-dive.** Anti-dive refers to the force that causes the front of the vehicle to drop down while braking. Some front-nose dive feels normal to most drivers. If 100% anti-dive were designed into a vehicle, it would remain perfectly level while braking.

The service technician cannot, and should not, attempt to change anti-squat or anti-dive characteristics built into the design of the vehicle. However, if the customer notices more squat or dive than normal, then the technician should carefully inspect all suspension components, especially those mounting points to the frame or body.

STEERING KNUCKLES

A **steering knuckle** is hard to classify either as part of the suspension or as part of the wheel. A knuckle serves two purposes:

- To join the suspension to the wheel
- Usually includes the spindle where the front wheel bearings are attached
- To provide pivot points between the suspension and wheel.

Knuckles are used with independent suspensions and at the wheels that steer the vehicle. ● **SEE FIGURE 112–31.**

The only knuckle that uses a **kingpin** is a steering knuckle on an I-beam or twin I-beam front suspension. ● **SEE FIGURE 112–32.** A kingpin steering knuckle keeps the wheel rigid in relation to the I-beam during up-and-down wheel movement, but rotates around the steering axis to turn the wheels left and right. The steering axis is the vertical center of the kingpin.

CONTROL ARMS

A **control arm** is a suspension link that connects a knuckle or wheel flange to the frame. One end of a control arm attaches to the knuckle or wheel flange, generally with either a ball joint or

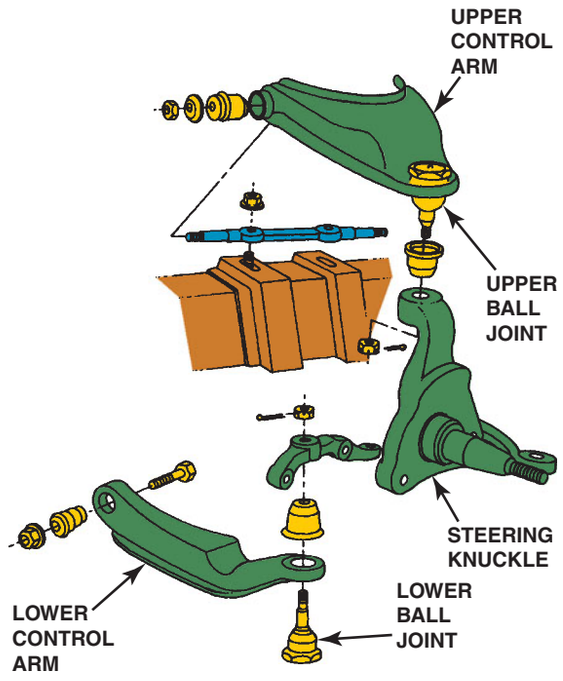


FIGURE 112–31 The steering knuckle used on a short/long-arm front suspension.

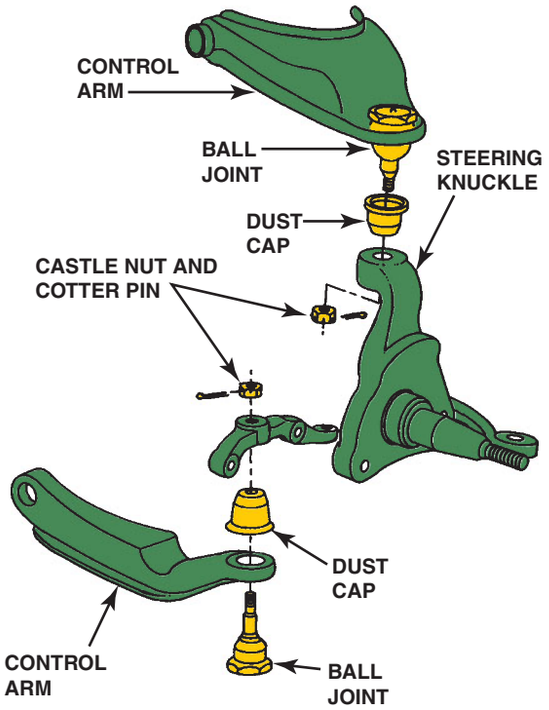


FIGURE 112–33 Control arms are used to connect the steering knuckle to the frame or body of the vehicle and provide the structural support for the suspension system.

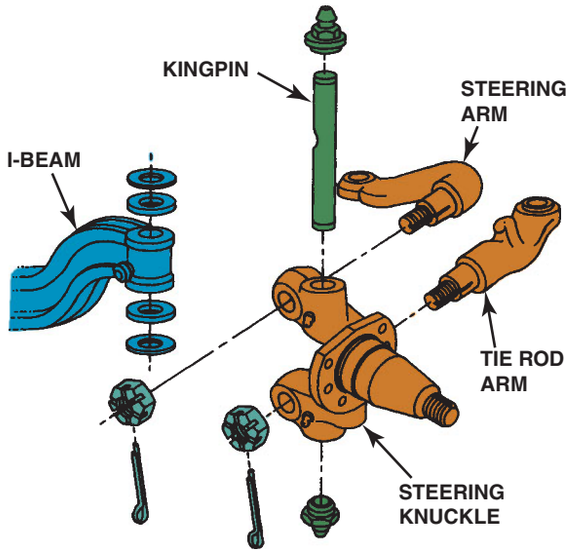


FIGURE 112–32 A kingpin is a steel shaft or pin that joins the steering knuckle to the suspension and allows the steering knuckle to pivot.

bushing. The opposite end of the arm, which attaches to a frame member, usually pivots on a bushing. ● **SEE FIGURE 112–33.** The end attached to the frame must pivot to allow the axle or knuckle to travel vertically.

BALL JOINTS

PURPOSE AND FUNCTION **Ball joints** are actually ball-and-socket joints, similar to the joints in a person's shoulder. Ball joints allow the front wheels to move up and down, as well as side to side (for steering).

A vehicle can be equipped with coil springs, mounted either above the upper control arm *or* on the lower control arm. ● **SEE FIGURE 112–34.**

If the coil spring is attached to the top of the upper control arm, then the upper ball joint is carrying the weight of the vehicle and is called the **load-carrying ball joint.** The lower ball joint is called the **non-load-carrying,** or *follower,* **ball joint.** ● **SEE FIGURE 112–35.**

If the coil spring is attached to the lower control arm, then the lower ball joint is the load-carrying ball joint and the upper joint is the follower ball joint. ● **SEE FIGURE 112–36.**

If a torsion-bar-type spring is used, the lower ball joint is a load-carrying joint because the torsion bar is attached to the lower control arm on most vehicles that use torsion bars.

BALL JOINT DESIGN There are two basic designs of ball joints: compression loaded and tension loaded. If the control arm rests on the steering knuckle, the ball joint is *compressed* into the control arm by the weight of the vehicle. If the knuckle rests on the control arm, the weight of the vehicle tends to pull the ball joint back into the control arm by *tension.* The type used is determined by the chassis design engineer, and the service technician cannot change the type of ball joint used for a particular application. ● **SEE FIGURE 112–37** on page 1303.

A specific amount of stud-turning resistance is built into each ball joint to stabilize steering. A ball joint that does not support the weight of the vehicle and acts as a suspension pivot is often called a follower ball joint or a *friction ball joint.* The load-carrying (weight-carrying) ball joint is subjected to the greatest amount of wear and is the most frequently replaced.

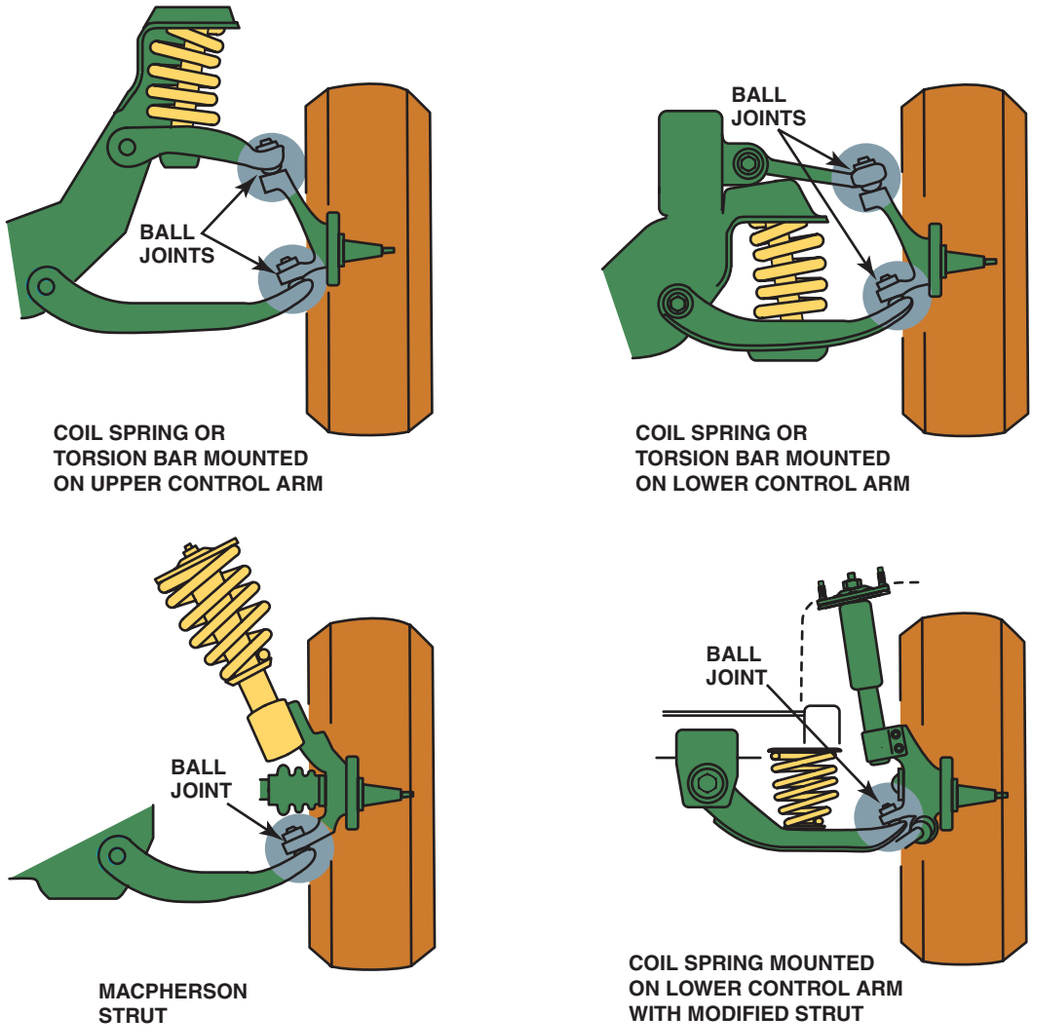


FIGURE 112–34 Ball joints provide the freedom of movement necessary for steering and suspension movements.

STRUT RODS

PURPOSE AND FUNCTION Some vehicles are equipped with round steel rods that are attached between the lower control arm at one end and the frame of the vehicle with rubber bushings, called strut rod bushings, at the other end. The purpose of these **strut rods** is to provide forward/backward support to the control arms. Strut rods are used on vehicles equipped with MacPherson struts and many short/long-arm-type suspensions. The bushings are very important in maintaining proper wheel alignment while providing the necessary up-and-down movement of the control arms during suspension travel. Strut rods prevent lower control arm movement back and forth during braking. ● **SEE FIGURE 112–38.**

TERMINOLOGY Strut rods are also called tension or compression rods or simply TC rods. Tension rods attach in *front* of the wheels to the body or frame where the rod is being pulled in tension. Compression rods attach to the body or frame *behind* the wheels where the rod is being pushed or compressed. Some vehicle manufacturers call the strut rod a drag rod because it is attached in front of the wheels, and therefore acts on the lower control arm as if to drag the wheels behind their attachment points.

The bushings are replaceable by removing a nut on the frame end of the strut rod. ● **SEE FIGURE 112–39.** If a strut rod has a nut on *both* sides of the bushings, then the strut rod is used to adjust *caster.*

STABILIZER BARS

Most cars and trucks are equipped with a **stabilizer bar** on the front suspension, which is a round, hardened steel bar (usually SAE 4560 or 4340 steel) attached to both lower control arms with bolts and rubber bushing washers called stabilizer bar bushings. ● **SEE FIGURE 112–40** on page 1304.

A stabilizer bar is also called an anti-sway bar (sway bar) or anti-roll bar (roll bar). A stabilizer bar operates by *twisting* the bar if one side of the vehicle moves up or down in relation to the other side, such as during cornering, hitting bumps, or driving over uneven road surfaces. ● **SEE FIGURE 112–41** on page 1304.

The purpose of the stabilizer bar is to prevent excessive body roll while cornering and to add stability while driving over rough road surfaces. The stabilizer bar is also used as a longitudinal (front/back) support to the lower control arm on many vehicles equipped

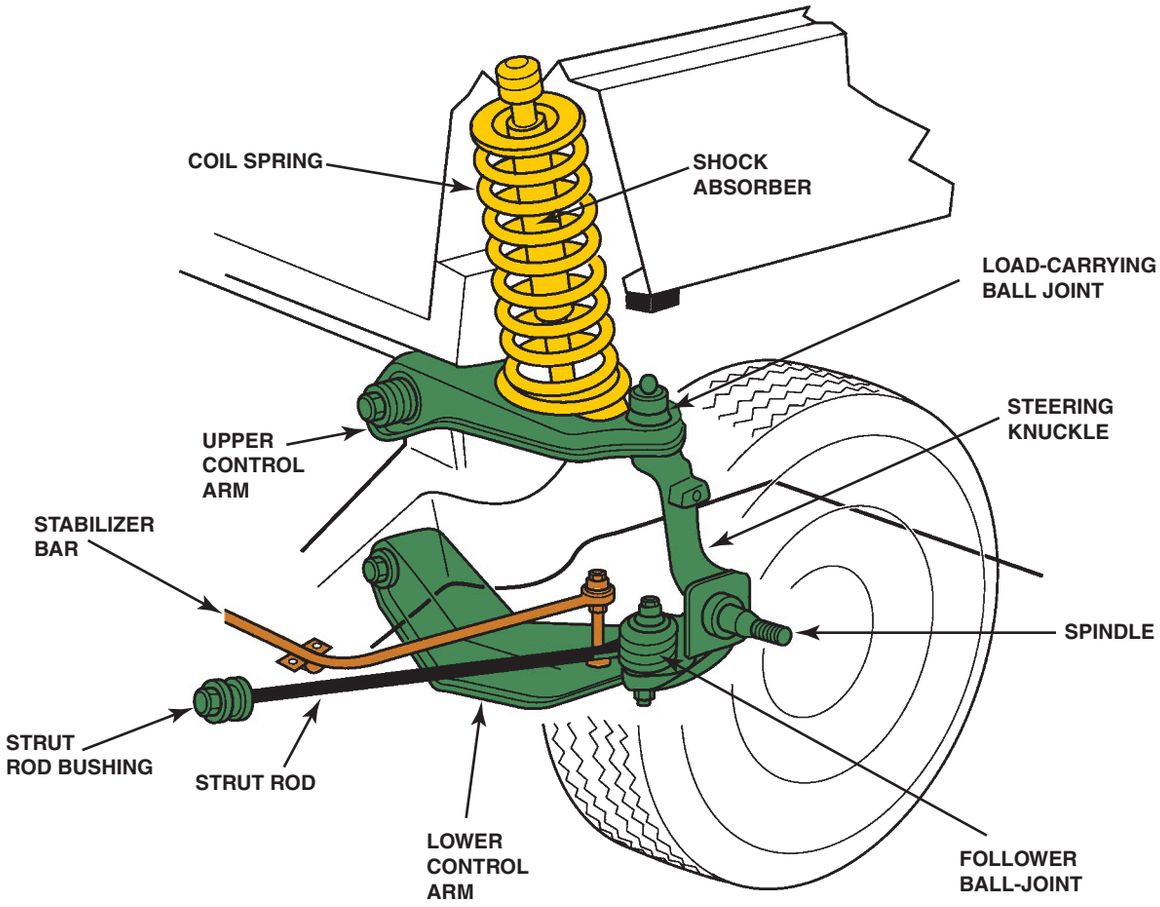


FIGURE 112–35 The upper ball joint is load carrying in this type of suspension because the weight of the vehicle is applied through the spring, upper control arm, and ball joint to the wheel. The lower control arm is a lateral link, and the lower ball joint is called a follower ball joint.

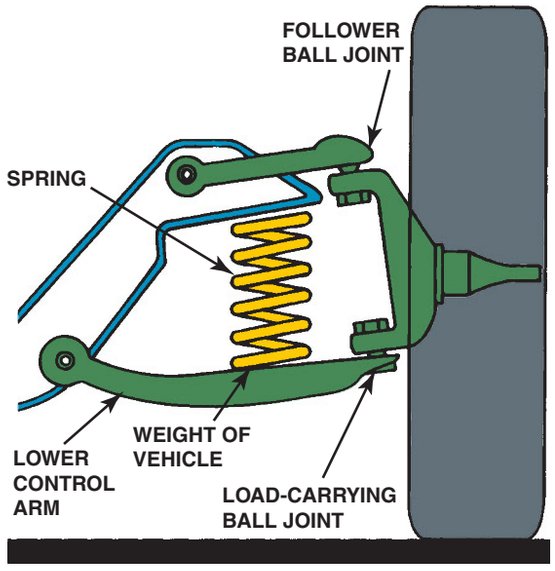


FIGURE 112–36 The lower ball joint is load carrying in this type of suspension because the weight of the vehicle is applied through the spring, lower control arm, and ball joint to the wheel.

with MacPherson struts. The effective force of a stabilizer bar is increased with the diameter of the bar. Therefore, optional suspensions often include larger-diameter stabilizer bars and bushings.

Stabilizer links connect the ends of the stabilizer bar to the lower control arm. ● **SEE FIGURES 112–42 AND 112–43.** Careful inspection of the stabilizer bar links is important. Links are commonly found to be defective (cracked rubber washers or broken spacer bolts) because of the great amount of force that is transmitted through the links and the bushings. Defective links and/or bushings can cause unsafe vehicle handling and noise.

SHOCK ABSORBERS

PURPOSE AND FUNCTION

Shock absorbers are used on all conventional suspension systems to dampen and control the motion of the vehicle's springs. Without shock absorbers (dampers), the vehicle would continue to bounce after hitting bumps. ● **SEE FIGURE 112–44.**

The major purpose of any shock or strut is to control ride and handling. Standard shock absorbers *do not* support the weight of a vehicle. *The springs support the weight of the vehicle; the shock absorbers control the actions and reactions of the springs.* Shock absorbers are also called dampers.

Most shock absorbers are *direct acting* because they are connected directly between the vehicle frame or body and the axles. ● **SEE FIGURE 112–45.**

As a wheel rolls over a bump, the wheel moves toward the body and compresses the spring(s) of the vehicle. As the spring compresses, it stores energy. The spring then releases this stored energy, causing the body of the vehicle to rise (rebound). ● **SEE FIGURE 112–46.**

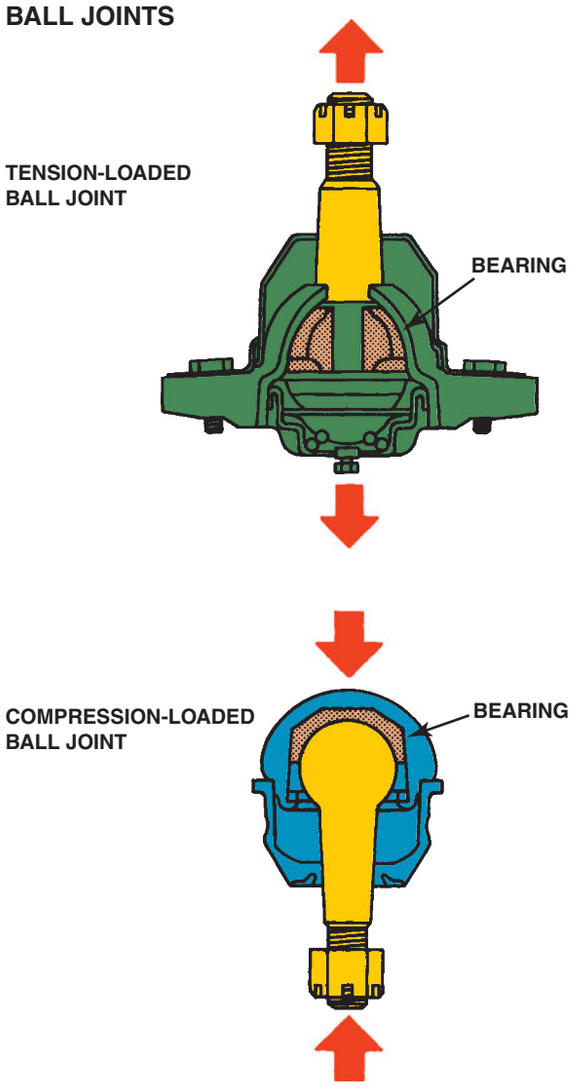


FIGURE 112–37 All ball joints, whether tension or compression loaded, have a bearing surface between the ball stud and socket.

After the energy in the spring is used up, the body starts downward, causing the spring to compress. Without shock absorbers, the energy released from the spring would be very rapid and violent. The shock absorber helps dampen the rapid up-and-down movement of the vehicle springs by converting energy of movement into heat by forcing hydraulic fluid through small holes inside the shock absorber.

SHOCK ABSORBER OPERATION The hydraulic shock absorber operates on the principle of fluid being forced through a small opening (orifice). ● **SEE FIGURES 112–47 AND 112–48.** Besides small openings, pressure relief valves are built into most shock absorbers to control vehicle ride under all operating conditions.

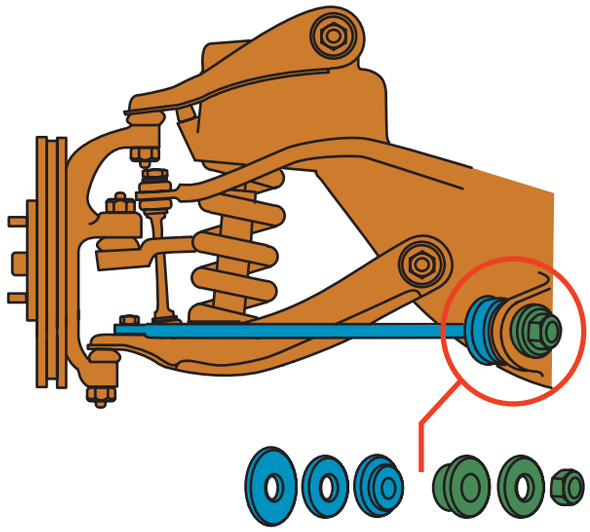


FIGURE 112–39 Strut rod bushings insulate the steel bar from the vehicle frame or body.

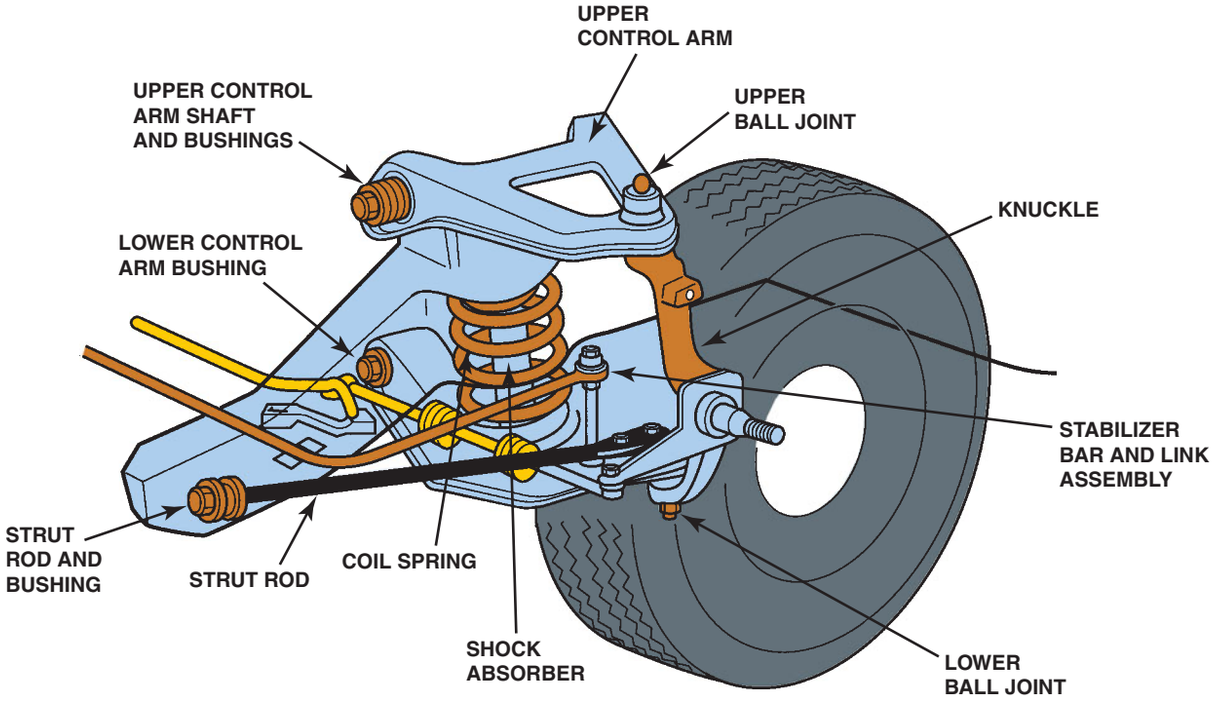


FIGURE 112–38 A strut rod is the longitudinal support to prevent front-to-back wheel movement. Struts rods are only used when there is only one lower control arm bushing and not used where there are two lower control arm bushings.

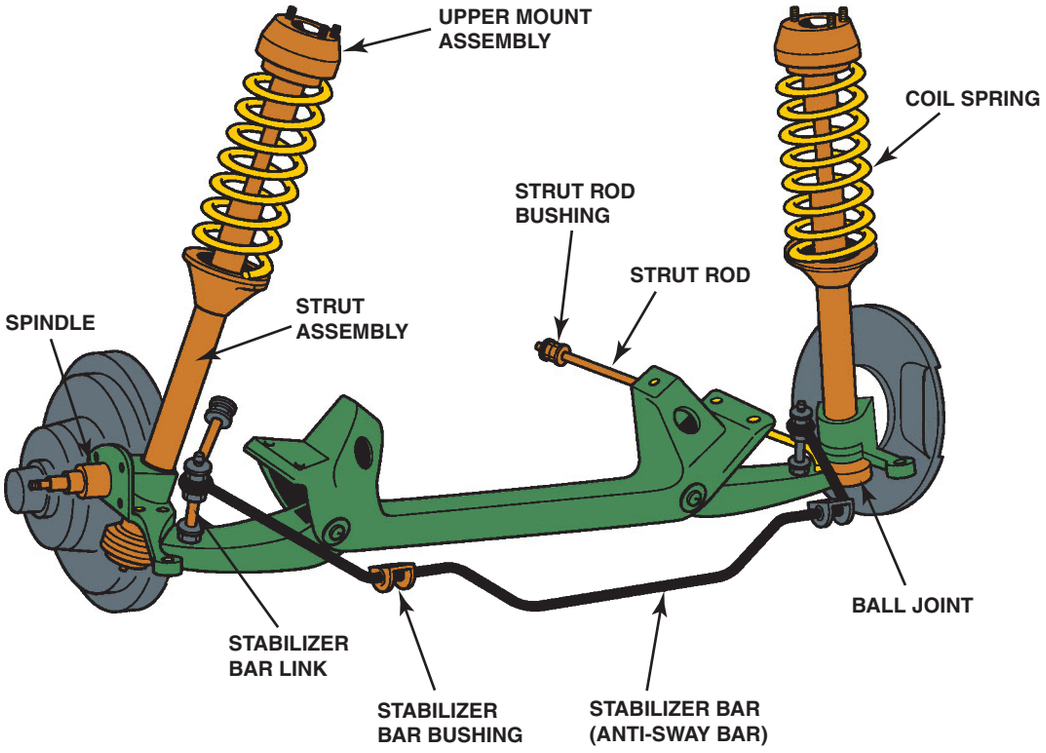


FIGURE 112–40 Typical stabilizer bar installation.

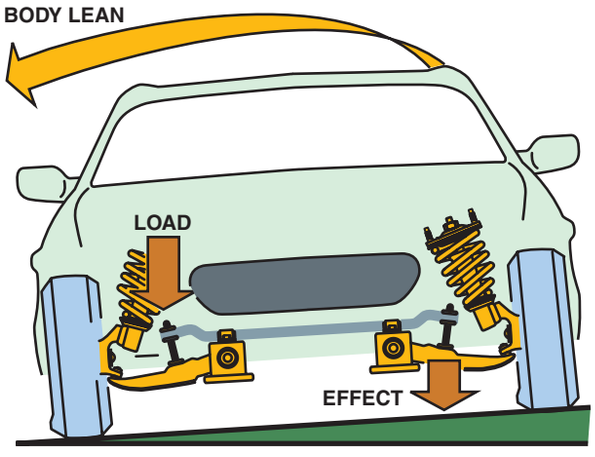


FIGURE 112–41 As the body of the vehicle leans, the stabilizer bar is twisted. The force exerted by the stabilizer bar counteracts the body lean.

The greater the pressure drop of the fluid inside the shock and the greater the amount of fluid moved through the orifice, the greater the amount of dampening; therefore, larger shock absorbers can usually provide better dampening than smaller units.

GAS-CHARGED SHOCKS Most shock absorbers on new vehicles are gas charged. Pressurizing the oil inside the shock absorber helps smooth the ride over rough roads. This pressure helps prevent air pockets from forming in the shock absorber oil as it passes through the small passages in the shock. After the oil is forced through small passages, the pressure drops and the oil expands. As the oil expands, bubbles are created. The oil becomes foamy. This air-filled oil does not effectively provide dampening. The result of all of this aeration (air being mixed with the oil) is lack of dampening and a harsh ride.

The use of higher-pressure radial tires and lighter vehicle weight has created the need for more effective shock absorbers. To meet this need, shock absorber design engineers use a pressurized gas that does not react chemically with the oil in the shock. If a substance does not react with any other substances, it is called *inert.* The gas most often used is nitrogen, which is about 78% of our atmosphere. Typical gas-charged shocks are pressurized with 130 to 150 PSI (900 to 1,030 kPa) to aid in both handling and ride control. Some shocks use higher pressures, but the higher the pressure, the greater the possibility of leaks and the harsher the ride.

Some gas-charged shock absorbers use a single tube that contains two pistons that separate the high-pressure gas from the working fluid. Single-tube shocks are also called monotube or DeCarbon after the French inventor of the principle and manufacturer of suspension components. ● **SEE FIGURE 112–49.**

AIR SHOCKS/STRUTS Air-inflatable shock absorbers or struts are used in the rear of vehicles to provide proper vehicle ride height while carrying heavy loads. Many air shock/strut units are original

? **FREQUENTLY ASKED QUESTION**

What Are Remote Reservoir Shocks?

Remote reservoir shock absorbers are units designed for heavy-duty use that use a separate container for the working fluid. ● **SEE FIGURE 112–50** on page 1308.

The purpose of the remote fluid reservoir is to keep the temperature of the fluid stable, which helps the shock absorber provide consistent dampening under all conditions.

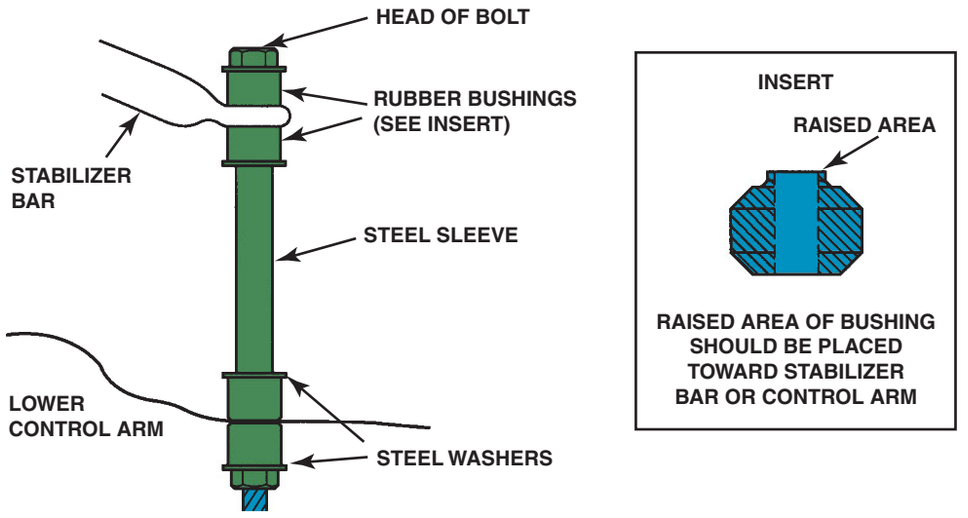


FIGURE 112–42 Stabilizer bar links are sold as a kit consisting of the long bolt with steel sleeve and rubber or urethane bushings. Steel washers are used on both sides of the rubber bushings as shown.

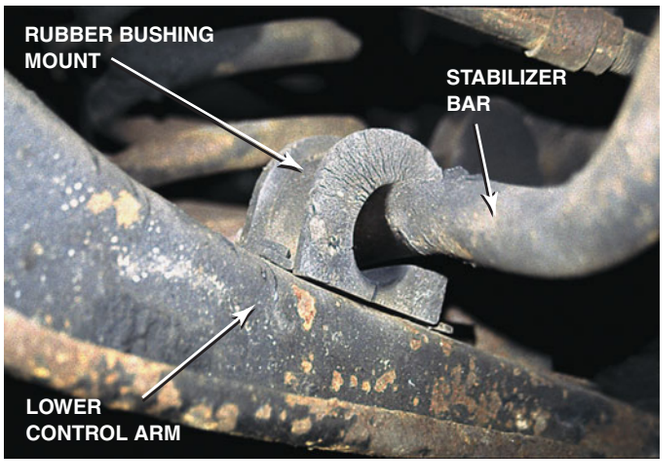


FIGURE 112–43 Notice how the lower control arm pulls down on the mounting bushing when the vehicle is hoisted off the ground, allowing the front suspension to drop down. These bushings are a common source of noise, especially when cold. Lubricating the bushings with paste silicone grease often cures the noise.

equipment. They are often combined with a built-in air compressor and ride height sensor(s) to provide automatic ride height control.

Air-inflatable shocks are standard shock absorbers with an air chamber and a rubber bag built into the dust cover (top) of the shock. ● **SEE FIGURE 112–51** on page 1308.

Air pressure is used to inflate the bag, which raises the installed height of the shock. As the shock increases in height, the rear of the vehicle is raised. Typical maximum air pressure in air shocks ranges from 90 to 150 PSI (620 to 1,030 kPa). As the air pressure increases in the air-inflatable reservoir of the shock, the stiffness of the suspension increases. This additional stiffness is due to the shock taking weight from the spring, and therefore the air in the air shock becomes an air spring. Now, with two springs to support the vehicle, the spring rate increases and a harsher ride often results. *It is important that the load capacity of the vehicle not be exceeded or serious damage can occur to the vehicle's springs, axles, bearings, and shock support mounts.*

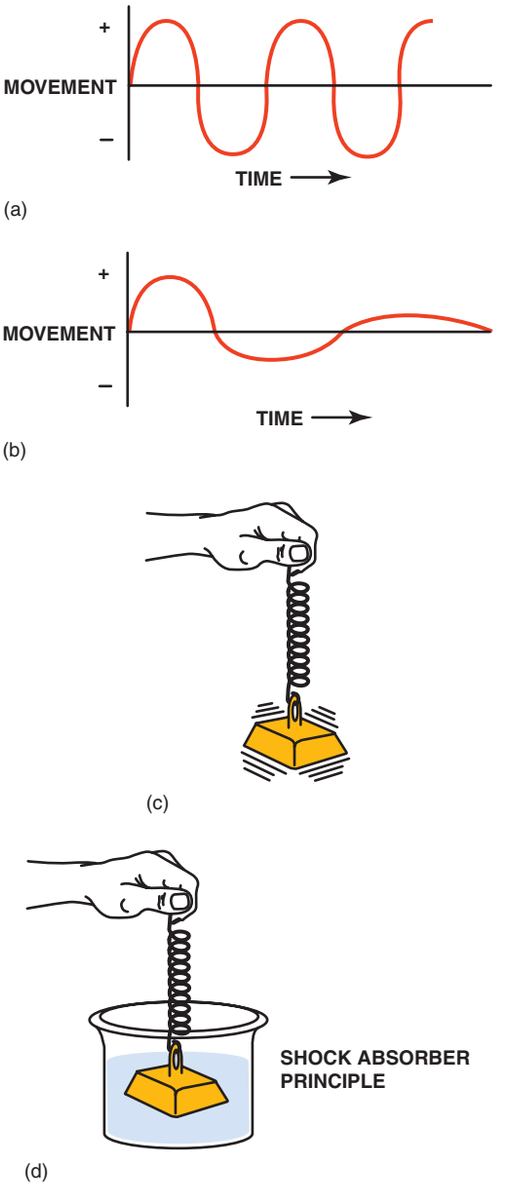


FIGURE 112–44 (a) Movement of the vehicle is supported by springs without a dampening device. (b) Spring action is dampened with a shock absorber. (c) The function of any shock absorber is to dampen the movement or action of a spring, similar to using a liquid to control the movement of a weight on a spring (d).

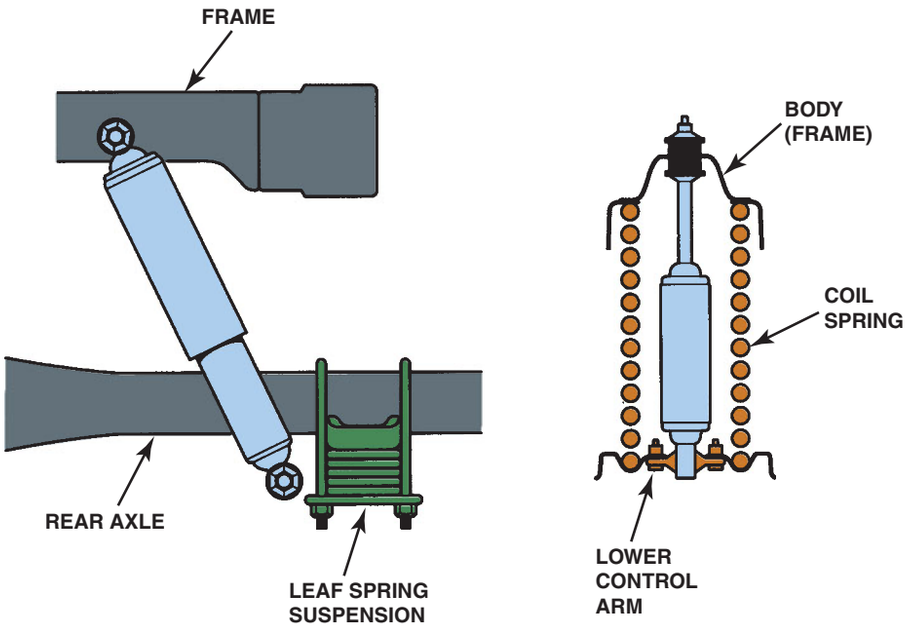


FIGURE 112–45 Shock absorbers work best when mounted as close to the spring as possible. Shock absorbers that are mounted straight up and down offer the most dampening.

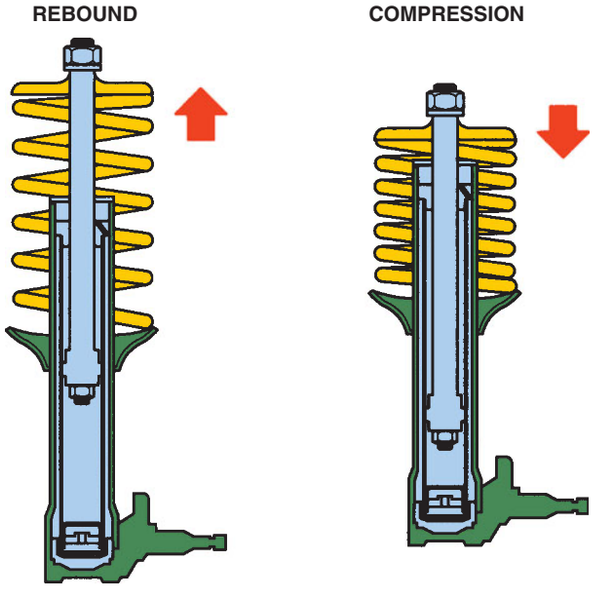


FIGURE 112–46 When a vehicle hits a bump in the road, the suspension moves upward. This is called compression or jounce. Rebound is when the spring (coil, torsion bar, or leaf) returns to its original position.

AIR SPRINGS

Some electronically controlled suspension systems use air springs. A basic **air spring** consists of a rubber air chamber, generally closed at the bottom by a piston fitted into a control arm, or by a strut shock absorber. ● **SEE FIGURE 112–52** on page 1309.

Electronically controlled suspension systems that use air springs as the only springs are available on some Hummer, and many Ford, Mercury, and Lincoln vehicles.

Some air springs are in effect auxiliary springs inside a coil-spring strut. In these designs, the coil spring supports the weight of the vehicle, while the air spring raises or lowers the body to adjust ride height according to load. ● **SEE FIGURE 112–53** on page 1309.

COIL-OVER SHOCKS. A coil-over shock absorber uses the force of an external coil spring to boost the performance of the basic shock absorber. ● **SEE FIGURE 112–54** on page 1309. The spring usually extends from the upper shock mount to a seat on the lower portion of the cylinder. The spring rate added to the hydraulic resistance makes the shock stiffer.

STRUTS

PURPOSE AND FUNCTION

A **strut** is a sturdy shock absorber that is also a structural component of the suspension. A strut is a suspension link as well as a shock absorber. The casing of a strut must be strong and rigid to function as a suspension link. The shock absorber assembles inside the casing of a strut, and may be either a removable cartridge or an integral part of the strut.

MACPHERSON STRUTS

The MacPherson strut, which is named after Earle S. MacPherson, who developed the suspension design in the late 1940s and patented it in 1953, is the most commonly used type. A MacPherson strut includes the suspension spring—a coil spring that surrounds the strut casing—so that it transfers the weight of the body to the wheel. ● **SEE FIGURE 112–55.**

A MacPherson strut typically incorporates an upper and a lower spring seat, a shock absorber mount and dust cap, a dust cover for the piston rod, and a bump stop. The upper mount secures the upper spring seat to the strut tower. A rubber bushing at the top of the strut absorbs vibrations. A bearing on a front-wheel strut allows it to rotate on the vertical steering axis without rubbing against the strut tower when the steering knuckle turns. The lower spring seat is attached to the strut casing.

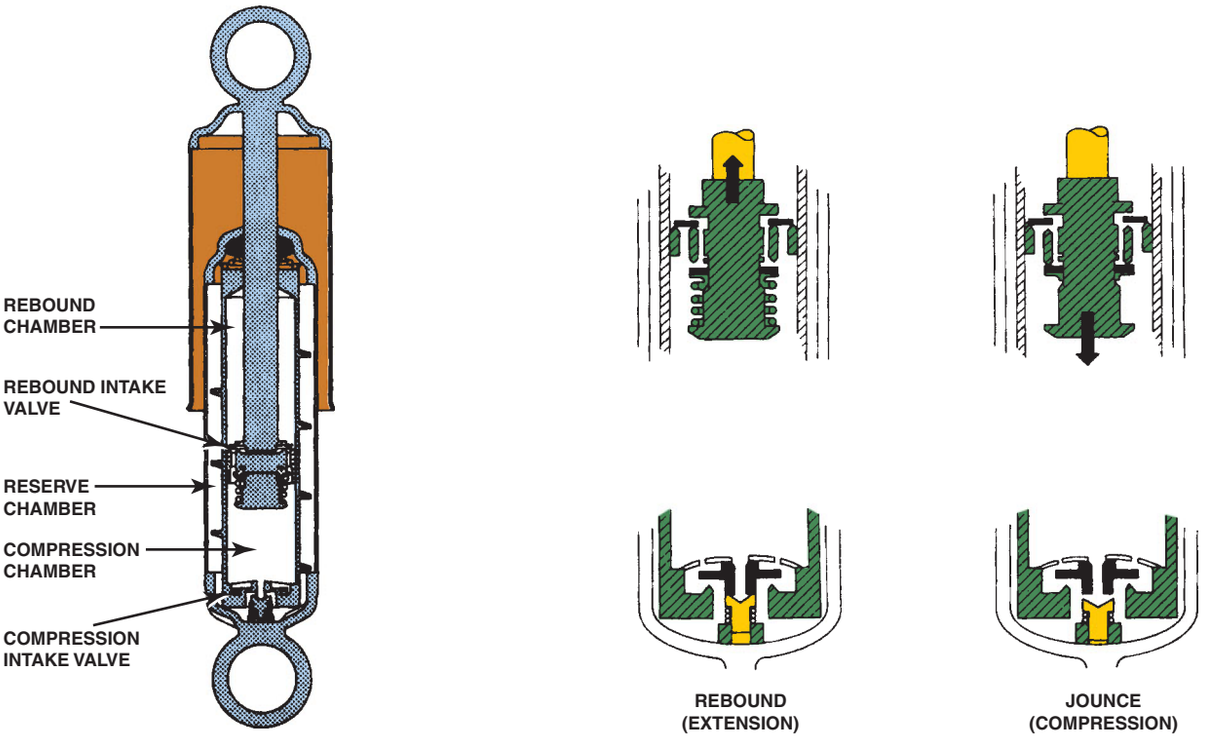


FIGURE 112–47 (a) A cutaway drawing of a typical double-tube shock absorber. (b) Notice the position of the intake and compression valve during rebound (extension) and compression.

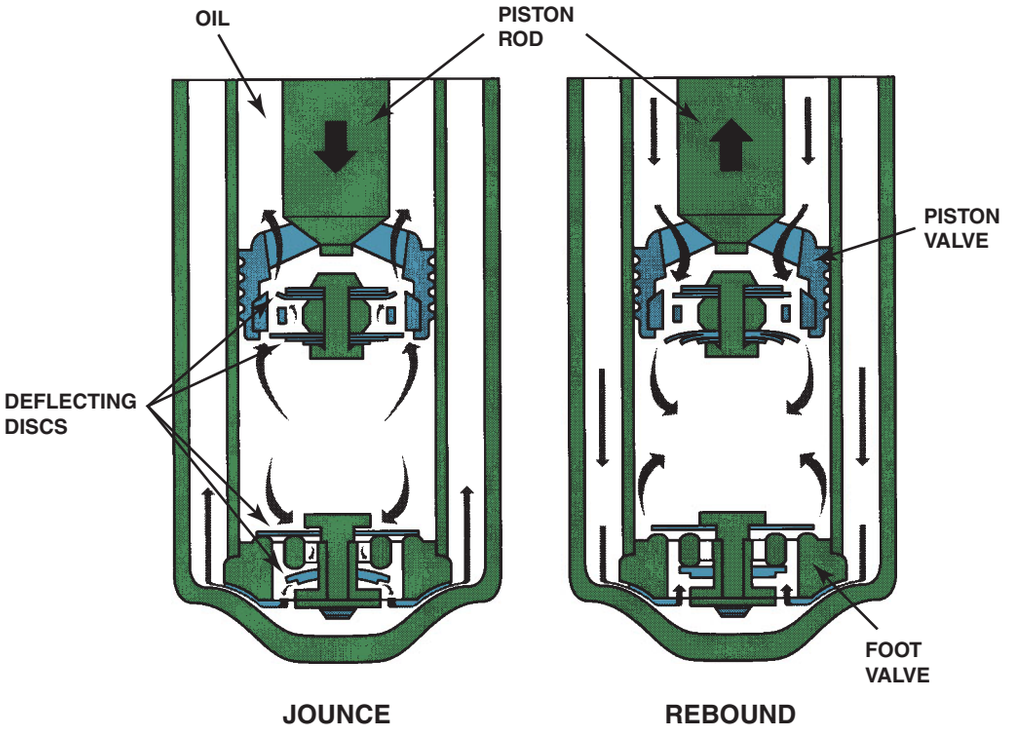


FIGURE 112–48 Oil flow through a deflected disc-type piston valve. The deflecting disc can react rapidly to suspension movement. For example, if a large bump is hit at high speed, the disc can deflect completely and allow the suspension to reach its maximum jounce distance while maintaining a controlled rate of movement.

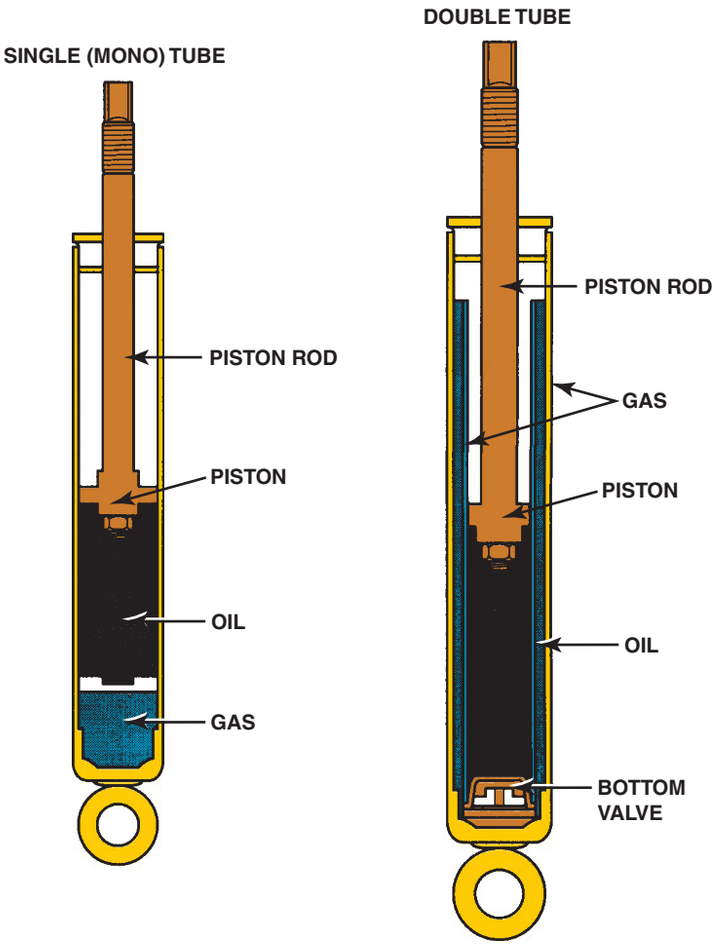


FIGURE 112–49 Gas-charged shock absorbers are manufactured with a double-tube design similar to conventional shock absorbers and with a single or monotube design.

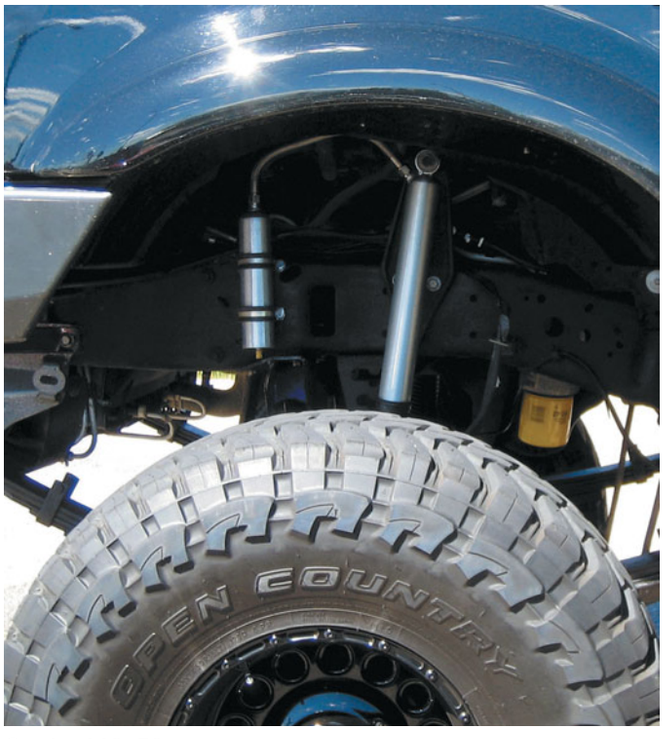


FIGURE 112–50 The shock absorber is on the right and the fluid reservoir for the shock is on the left.

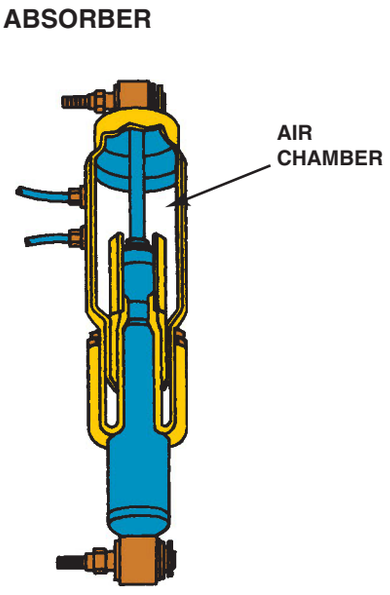


FIGURE 112–51 A rubber tube forms an inflatable air chamber at the top of an air shock. The higher the air pressure in the chamber, the stiffer the shock.

MODIFIED STRUTS Unlike a MacPherson unit, a modified strut does not include a spring as part of the assembly and is used in the front on some vehicles and on the rear of others. ● **SEE FIGURE 112–56.** Most modified strut rear suspensions use coil springs mounted on the lower control arm.

BUMP STOPS

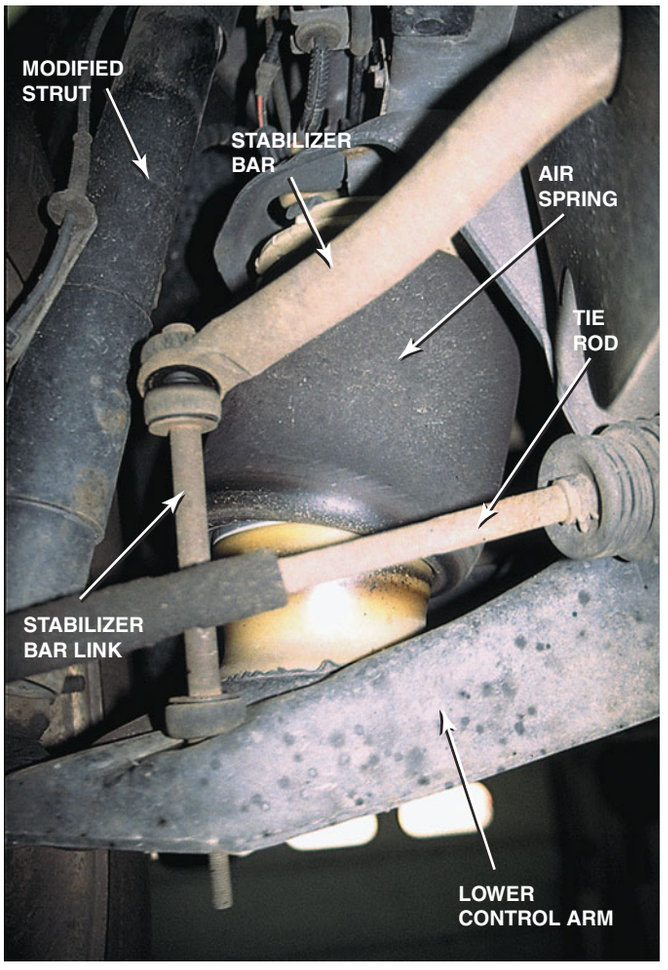
All suspension systems have a limit of travel. If the vehicle hits a large bump in the road, the wheels are forced upward toward the vehicle with tremendous force. This force is absorbed by the springs of the suspension system. If the bump is large enough, the suspension is compressed to its mechanical limit. Instead of allowing the metal components of the suspension to hit the frame or body of the vehicle, a rubber or foam bumper is used to absorb and isolate the suspension from the frame or body. ● **SEE FIGURE 112–57.**

These bumpers are called **bump stops,** suspension bumpers, strike-out bumpers, or jounce bumpers. *Jounce* means jolt, or to cause to bounce or move up and down. Bumpers are made from rubber or microcellular urethane. Urethane is a high-strength material with good resistance to wear and tear as well as good chemical resistance to most fluids. Forming urethane foam with small, regular air cells makes the material ideal for jounce bumpers.

Damaged suspension-limiting bump stops can be caused by the following:

1. Sagging springs that result in lower-than-normal ride (trim) height
2. Worn or defective shock absorbers

Most suspensions also use a rubber or foam stop to limit the downward travel of the suspension during rebound. The rebound stop also prevents metal-to-metal contact of the suspension on the frame when the vehicle is on a body-contact-type hoist and the wheels are allowed to hang or droop down. Some stops are built into the shock absorber or strut.



(a)



(b)

FIGURE 112–52 (a) The front suspension of a Lincoln with an air-spring suspension. (b) Always check in the trunk for the cutoff switch for a vehicle equipped with an air suspension before hoisting or towing the vehicle.

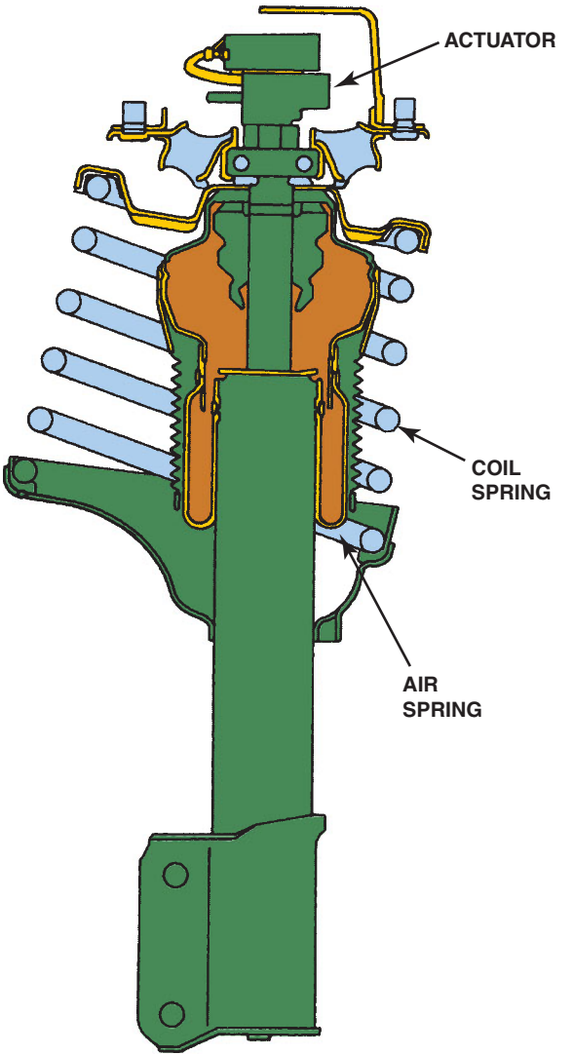


FIGURE 112–53 Some air springs are auxiliary units to the coil spring and are used to control ride height while the coil spring is the weight-bearing unit.

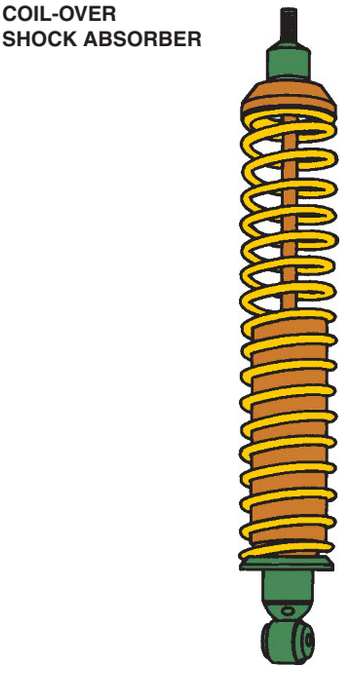


FIGURE 112–54 A coil-over shock is a standard hydraulic shock absorber with a coil spring wrapped around it to increase stiffness and/or take some of the carrying weight off of the springs.

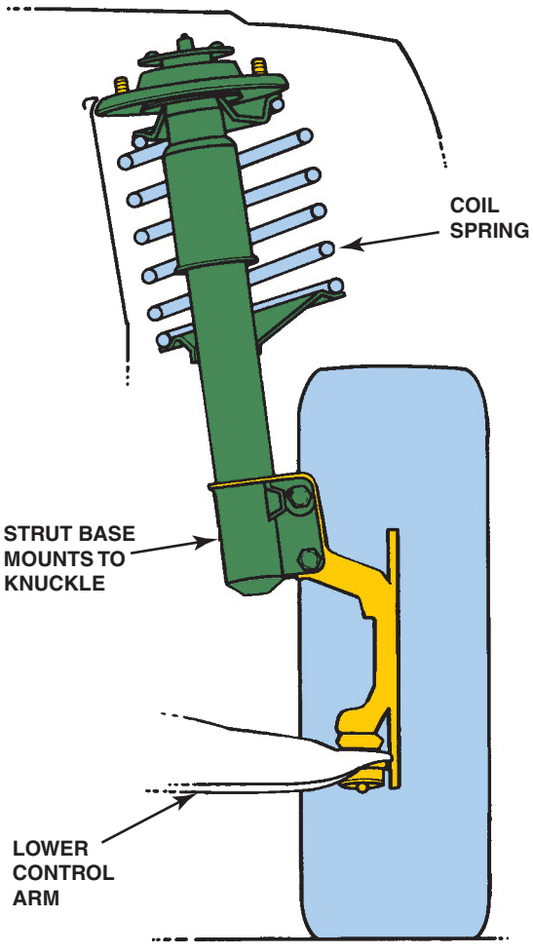


FIGURE 112–55 A strut is a structural part of the suspension and includes the spring and shock absorber in one assembly.

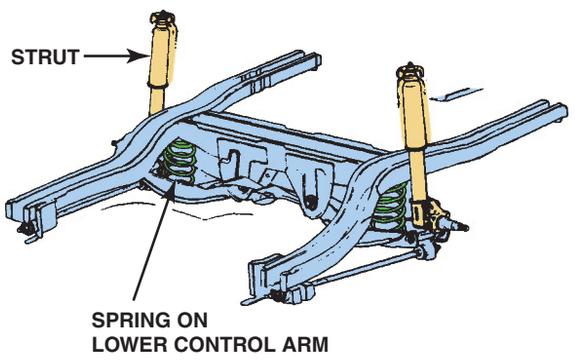
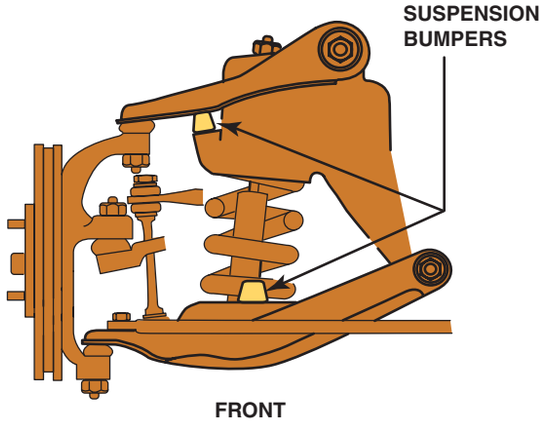


FIGURE 112–56 A modified strut used on the rear suspension; it is part of the structural part of the assembly.



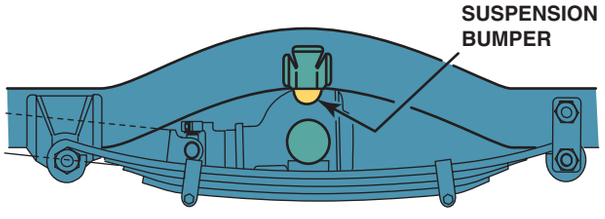


FIGURE 112–57 Suspension bumpers are used on all suspension systems to prevent metal-to-metal contact between the suspension and the frame or body of the vehicle when the suspension "bottoms out" over large bumps or dips in the road.

FREQUENTLY ASKED QUESTION

What Is a Track Rod?

A track rod, also called a Panhard rod, is used in the rear of some suspension systems to keep the rear axle centered under the center of the vehicle. It is a straight rod or channel that connects to the frame on one end and the axle on the other end.

REVIEW QUESTIONS

1. List the types of suspensions and name their component parts.
2. Explain Hooke's Law.
3. Describe the purpose and function of a stabilizer bar.
4. Explain the difference between a load-carrying and a follower (friction) ball joint.

CHAPTER QUIZ

1. The spring rate of a spring is measured in units of _____.
   a. lb per inch **c.** PSI
   b. ft-lb **d.** in.-lb
2. Two technicians are discussing torsion bars. Technician A says that many torsion bars are adjustable to allow for ride height adjustment. Technician B says that torsion bars are usually marked left and right and should not be switched side to side. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. What component(s) is considered to be unsprung weight?
   a. Frame **c.** Wheels and tires
   b. Body **d.** Both a and b
4. Two technicians are discussing MacPherson struts. Technician A says that in most applications the entire strut assembly rotates when the front wheels are turned. Technician B says a typical MacPherson strut suspension system uses only one control arm and one ball joint per side. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
5. Technician A says that regular replacement shock absorbers will raise the rear of a vehicle that is sagging down. Technician B says that replacement springs will be required to restore the proper ride height. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. What suspension component is used to counteract body lean during cornering?
   a. Torsion bar
   b. Strut rod
   c. Stabilizer bar
   d. Control arm
7. A center bolt is used in what type of spring?
   a. Coil
   b. Leaf
   c. Torsion bar
   d. All of the above
8. Two technicians are discussing air shocks. Technician A says that air is forced through small holes to dampen the ride. Technician B says that air shocks are conventional hydraulic shock absorbers with an airbag to control vehicle ride height. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. The owner of a pickup truck wants to cut the coil springs to lower the vehicle. Technician A says that the ride will be harsher than normal if the springs are cut. Technician B says that the springs could be damaged, especially if a cutting torch is used to cut the springs. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. A MacPherson strut is a structural part of the vehicle.
    a. True
    b. False

chapter 113

FRONT SUSPENSIONS AND SERVICE

OBJECTIVES: **After studying Chapter 113, the reader will be able to:** • Prepare for ASE Suspension and Steering (A4) certification test content area "B" (Suspension System Diagnosis and Repair). • Explain how to perform a road test, a dry park test, a visual inspection, and a bounce test. • Discuss the procedures for testing load-carrying and follower-type ball joints. • Describe ball joint replacement procedures. • List the steps required to replace control arm and stabilizer bar bushings. • Describe how to replace coil springs, MacPherson struts, and torsion bars safety. • Explain routine service procedures of the suspension system.

KEY TERMS: A-arm 1313 • Cow catcher 1325 • Cuppy tire wear 1324 • Dry park test 1317 • Durometer 1330 • Indicator ball joints 1318 • Kingpin 1312 • Pinch bolt 1321 • Radius rod 1312 • SLA 1313 • Steering knuckle 1312 • Strut suspension 1314 • Twin I-beam 1312



FIGURE 113–1 Most early vehicles used single straight axles.

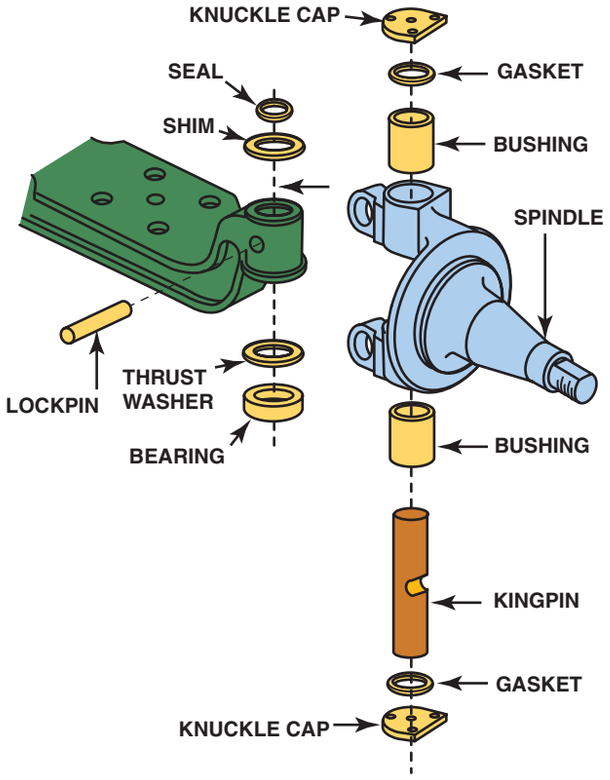


FIGURE 113–2 Typical kingpin used with a solid axle.

FRONT SUSPENSION TYPES

SOLID AXLES Early cars and trucks used a solid (or *straight*) front axle to support the front wheels. ● **SEE FIGURE 113–1.**

A solid-axle front suspension is very strong and is still being used in the manufacture of medium and heavy trucks. The main disadvantage of solid-axle design is its lack of ride quality. When one wheel hits a bump or dip in the road, the forces are transferred through the axle to the opposite wheel. Solid axles are currently used in the rear of most vehicles.

KINGPINS At the end of many solid I-beam or tube axles are **kingpins** that allow the front wheels to rotate for steering. Kingpins are hardened steel pins that attach the steering knuckle to the front axle, allowing the front wheels to move for steering. Kingpins usually have grease fittings to lubricate the kingpin bushings. Failure to keep these bushings lubricated with chassis grease can cause wear and freeplay or can cause the pins to become galled (seized or frozen), resulting in hard steering and/or loud noise while turning. ● **SEE FIGURE 113–2.**

TWIN I-BEAMS A **twin I-beam** front suspension was used for over 30 years on Ford pickup trucks and vans, beginning in the mid-1960s. Strong steel twin beams that cross provide independent front suspension operation with the strength of a solid front axle. Early versions of the twin I-beam systems used kingpins, while later models used ball joints to support the **steering knuckle** and spindle. Coil springs are usually used on twin I-beam suspensions, even though the original design and patent used leaf springs. ● **SEE FIGURE 113–3.**

To control longitudinal (front-to-back) support, a **radius rod** is attached to each beam and is anchored to the frame of the truck using rubber bushings. These bushings allow the front axle to move up and down while still insulating road noise and vibration from the frame and body.

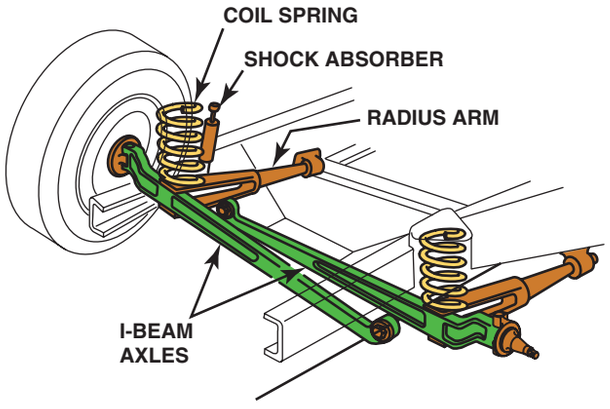


FIGURE 113–3 Twin I-beam front suspension. Rubber bushings are used to support the I-beams to the frame and help isolate road noise.

TECH TIP

Radius Rod Bushing Noise

When the radius rod bushing on a Ford truck or van deteriorates, the most common complaint from the driver is noise. ● **SEE FIGURE 113–4.** Besides causing tire wear, worn or defective radius rod bushing deterioration can cause the following:

1. A clicking sound when braking (it sounds as if the brake caliper may be loose).
2. A clunking noise when hitting bumps.

When the bushing deteriorates, the axles can move forward and backward with less control. Noise is the first sign that something is wrong. Without proper axle support, handling and cornering can also be affected.

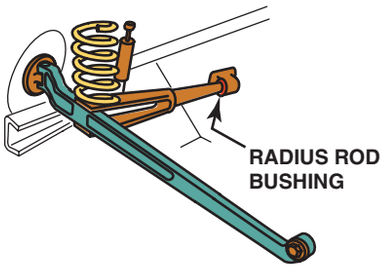


FIGURE 113–4 The rubber radius rod bushing absorbs road shocks and helps isolate road noise.

SHORT/LONG-ARM (SLA) SUSPENSION

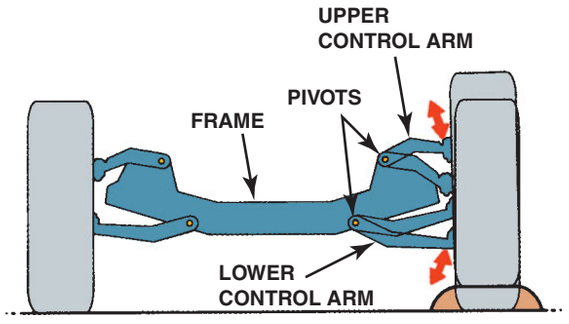


FIGURE 113–5 The upper control arm is shorter than the lower control arm on a short/long-arm (SLA) suspension.

SHORT/LONG-ARM SUSPENSIONS

The short/long-arm suspension uses a short upper control arm and a longer lower control arm and usually is referred to as the *SLA-type suspension.*

The two main links in a **short/long-arm (SLA)** suspension are the upper control arm and the lower control arm. The upper control arm is shorter than the lower one. ● **SEE FIGURE 113–5.** This type of suspension system goes by a variety of names, including unequal-arm suspension, double-wishbone suspension, or **A-arm** suspension. Unequal arm refers to the fact that the two arms are of different lengths, while double-wishbone and A-arm derive from the shape of the arms, which are frequently triangular with one mounting point at the knuckle and two at the frame. When an SLA suspension uses a straight, two-point lower control arm, there is almost always a strut rod that braces the lower arm against the frame. The strut rod can attach to the frame at a point either forward or to the rear of the control arm.

A strut rod, also called a *reaction rod,* provides support to the axle during braking and acceleration forces.

Using a strut rod provides triangulation between the wheel and the frame. *Triangulation* means that the front suspension has a three-point brace that resists forces from every direction, while still allowing the wheels to pivot on the steering axis.

Locating the coil spring on the lower control arm is the most common SLA-type suspension configuration. ● **SEE FIGURE 113–6.**

The upper control arm is A-shaped, with two mounting points at the frame side member and one at the steering knuckle. The inboard ends of the arm attach to a pivot bar that is rigidly bolted to the frame, and the outboard end connects to the steering knuckle with a ball joint. Bushings between the inner arm mounts and the pivot bar allow the arm to swing vertically. The lower control arm is also A-shaped with two inboard pivot mounts and a ball joint connection at the knuckle. Bolts attach the inboard ends of the lower arm to brackets that extend from the bottom of the frame crossmember. Bushings on the inboard mounts allow the arm to pivot vertically.

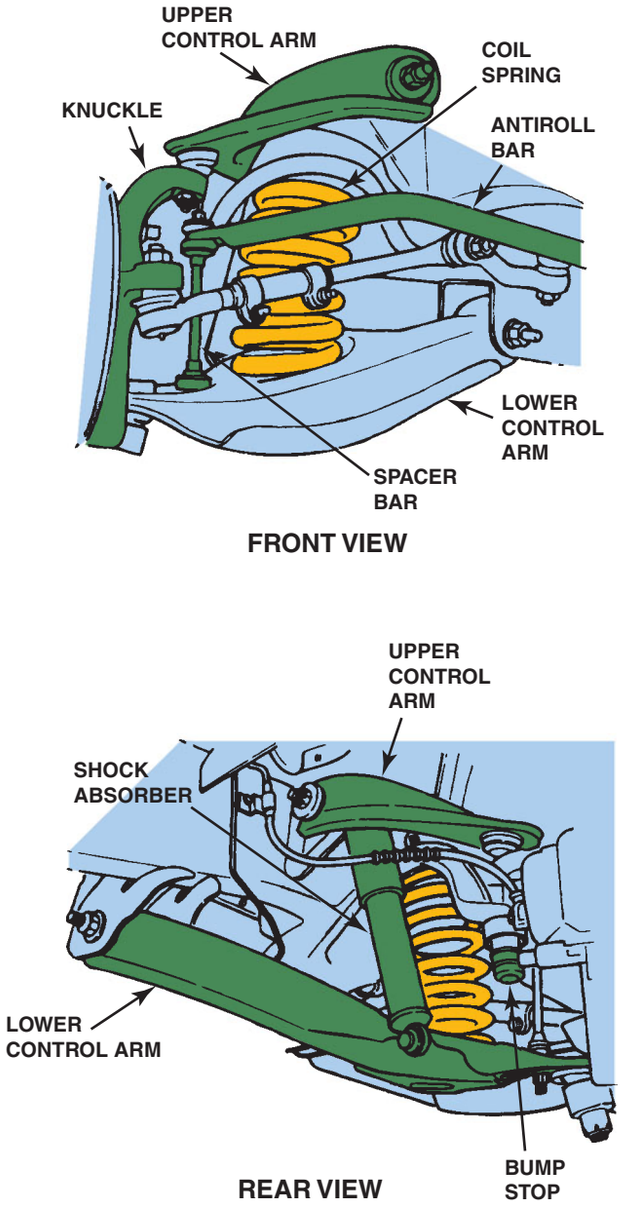


FIGURE 113–6 A typical SLA front suspension using coil springs.

The coil springs seat between the lower control arm and a bracket below the frame side member. The shock absorber attaches to the lower control arm and the frame side member.

In a typical coil spring on the upper control arm design, a portion of the unit-body wheel well is reinforced to withstand spring force and act as the upper spring seats. ● **SEE FIGURE 113–7.** Short/long-arm suspensions use longitudinal torsion bars, especially in trucks.

The forward end of the torsion bar has external splines or hexagonal (six sided) shaped end and shares the splined socket of the torque arm with the control arm through a bolt. Because the torque arm is rigidly bolted to the control arm, motion transfers to the torsion bar whenever the control arm pivots. The torsion bar extends rearward from the control arm and connects to an anchor arm that attaches to a frame crossmember. The torsion bar splines to the

SLA SUSPENSION - COIL SPRING ON UPPER ARM

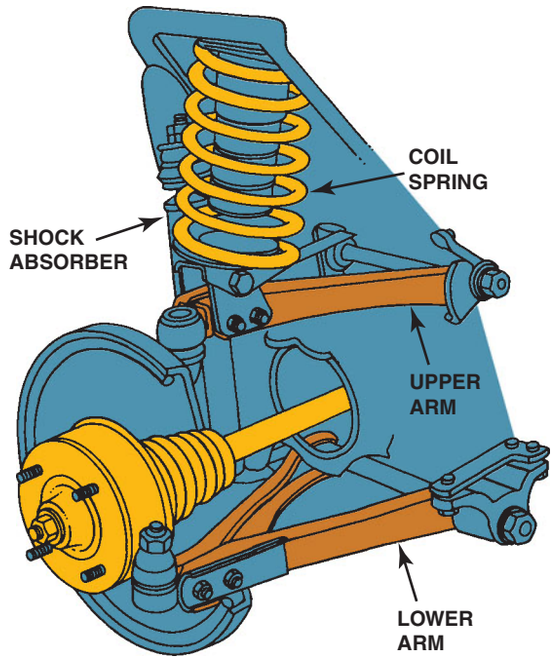


FIGURE 113–7 An SLA-type suspension with the coil spring placed on top of the upper control arm.

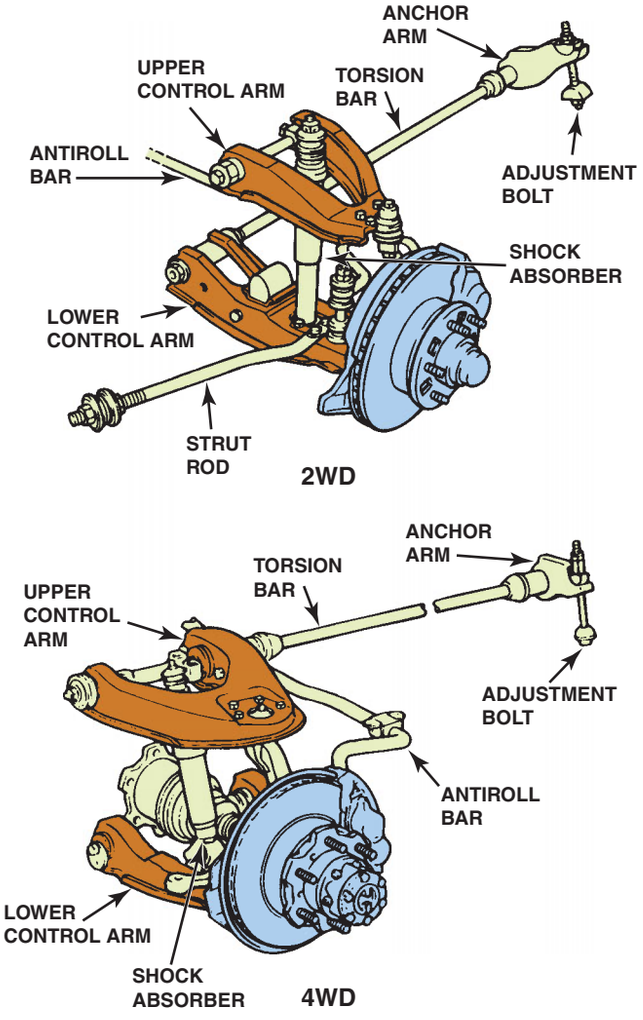


FIGURE 113–8 A torsion bar SLA suspension can use either the lower or the upper control arm.

MACPHERSON STRUT SUSPENSION

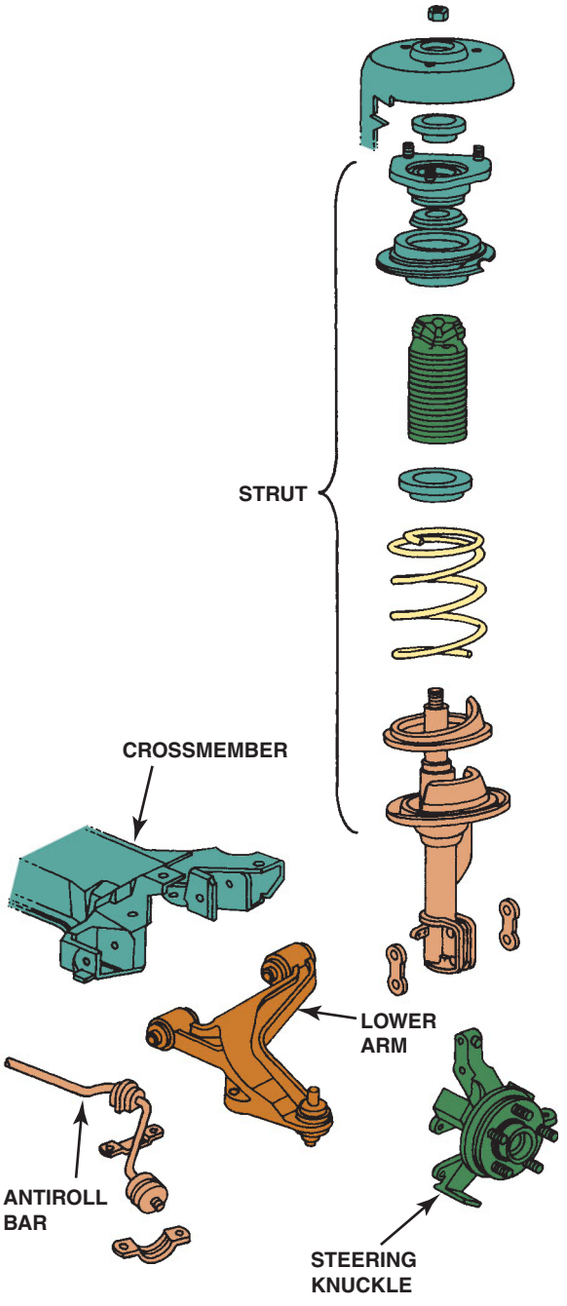


FIGURE 113–9 A typical MacPherson strut showing all of the components of the assembly. A strut includes the shock and the spring in one structural assembly.

anchor arm and the anchor arm is secured to the frame by a bolt and adjusting nut. The adjusting nut varies the spring force of the torsion bar to establish the ride height of the vehicle. ● **SEE FIGURE 113–8.**

STRUT SUSPENSION

Strut suspension can be of several types. A MacPherson strut includes the suspension spring that transfers the weight of the body to the wheel. A MacPherson strut is the main, load-carrying suspension spring. ● **SEE FIGURE 113–9.**

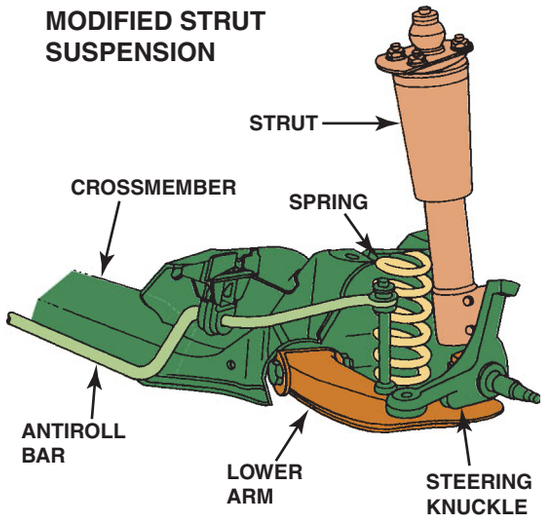


FIGURE 113–10 The modified strut front suspension is similar to a MacPherson strut suspension except that the coil spring is seated on the lower control arm and is not part of the strut assembly.

A MacPherson strut typically incorporates an upper and a lower spring seat, a shock absorber mount and dust cap, a dust cover for the piston rod, and a bump stop. The upper mount secures the upper spring seat to the strut tower. A rubber bushing at the top of the strut absorbs vibrations. In most applications, a bearing on the top of a front-wheel strut allows it to rotate on the vertical steering axis without rubbing against the strut tower when the steering knuckle turns. The lower spring seat is attached to the strut casing. The piston rod dust cover is similar to the dust cover on a conventional shock absorber, and a bump stop at the top of the piston rod keeps the strut from bottoming out during suspension jounce.

A modified strut does not include a spring as part of the assembly. ● **SEE FIGURE 113–10.** A modified strut is used on the rear of some GM vehicles. Except for the lack of a spring and spring seats, the construction and function of a modified strut are basically the same as those of a MacPherson strut. When used on the front suspension, a modified strut also rotates on the steering axis when the wheels turn.

A multilink front suspension uses two control arms as well as a structural strut assembly. This type of suspension is also called a strut/SLA or long spindle, short/long-arm suspension. ● **SEE FIGURE 113–11.**

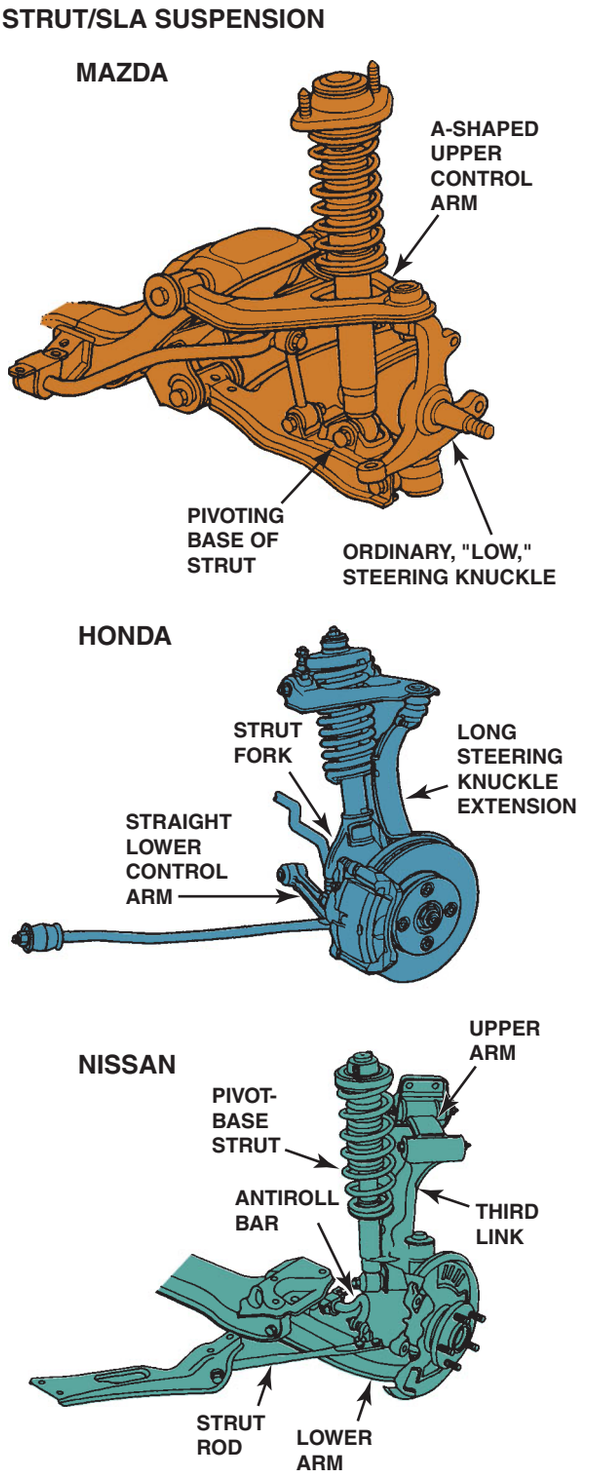


FIGURE 113–11 Multilink front suspension design varies depending on the vehicle manufacturer.

SERVICING THE SUSPENSION SYSTEM

Suspension systems are designed and manufactured to provide years of trouble-free service with a minimum amount of maintenance. In fact, the suspension system is often "invisible" or "transparent" to the driver because the vehicle rides and handles as expected. It is when the driver notices that the vehicle is not riding or handling as it did, or should, that a technician is asked to repair or align the vehicle and fix the problem.

The smart technician should always road test any vehicle before and after servicing (see Tech Tip for details). *The purpose of any diagnosis is to eliminate known good components.* (See the suspension problem symptom chart for a list of components that can cause the problem or customer complaint.)

SUSPENSION PROBLEM SYMPTOM CHART

Item or System to Check	CONCERN/PROBLEM: Noise	Instability/ Wander	Pull to One Side	Excessive Steering Play	Hard Steering	Shimmy
Tires/Wheels	Road/tire noise	Low/uneven air pressure	Low/uneven air pressure, mismatched tire sizes	Low/uneven air pressure	Low/uneven air pressure	Wheel out of balance/uneven tire wear/ overworn tires
Shock Absorbers (Struts)	Loose/worn mounts/ bushings	Loose/worn mounts/ bushings, worn/ damaged struts/shock absorbers			Loose/worn mounts/ bushings on strut assemblies	Worn/damaged struts/shock absorbers
Strut Rods (If Equipped)	Loose/worn mounts/ bushings	Loose/worn mounts/ bushings	Loose/worn mounts/ bushings			Loose/worn mounts/ bushings
Springs	Broken/ unseated	Broken/ unseated	Broken/ unseated especially rear			
Control Arms	Steering knuckle contacting control arm stop, worn/damaged mounts/bushings	Worn/damaged mounts/ bushings	Worn/damaged mounts/ bushings		Worn/damaged mounts/ bushings	Worn/damaged mounts/ bushings
Steering System	Component wear/damage	Component wear/damage	Component wear/damage	Component wear/damage	Component wear/damage	Component wear/damage
Wheel Alignment		Front and rear, especially caster	Front, camber and caster	Front alignment	Front, especially caster	Front, especially caster
Wheel Bearings	Front-wheel bearings	Loose/worn (front and rear)	Loose/worn (front and rear)	Loose/worn (front and rear)		Loose/worn (front and rear)
Brake System			Stuck caliper/slide			
Other					Ball joint lubrication	Loose/worn friction ball joints

CAUTION: More than one factor may be the cause of a problem. Be sure to inspect all suspension components, and repair all parts that are worn or damaged. Failure to do so may allow the problem to reoccur and cause premature failure of other suspension components.

ROAD TEST DIAGNOSIS

If possible, perform a road test of the vehicle with the owner of the vehicle. It is also helpful to have the owner drive the vehicle. While driving, try to determine when and where the noise or problem occurs, such as the following:

1. In cold or warm weather
2. With cold or warm engine/vehicle
3. While turning, left only, right only

A proper road test for any suspension system problem should include the following:

1. **Drive beside parked vehicles.** Any noise generated by the vehicle suspension or tires is reflected off solid objects, such as a row of parked vehicles along a street. For best results, drive with the windows down and drive close to parked vehicles or a retaining wall on the left side. Repeat the drive for the right side. Defective wheel bearings or power steering pumps usually make noise and can be heard during this test.
2. **Drive into driveways.** Suspension problems often occur when turning at the same time the suspension hits a bump. This action is best repeated by driving slowly into a driveway with a curb. The curb causes the suspension to compress while the wheels are turned (see the Real World Fix titled "The Rock-Hard Problem" for an example). Defective stabilizer bar bushings, control arm bushings, and ball joints will usually make noise during this test procedure.
3. **Drive in reverse while turning.** This technique is usually used to find possible defective outer CV joints used on the drive axle

TECH TIP

Road Test—Before and After

Many times technicians will start to work on a vehicle based on the description of the problem by the driver or owner. A typical conversation was overheard where the vehicle owner complained that the vehicle handled "funny," especially when turning. The owner wanted a wheel alignment, and the technician and shop owner wanted the business. The vehicle was aligned, but the problem was still present. The real problem was a defective tire. The service technician should have road-tested the vehicle *before* any service work was done to confirm the problem and try to determine its cause. Every technician should test drive the vehicle *after* any service work is performed to confirm that the service work was performed correctly and that the customer complaint has been resolved. This is especially true for any service work involving the steering, suspension, or braking systems.

shaft of front-wheel-drive vehicles. This technique also forces the suspension system to work in reverse of normal. Any excessive clearances in the suspension system are reversed and often make noise or cause a vibration during the test. Besides defective CV joints, this test can often detect worn control arm bushings, ball joints, stabilizer bar bushings, or links. This test can also detect defective or worn steering system components such as an idler arm, tie rod end, or center link.

4. **Drive over a bumpy road.** Worn or defective suspension (and steering) components can cause the vehicle to bounce or dart side to side while traveling over bumps and dips in the road. Worn or defective ball joints, control arm bushings, stabilizer bar bushings, stabilizer bar links, or worn shock absorbers can be the cause.

Once the problem has been confirmed, then a further inspection can be performed in the service bay.

DRY PARK TEST (SUSPENSION)

A **dry park test** can also be used to help locate worn or defective suspension components. The dry park test is performed by having an assistant move the steering wheel side to side while feeling and observing for any freeplay in the steering or suspension. For best results, the vehicle should be on a level floor or on a drive-on-type hoist with the front wheels pointing straight ahead. In this suspension analysis using the dry park test, the technician should observe the following for any noticeable play or unusual noise:

1. **Front wheel bearings.** Loose or defective wheel bearings are often overlooked as a possible cause of poor handling or darting vehicle performance.
2. **Control arm bushing wear or movement.** Check for any abnormal movement in upper control arm bushings or lower control arm bushings.
3. **Ball joint movement.** Check for any noticeable play or noise from both load-carrying and follower-type ball joints on both sides of the vehicle.

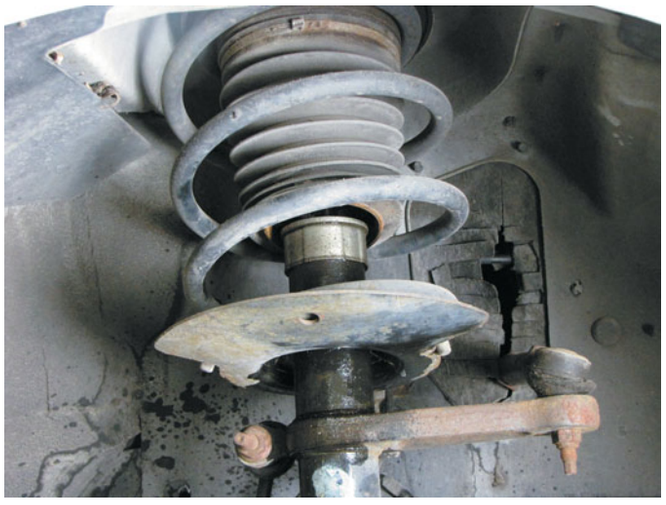


FIGURE 113–12 A leaking strut. Either a cartridge insert or the entire strut will require replacement. If a light film of oil is seen, this is to be considered normal. If oil is dripping, then this means that the rod seal has failed.

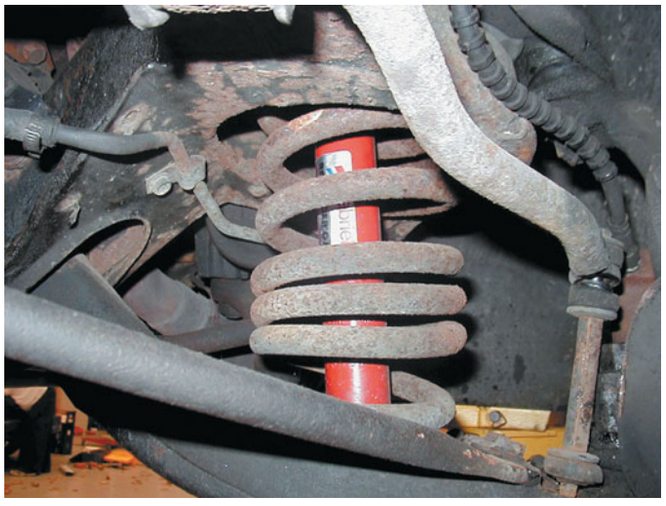


FIGURE 113–13 This front coil spring looks as if it has been heated with a torch in an attempt to lower the ride height of the vehicle. Both front springs will require replacement.

NOTE: The dry park test (and many other chassis system tests) relies on the experience of the technician to be able to judge normal wear from abnormal wear. It is extremely important that all beginning technicians work closely with an experienced technician to gain this knowledge.

VISUAL INSPECTION

All suspension components should be carefully inspected for signs of wear or damage. A thorough visual inspection should include checking all of the following:

1. Shock absorbers or struts. ● **SEE FIGURE 113–12.**
2. Springs. ● **SEE FIGURE 113–13.**
3. Stabilizer bar links



FIGURE 113–14 It is easy to see that this worn control arm bushing needed to be replaced. The new bushing is shown next to the original.

4. Stabilizer bar bushings
5. Upper and lower shock absorber mounting points
6. Bump stops
7. Body-to-chassis mounts
8. Engine and transmission (transaxle) mounts
9. Suspension arm bushings. ● **SEE FIGURE 113–14.**

Alignment equipment and procedures can often determine if a suspension component is bent or has been moved out of position. A careful *visual* inspection can often reveal suspected damaged components by observing scrape marks or rusty sections that could indicate contact with the road or another object.

While an assistant bounces the vehicle up and down, check to see if there is any freeplay in any of the suspension components.

BALL JOINTS

DIAGNOSIS AND INSPECTION The life of ball joints depends on driving conditions, vehicle weight, and lubrication. Even with proper care and lubrication, the load-carrying (weight-carrying) ball joints wear more than the follower ball joints. Ball joints should be replaced in pairs, both lower or both upper, to ensure the best handling.

Defective or worn ball joints can cause looseness in the suspension and the following common driver complaints:

1. Loud popping or squeaking whenever driving over curbs, such as into a driveway
2. Shimmy-type vibration felt in the steering wheel
3. Vehicle wander or a tendency not to track straight
4. Excessive freeplay in the steering wheel

A ball joint inspection should also be performed when an alignment is performed or as part of any other comprehensive vehicle inspection.

INDICATOR BALL JOINTS Many load-carrying ball joints have wear indicators with a raised area around the grease fitting, called **indicator ball joints.** ● **SEE FIGURES 113–15 AND 113–16.**

Always check wear-indicator-type ball joints with the wheels of the vehicle on the ground. If the raised area around the grease fitting is flush or recessed with the surrounding area, the ball joint is worn more than 0.050 in. and must be replaced.



FIGURE 113–15 Grease fitting projecting down from the surrounding area of a ball joint. The ball joint should be replaced when the area around the grease fitting is flush or recessed.

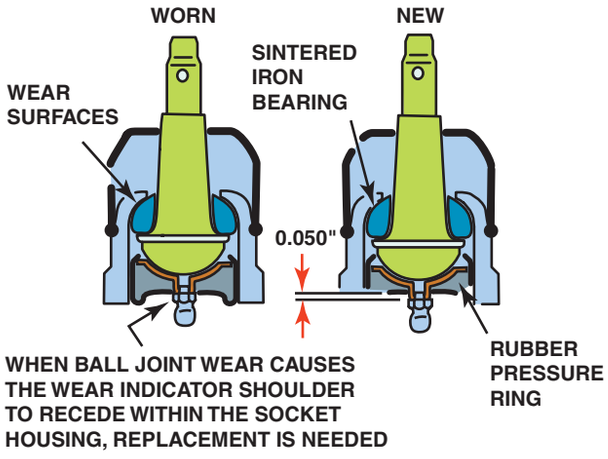


FIGURE 113–16 Indicator ball joints should be checked with the weight of the vehicle on the ground.

TECH TIP

Think of a Nickel

Most ball joints must be replaced if the joint has more than 0.050 in. axial (up-and-down) movement. To help visualize this distance, consider that the thickness of an American nickel coin is about 0.060 in. It is helpful to know that maximum wear should be less than the thickness of a nickel. A dial indicator (gauge) can be used to measure the exact movement of the ball joint so it can be compared to factory specifications. ● **SEE FIGURE 113–17.**

NON-INDICATOR BALL JOINT TESTING To perform a proper non-indicator-type ball joint inspection, the force of the vehicle's springs *must* be *unloaded* from the ball joint. If this force is not relieved, the force of the spring pushes the ball and socket joint tightly together and any wear due to movement will not be detected.

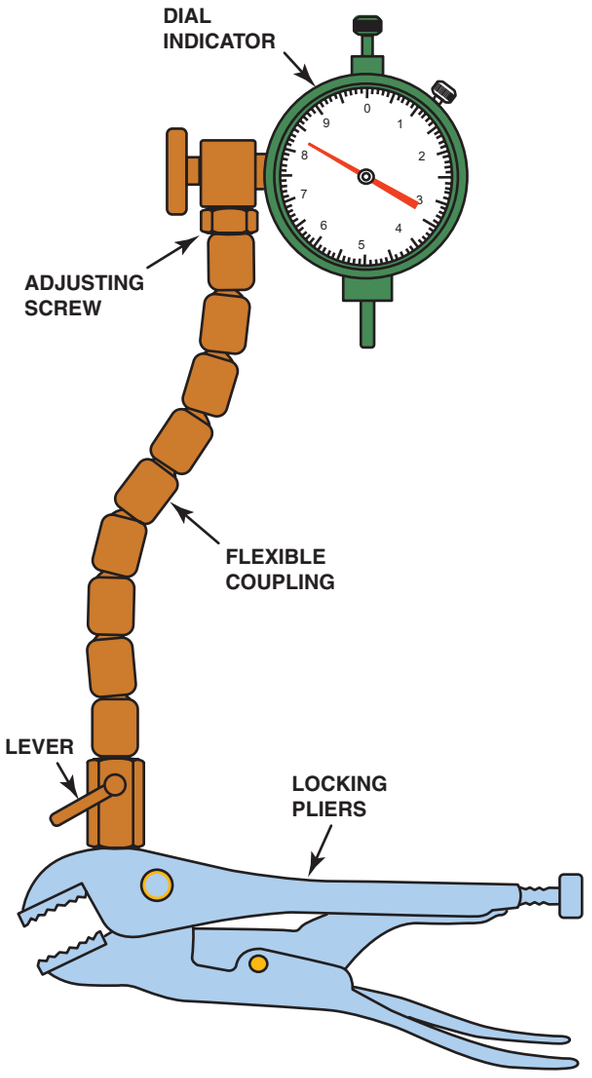


FIGURE 113–17 Typical dial indicator used to measure the suspension component movement. The locking pliers attach the gauge to a stationary part of the vehicle and the flexible coupling allows the dial indicator to be positioned at any angle.

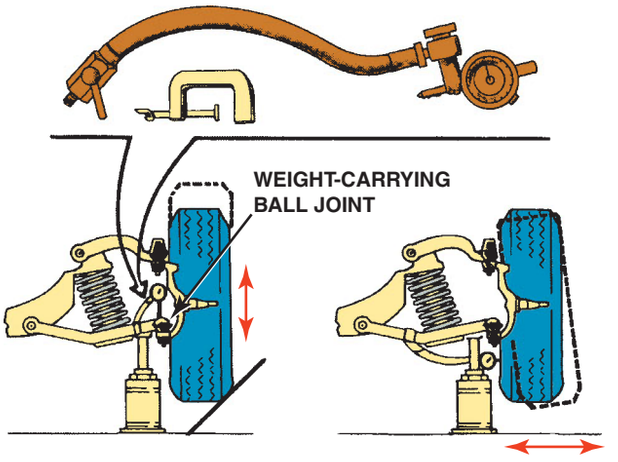


FIGURE 113–18 If the spring is attached to the lower control arm as in this SLA suspension, the jack should be placed under the lower control arm as shown. A dial indicator should be used to measure the amount of freeplay in the ball joints. Be sure that the looseness being measured is not due to normal wheel bearing endplay.

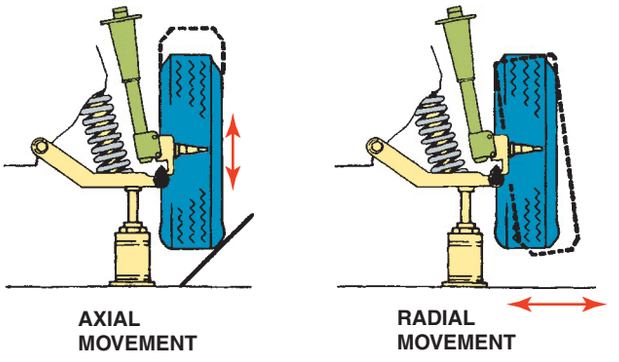


FIGURE 113–19 The jack should be placed under the lower control arm of this modified MacPherson-type suspension.

NOTE: The location of the load-carrying ball joint is closest to the seat of the spring or torsion bar.

If the coil spring or torsion bar is attached to the *lower* control arm, the *lower* ball joint is the load-carrying ball joint. ● **SEE FIGURE 113–18.** This includes vehicles equipped with modified MacPherson-strut-type suspension. ● **SEE FIGURE 113–19.**

1. Place the jack under the lower control arm as close to the ball joint as possible and raise the wheels approximately 1 to 2 in. (2.5 to 5 cm) off the ground to unload the lower ball joint.
2. Using a pry bar under the tire, lift the wheel up. If there is excessive vertical movement in the ball joint itself, it must be replaced. Most manufacturers specify a maximum vertical play of approximately 0.050 in. (1.3 mm), or the thickness of a nickel. Always check the manufacturer's specifications for exact maximum allowable movement. Vertical movement of a ball joint is often called axial play because the looseness is in the same axis as the ball joint stud. To check for *lateral* play, grip the tire at the top and bottom and move your hands in opposite directions.

NOTE: Be sure that the cause of any freeplay or looseness is not due to the wheel bearing. Closely observe the exact source of the freeplay movement.

If the coil spring is attached to the *upper* control arm, the *upper* ball joint is the load-carrying ball joint.

1. Place a block of wood (2 × 4 in.) between the upper control arm and the frame, or use a special tool designed for this purpose. ● **SEE FIGURE 113–20.**
2. Place the jack under the vehicle's *frame* and raise the wheel approximately 1 in. to 2 in. off the ground. (The wood block or special tool keeps the weight of the vehicle off the upper ball joint.)
3. Using a pry bar under the tire, lift the wheel. If there is excessive vertical movement in the ball joint itself, it must be replaced. Always check the manufacturer's specifications for exact maximum allowable movement.

Follower ball joints (friction ball joints) should also be inspected while testing load-carrying ball joints. Grasp the tire at the top and the bottom and attempt to shake the wheel assembly while looking directly at the follower ball joint. Generally, there should be no lateral or axial movement at all in the follower ball joint. However, some manufacturers specify a maximum of 0.250 in. (1/4 in. or 0.6 cm) measured at the top of the tire. Always check the manufacturer's specifications before condemning a ball joint because of excessive play.

MacPherson-strut-equipped vehicles do not have a load-carrying ball joint. The weight of the vehicle is carried through the upper strut mount and bearing assembly. ● **SEE FIGURE 113–21.**

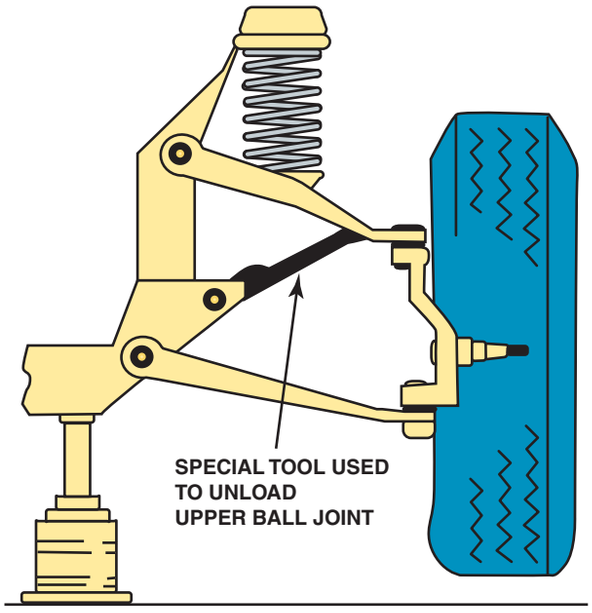


FIGURE 113–20 A special tool or a block of wood should be inserted between the frame and the upper control arm before lifting the vehicle off the ground. This tool stops the force of the spring against the upper ball joint so that a true test can be performed on the condition of the ball joint.

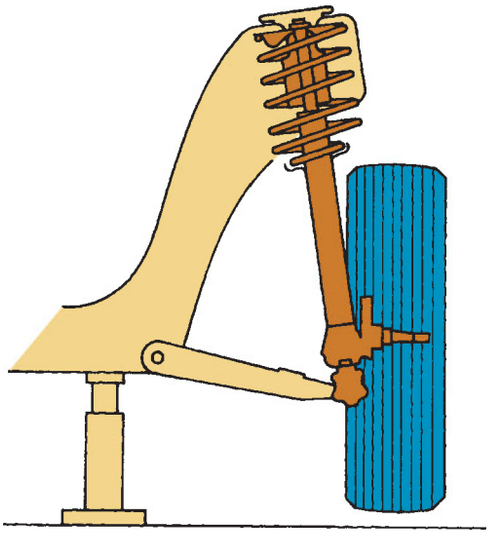


FIGURE 113–21 The jacking point is under the frame for checking the play of a lower ball joint used with a MacPherson strut.



FIGURE 113–22 This worn and rusty ball joint was found by moving the wheel and looking for movement in the joint.

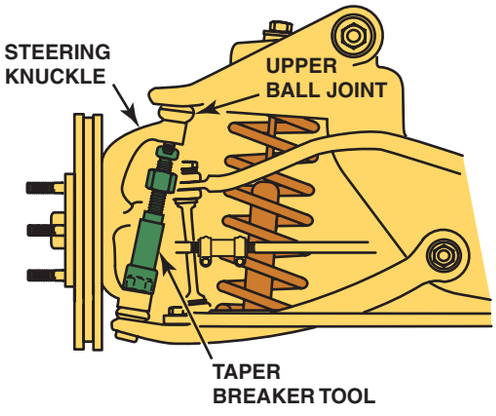


FIGURE 113–23 Taper breaker tool being used to separate the upper ball joint from the steering knuckle. This is especially important for vehicles equipped with aluminum alloy control arms.

FREQUENTLY ASKED QUESTION

What Is the Difference Between a Low-Friction Ball Joint and a Steel-on-Steel Ball Joint?

Before the late 1980s, most ball joints were constructed with a steel ball that rubbed on a steel socket. This design created friction and provided for a tight high-friction joint until wear caused looseness in the joint.

Newer designs use a polished steel ball that is installed in a hard plastic polymer, resulting in a low-friction joint assembly. Because of the difference in friction characteristics, the vehicle may handle differently than originally designed if incorrect-style ball joints are installed. Most component manufacturers state that low-friction ball joints in a vehicle originally equipped with steel-on-steel high-friction ball joints are usually acceptable, but high-friction replacement ball joints should be avoided on a vehicle originally equipped with low-friction ball joints.

After checking axial play in a ball joint, grasp the tire from the side at the top and bottom and alternately push and pull. *Any* lateral movement at the ball joint should generally be considered a good reason to replace the ball joints. ● **SEE FIGURE 113–22.**

BALL JOINT REMOVAL Take care to avoid damaging grease seals when separating ball joints from their mounts. *The preferred method to separate tapered parts is to use a puller-type tool that applies pressure to the tapered joint as the bolt is tightened on the puller.* ● **SEE FIGURE 113–23.**

Sometimes the shock of a hammer can be used to separate the ball joint from the steering knuckle. For best results, another hammer should be used as a backup while striking the joint to be separated on the side with a heavy hammer.

CAUTION: The use of tapered "pickle forks" should be avoided, unless the part is to be replaced, because they often damage the grease seal of the part being separated.

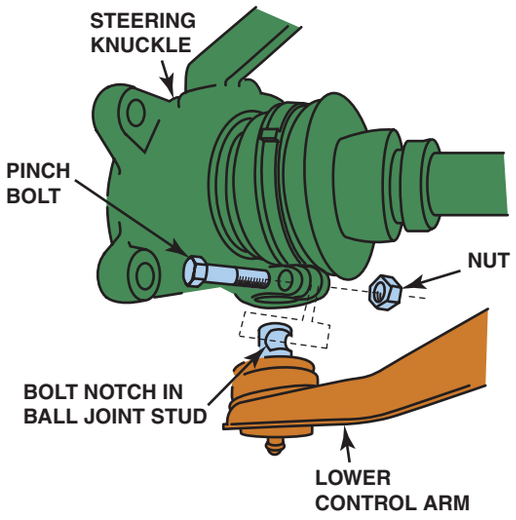


FIGURE 113–24 A pinch bolt attaches the steering knuckle to the ball joint. Remove the pinch bolt by turning the nut, not the bolt.

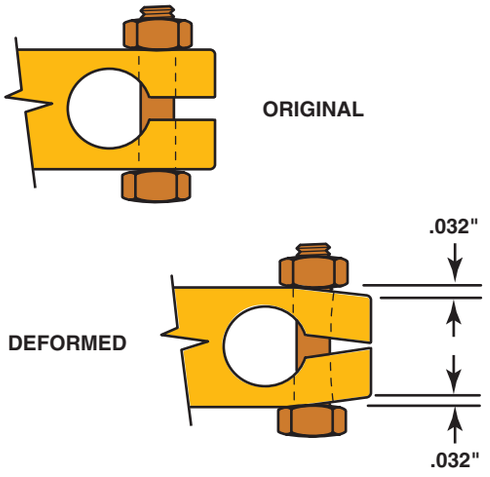


FIGURE 113–25 If the pinch bolt is overtightened, the steering knuckle can be deformed. A deformed knuckle can cause the pinch bolt to break and the ball joint could become separated from the steering knuckle.

PINCH BOLT BALL JOINTS Some ball joint studs have a slot or groove where a **pinch bolt** is used to hold the ball joint to the steering knuckle. ● **SEE FIGURE 113–24.** Use penetrating oil in the steering knuckle groove and rotate the knuckle several times. Do not use a hammer on the pinch bolt because this can cause damage to the bolt and the ball joint. Do not widen the slot in the steering knuckle. Once separated, check the shape of the steering knuckle. ● **SEE FIGURE 113–25.** If the pinch bolt has been deformed by overtightening, the steering knuckle should be replaced.

RIVETED BALL JOINTS When removing ball joints that are riveted in place, always cut off or drill rivet heads before separating the ball joint from the spindle. This provides a more solid base to assist in removing rivets. *The preferred method to remove rivets from ball joints is to center punch and drill out the center of the rivet before using a drill or an air-powered chisel to remove the rivet heads.* Be careful not to drill or chisel into the control arms. ● **SEE FIGURES 113–26 THROUGH 113–28.**

Press-in-type ball joints are removed and installed using a special C-clamp-type tool. ● **SEE FIGURE 113–29.**

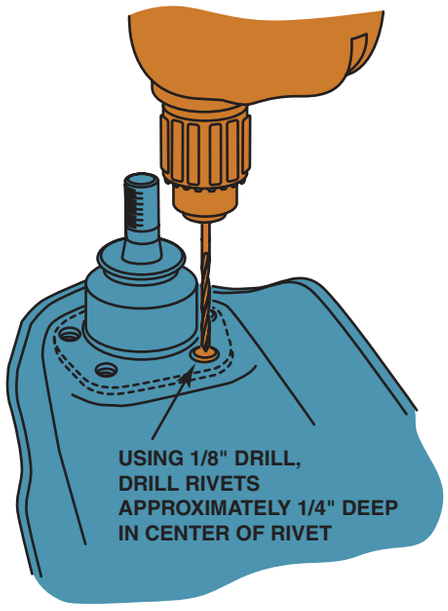


FIGURE 113–26 By drilling into the rivet, the holding force is released.



FIGURE 113–27 The head of the rivet can be removed by using a larger-diameter drill bit as shown.

NOTE: Many replacement press-in-type ball joints are slightly larger in diameter—about 0.050 in. (1.3 mm)—than the original ball joint to provide the same press fit. If the ball joints have been replaced before, then the control arm must be replaced.

Avoid using heat to remove suspension or steering components. Many chassis parts use rubber and plastic that can be damaged if heated with a torch. *If heat is used to remove a part, it must be replaced.* For best results, try soaking with a penetrating oil and use the proper tools and procedures as specified by the manufacturer.

NON-REPLACEABLE BALL JOINTS Many vehicles are equipped with nonreplaceable ball joints, and the entire control arm must be replaced if the ball joint is worn or defective.

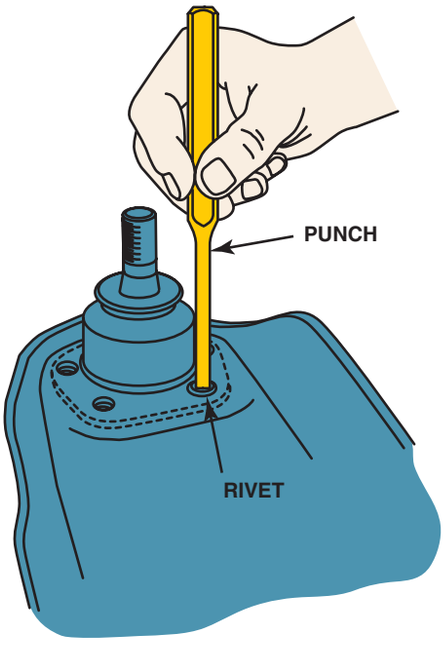


FIGURE 113–28 Using a punch and a hammer to remove the rivet after drilling down through the center and removing the head of the rivet.

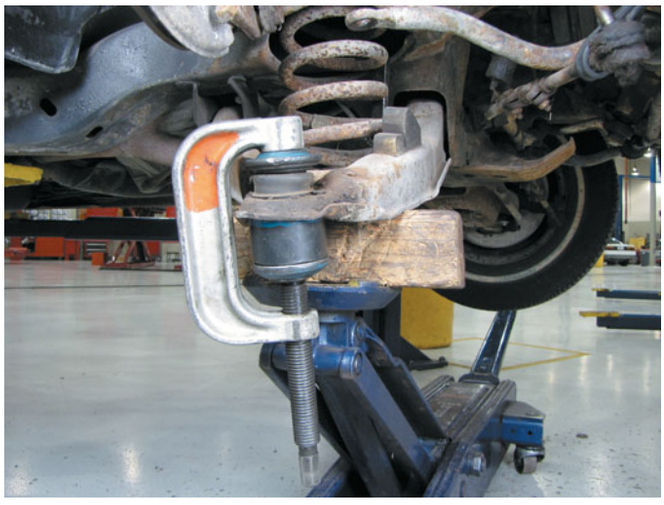


FIGURE 113–29 Press-in ball joints are best removed using a large C-clamp press, as shown.

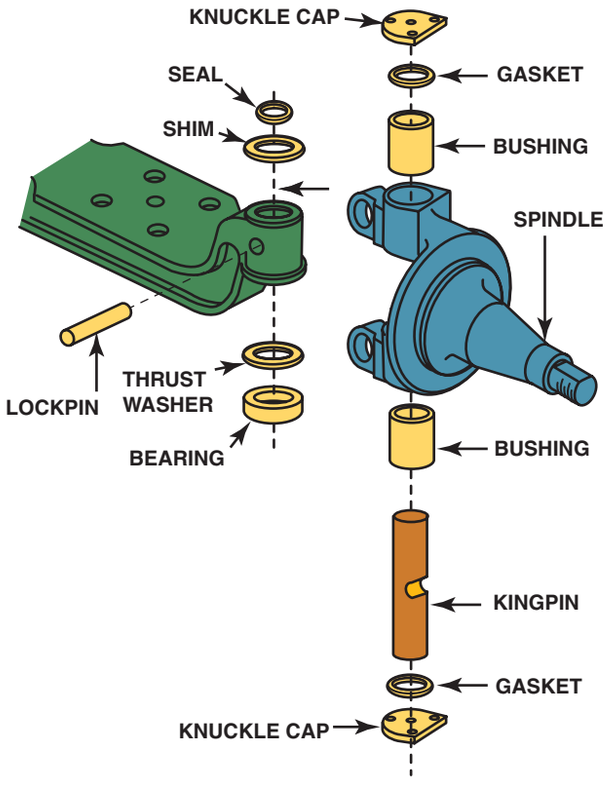


FIGURE 113–30 Typical kingpin assembly.

REAL WORLD FIX

The Rattle Story

A customer complained that a rattle was heard every time the vehicle hit a bump. The noise sounded as if it came from the rear. All parts of the exhaust system and suspension system were checked. Everything seemed okay until the vehicle was raised with a frame-type hoist instead of a drive-on type. Then, whenever the right rear wheel was lifted, the noise occurred. The problem was a worn (elongated) shock absorber mounting hole. A washer with the proper-size hole was welded over the worn lower frame mount and the shock absorber was bolted back into place.

CAUTION: Always follow manufacturers' recommended installation instructions whenever replacing any suspension or other chassis component part. Tie rod ends and ball joints use a taper to provide the attachment to other components. Whenever a nut is used to tighten a tapered part, it is important not to back off (loosen) the nut after tightening. As the nut is being tightened, the taper is being pulled into the taper of the adjoining part. The specified torque on the nut ensures that the two pieces of the taper are properly joined. If the cotter key does not line up with the hole in the tapered stud when the nut has been properly torqued, tighten it more to line up a hole—never loosen the nut.

KINGPIN DIAGNOSIS AND SERVICE

DIAGNOSIS Kingpins are usually used on trucks, and other heavy-duty vehicles. ● **SEE FIGURE 113–30.**

Kingpins are designed to rotate inside kingpin bushings with a clearance between them of approximately 0.001 to 0.003 in. (0.025 to 0.075 mm). As wear occurs, this clearance distance increases and the kingpin becomes loose. Looseness in the kingpin causes looseness in the wheels and steering. *Kingpins can also gall or seize due to lack of lubrication, resulting in very hard steering.*

After supporting the vehicle safely off the ground, inspect for looseness by positioning a dial gauge (indicator) on the extreme inside bottom of the edge of the wheel and rock the tire. If the dial indicator registers more than 1/4 inch (6 mm), replace the kingpin and/or kingpin bushings.

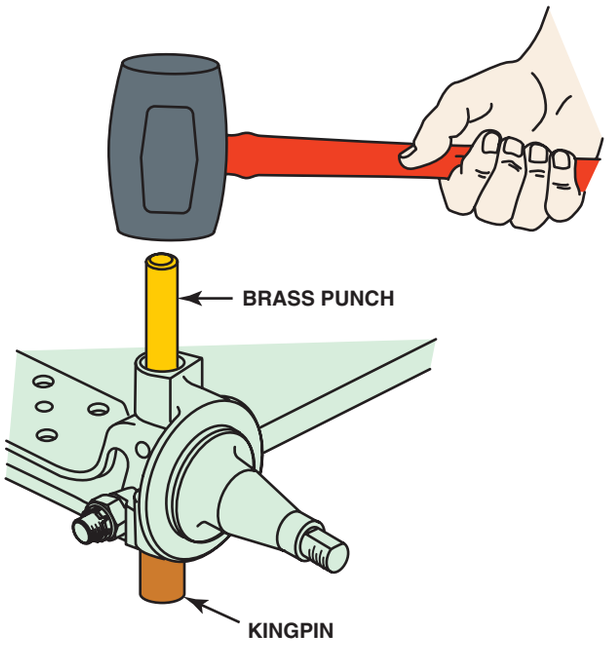


FIGURE 113–31 Driving a kingpin out with a hammer.

KING PIN REPLACEMENT To remove a typical kingpin, follow these basic steps:

STEP 1 Remove the tire, brake drum, and backing plate or caliper.

STEP 2 Remove the lockpin. The lockpin is usually tapered with a threaded end for the nut. Drive the lockpin out with a drift (punch).

STEP 3 Remove the grease caps and drive the kingpin from the steering knuckle and axle with a hammer and a brass punch or a hydraulic press, if necessary. ● **SEE FIGURE 113–31.**

To replace the kingpin bushings and/or kingpin, refer to the manufacturer's procedure and specifications. ● **SEE FIGURE 113–32.**

Some bronze bushings must be sized by reaming or honing to provide from 0.001 to 0.003 in. (0.025 to 0.075 mm) clearance between the kingpin and the bushing.

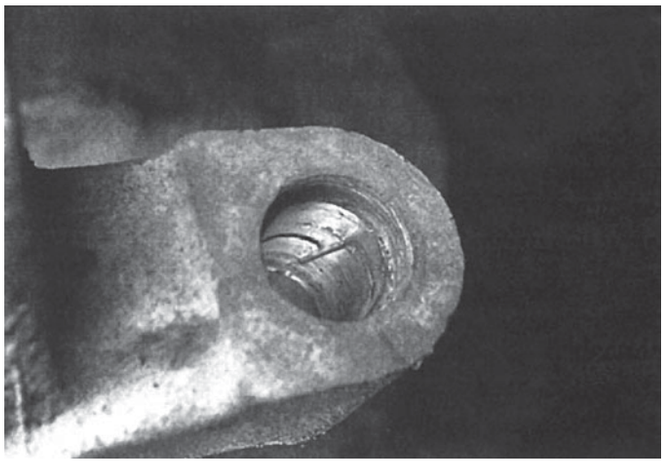


FIGURE 113–32 This galled kingpin bushing must be replaced.

TECH TIP

The Shock Stud Trick

Front shock absorbers used on many rear-wheel-drive vehicles equipped with an SLA-type front suspension are often difficult to remove because the attaching nut is rusted to the upper shock stub. A common trick is to use a deep-well 9/16-in. socket and a long extension and repeatedly bend the shock stud until it breaks off. At first you would think that this method causes harm, and it does ruin the shock absorber—but the shock absorber is not going to be reused and will be discarded anyway.

The usual procedure followed by many technicians is to simply take a minute or two to break off the upper shock stud, then hoist the vehicle to allow access to the lower two shock bolts, and then the shock can easily be removed. To install the replacement shock absorber, attach the lower bolts, lower the vehicle, and attach the upper rubber bushings and retaining nut.

SHOCK ABSORBERS AND STRUTS

DIAGNOSIS Shock absorber life depends on how and where the vehicle is driven. Original equipment (OE) shock absorbers are carefully matched to the vehicle springs and bushings to provide the best ride comfort and control. As the control arm bushings and ball joints age, the energy built up in the springs of the vehicle is controlled less by the friction of these joints and bushings, requiring more control from the shock absorbers. Shock absorber action is also reduced as the seals inside wear. Replacement shock absorbers may be required when any or all of the following symptoms appear:

1. **Ride harshness.** As the effectiveness of the shock absorber decreases, the rapid forces of the springs are not as dampened or controlled. Worn shocks can cause ride harshness and yet not cause the vehicle to bounce after hitting a bump.
2. **Frequent bottoming out on rough roads.** Shock absorbers provide a controlled movement of the axle whenever the vehicle hits a bump or dip in the road. As fluid is lost or wear occurs, the shock absorber becomes weaker and cannot resist the forces acting on the axle. The worn shock absorber can allow the spring to compress enough so that the axle contacts the jounce bumper (bump stop) on the body or frame of the vehicle.

NOTE: Frequent bottoming out is also a symptom of reduced ride height due to sagging springs. Before replacing the shock absorbers, always check for proper ride height as specified in the vehicle service manual or any alignment specification booklet available from suppliers or companies of alignment or chassis parts and equipment.

3. **Extended vehicle movement after driving on dips or a rise in the road.** The most common shock absorber test is the bounce test. Push down on the body of the vehicle and let go; the vehicle should return to its normal ride height and stop. Worn shock absorbers can cause poor driver control due to excessive up-and-down suspension movements. If the vehicle

continues to bounce two or three times, then the shocks or struts are worn and must be replaced.

4. **Cupped-type tire wear.** Defective shock absorbers can cause **cupped tire wear.** This type of tire wear is caused by the tire's bouncing up and down as it rotates.
5. **Leaking hydraulic oil.** When a shock or strut leaks oil externally, this indicates a defective seal. The shock absorber or strut cannot function correctly when low on oil inside.
6. **Springs and shock absorbers should be replaced in pairs.** Both front or both rear shocks should be replaced together to provide the best handling and control.

NOTE: Shock absorbers do not affect ride height except where special air shocks or coil overload carrying shocks are used. If a vehicle is sagging on one side or in the front or the rear, the springs should be checked and replaced if necessary.

Shock absorbers are filled with fluid and sealed during production. They are not refillable; if worn, damaged, or leaking, they must be replaced. A slight amount of fluid may bleed by the rod seal in cold weather and deposit a light film on the upper area of the shock absorber. This condition will not hurt the operation of the shock and should be considered normal. If noisy when driving, always check the tightness and condition of all shock absorber mounts.

Replacement shock absorbers and/or struts should match the original equipment unit in physical size.

FRONT SHOCK REPLACEMENT

Front shock absorbers provide ride control and are usually attached to the lower control arm by bolts and nuts. The upper portion of the shock usually extends through the spring housing and is attached to the frame of the vehicle with rubber grommets to help insulate noise, vibration, and harshness.

Most front shock absorbers can be replaced either with the vehicle still on the ground or while on a hoist. The front suspension of most vehicles allows the removal of the shocks without the need to support the downward travel of the lower control arm. The downward travel limit is stopped by a rubber stop or by the physical limit of the suspension arms.

Special sockets and other tools are available to remove the nut from the shocks that use a single mounting stem. The removal of the lower mounting of most front shock absorbers usually involves the removal of two bolts. After removal of the attaching hardware, the shock absorber is simply pulled through the front control arm. ● **SEE FIGURE 113–33.**

Reverse the removal procedure to install replacement shock absorbers. Always consult the manufacturer's recommended procedures and fastener tightening torque.

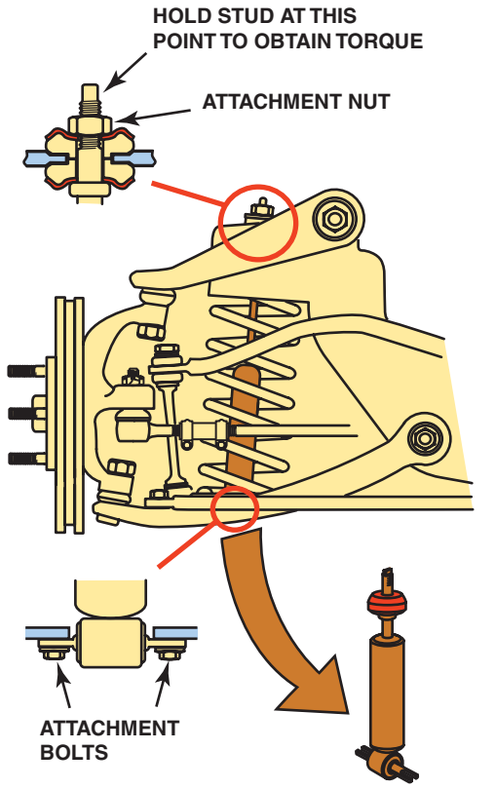


FIGURE 113–33 Most shock absorbers used on the front suspension can be removed from underneath the vehicle after removing the attaching bolts or nuts.

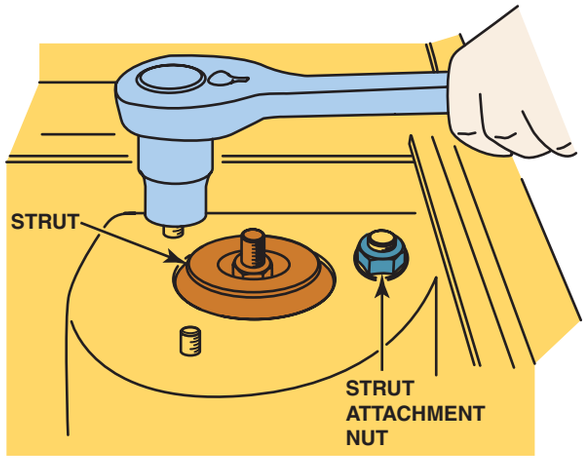


FIGURE 113–34 Removing the upper strut mounting bolts. Some experts recommend leaving one of the upper strut mount nuts loosely attached to prevent the strut from falling when the lower attaching bolts are removed.

MACPHERSON STRUT REPLACEMENT

On most vehicles equipped with MacPherson strut suspensions, strut replacement involves the following steps.

CAUTION: Always follow the manufacturer's recommended methods and procedures whenever replacing a MacPherson strut assembly or component.

1. Hoist the vehicle, remove the wheels, and mark the attaching bolts/nuts.
2. Remove the upper strut mounting bolts except for one to hold the strut until ready to remove the strut assembly. ● **SEE FIGURE 113–34.**
3. Remove the brake caliper or brake hose from the strut housing. ● **SEE FIGURE 113–35.**
4. After removing all lower attaching bolts, remove the final upper strut bolt and remove the strut assembly from the vehicle. Place the strut assembly into a strut spring compressor fixture or use manual spring compressors as shown in ● **FIGURE 113–36.**

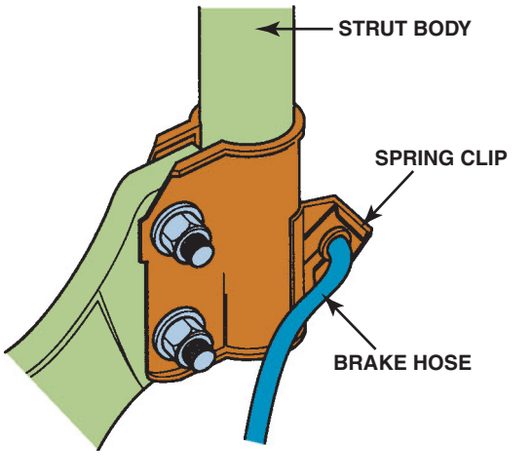


FIGURE 113–35 A brake hydraulic hose is often attached to the strut housing. Sometimes all that is required to separate the line from the strut is to remove a spring clip.



FIGURE 113–36 Use a strut spring compressor fixture to compress the spring on a MacPherson strut before removing the strut retaining nut.

5. Mark the relationship of the coil spring to the strut before removing. This step helps insure that the assembly will be reassembled correctly.
6. Compress the coil spring enough to relieve the tension on the strut rod nut. Remove the strut rod nut as shown in ● **FIGURE 113–37**.
7. After removing the strut rod nut, remove the upper strut bearing assembly and the spring. ● **SEE FIGURE 113–38**.

NOTE: The bearing assembly should be carefully inspected and replaced if necessary. Some automotive experts recommend replacing the bearing assembly whenever the strut is replaced.

8. Many MacPherson struts are replaced as an entire unit assembly. Other struts can have the cartridge inside the housing replaced. The cartridge is installed after removing the gland nut at the top of the strut tube and removing the original strut rod, valves, and hydraulic oil. Always replace the cartridge assembly per the manufacturer's recommended procedure. ● **SEE FIGURES 113–39, 113–40, AND 113–41**.
9. Reinstall the strut in the vehicle.

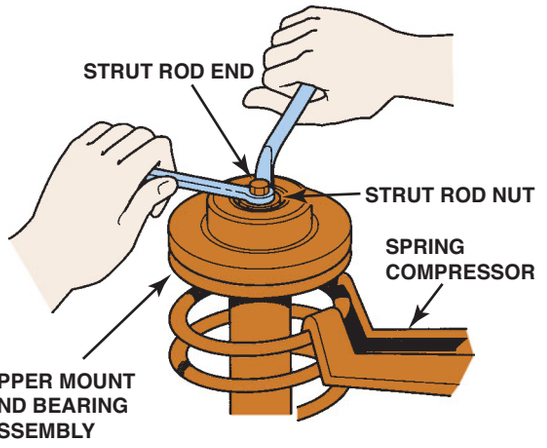


FIGURE 113–37 Removing the strut rod nut. The strut shaft is being helped with one wrench while the nut is being removed with the other wrench. Notice that the spring is compressed before the nut is removed.

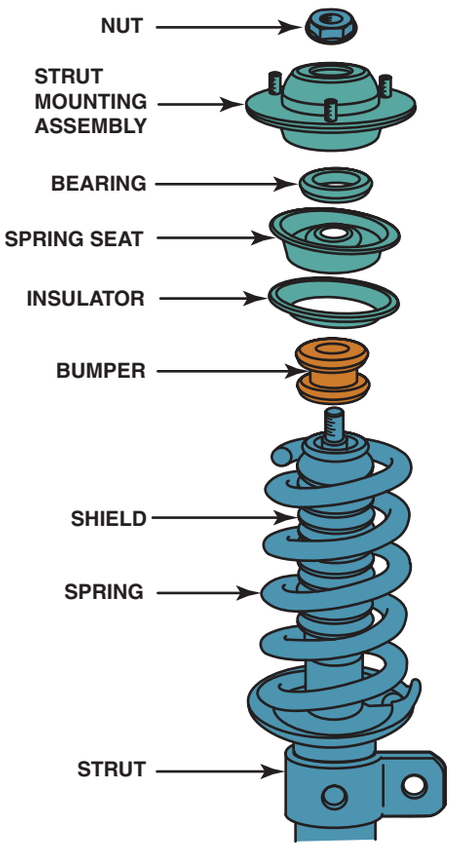


FIGURE 113–38 Typical MacPherson strut showing the various components.

CAUTION: Many GM front-wheel-drive vehicles use a MacPherson strut with a large-diameter spring seat area. GM chassis engineers call this a cow catcher design. If the coil spring breaks, the extra-large cow catcher will prevent the end of the broken spring from moving outward where it could puncture a tire and possibly cause an accident. Always use a replacement strut that has this feature.

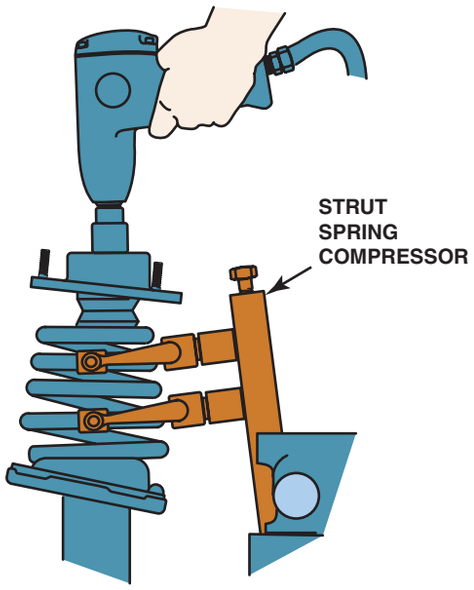


FIGURE 113–39 After installing the replacement strut cartridge, reinstall the spring and upper bearing assembly after compressing the spring. Notice that the strut is being held in a strut spring compressor fixture.

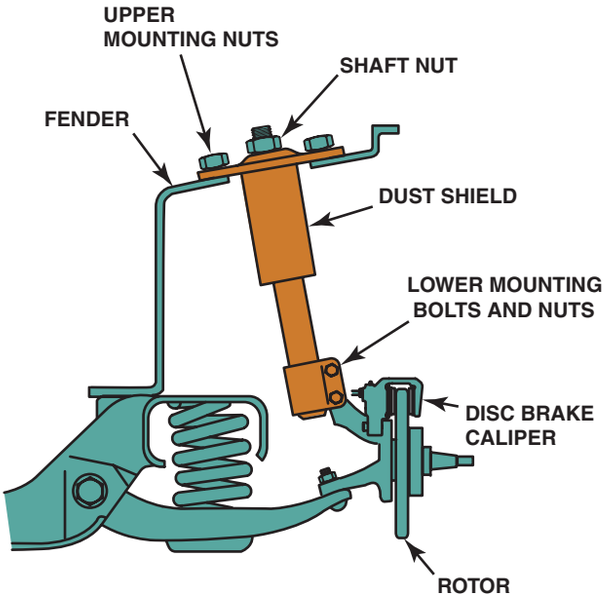


FIGURE 113–41 The strut on a modified MacPherson strut assembly can be replaced by removing the upper mounting nuts.

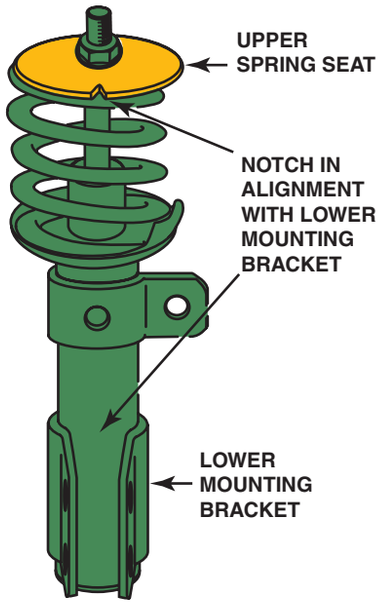


FIGURE 113–40 Before final assembly, make sure the marks you made are aligned. Some struts are manufactured with marks to ensure proper reassembly.

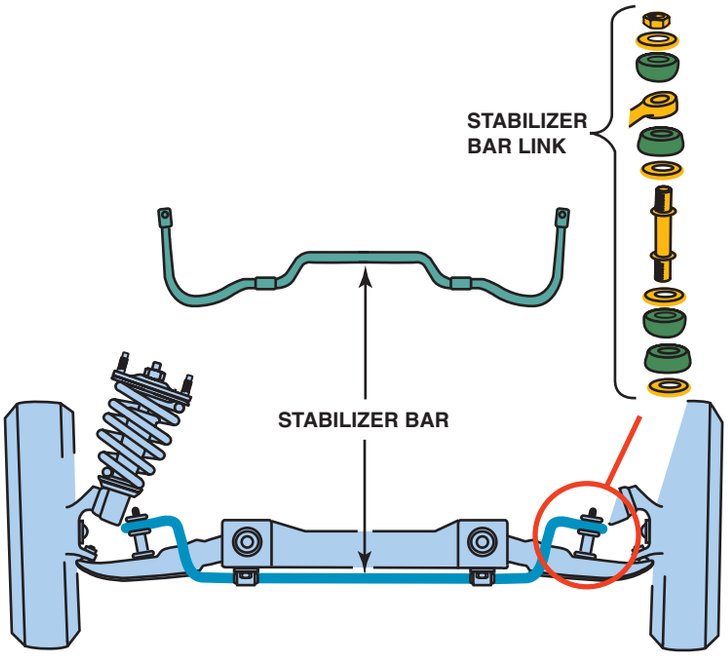


FIGURE 113–42 Stabilizer bar links should be replaced as a pair.

STABILIZER BAR LINK AND BUSHING SERVICE

DIAGNOSIS Stabilizer bars twist whenever a vehicle turns a corner or whenever one side of the vehicle rises or lowers. The more the body of the vehicle leans, the more the bar twists, and the more the bar counteracts the roll of the body. A great deal of force is transferred from the stabilizer bar to the body or frame of the vehicle through the stabilizer links at the control arm and the stabilizer bar mounting bushings on the body or frame. *The most common symptom of defective stabilizer bar links or bushings is noise while turning, especially over curbs.* When driving up and over a curb at an angle, one wheel is pushed upward. Since the stabilizer bar connects both wheels, the bar tends to resist this motion by twisting. If one or both links are broken, a loud knock or clanking sound is heard as the bar contacts the control arm. Any sound heard when driving should be investigated and the cause determined by a thorough visual inspection.

REPLACEMENT Stabilizer links are usually purchased as a kit consisting of replacement rubber bushings, retainers, a long bolt, and spacer with a nut and lock nut. General Motors recommends that stabilizer links be replaced in pairs and two kits purchased so that the links on both the left and the right can be replaced at the same time. ● **SEE FIGURE 113–42.**

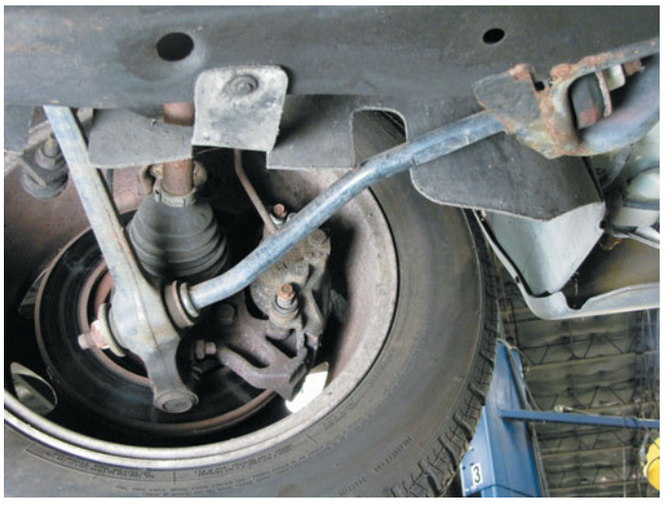


FIGURE 113–43 A strut rod as viewed from the front of the vehicle.

Stabilizer links are replaced by simply unbolting the old parts and installing replacement parts. Special precautions are usually not necessary, but, as always, consult a service manual for the exact recommended procedure and fastener torque.

If the mounting bushings (also called isolator bushings) on the body or frame are worn or defective, a loud squeaking or knocking sound is usually heard.

Stabilizer bar bushings often fail because the rubber has deteriorated from engine oil or other fluid leaks. Before replacing defective bushings, make certain that all other fluid leaks are stopped. Stabilizer bar bushing replacement involves the removal (unbolting) of the bushing retainers that surround the bushing and attach to the vehicle body or frame. The bushings are usually split so that they can be easily removed and replaced on the stabilizer bar and can slide into proper position. Reinstall the bushing retainer bolts and tighten to the specified torque.

STRUT ROD BUSHINGS

DIAGNOSIS Strut rods are used on the front suspension of many front-wheel-drive and rear-wheel-drive vehicles. As with any rubber suspension component, strut rod bushings can deteriorate and crack. When strut rod bushings fail, the lower control arm can move forward and backward during braking or when hitting bumps in the road.

Since the lower control arm position is important to vehicle control, when the bushing fails, a pulling or drifting of the vehicle often occurs. *A common symptom of a defective strut rod bushing is noise and a pull toward one side while braking.*

REPLACEMENT To replace a strut rod bushing, the nut on the end of the strut rod has to be removed. ● **SEE FIGURE 113–43.** As the nut is being removed, the lower control arm is likely to move forward or backward, depending on the location of the strut rod frame mount. After removing the strut rod nut, remove the one or two fasteners that retain the strut rod to the lower control arm. The strut rod can now be removed from the vehicle and the replacement rubber bushings can be installed. Install the strut rod in the reverse order of installation. Most bushings use a serrated spacer to maintain the proper force on the rubber bushings; this prevents the technician from compressing the rubber bushing when the strut rod nut is tightened. ● **SEE FIGURE 113–44.**

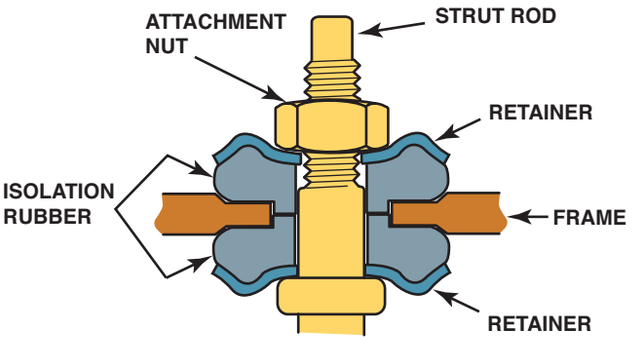


FIGURE 113–44 Typical strut rod bushing with rubber on both sides of the frame to help isolate noise, vibration, and harshness from being transferred to the passengers.

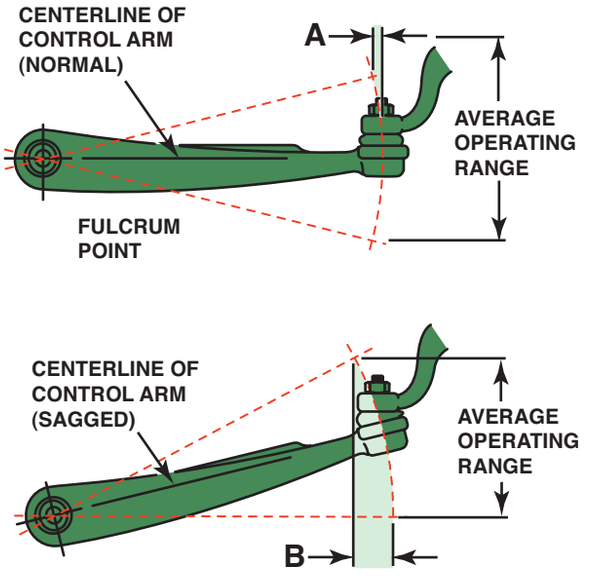


FIGURE 113–45 Notice that if the front coil springs are sagging, the resulting angle of the lower control arm causes the wheels to move from side to side as the suspension moves up and down. Note the difference between the distance at "A" with good springs and the distance at "B" with sagging springs.

CAUTION: Some suspension bushings are directional and must be installed according to the vehicle manufacturer's instructions. For example, on some vehicles, the bushings have a slit or void which must face the front of the vehicle. Always check service information when installing new bushings.

FRONT COIL SPRINGS

DIAGNOSIS Coil springs should be replaced in pairs if the vehicle ride height is lower than specifications. Sagging springs can cause the tires to slide laterally (side to side) across the pavement, causing excessive tire wear. ● **SEE FIGURE 113–45.** Sagging springs can also cause the vehicle to bottom out against the suspension bumpers when traveling over normal bumps and dips in the road.

If a vehicle is overloaded, the springs of the vehicle can *take a set* and not recover to the proper ride height. This commonly occurs with all types of vehicles whenever a heavy load is carried, even on a short trip.



FIGURE 113–46 Spring compressing tool in place to hold the spring as the ball joint is separated. Note that the stabilizer bar links have been removed to allow the lower control arm to move downward enough to remove the coil spring.

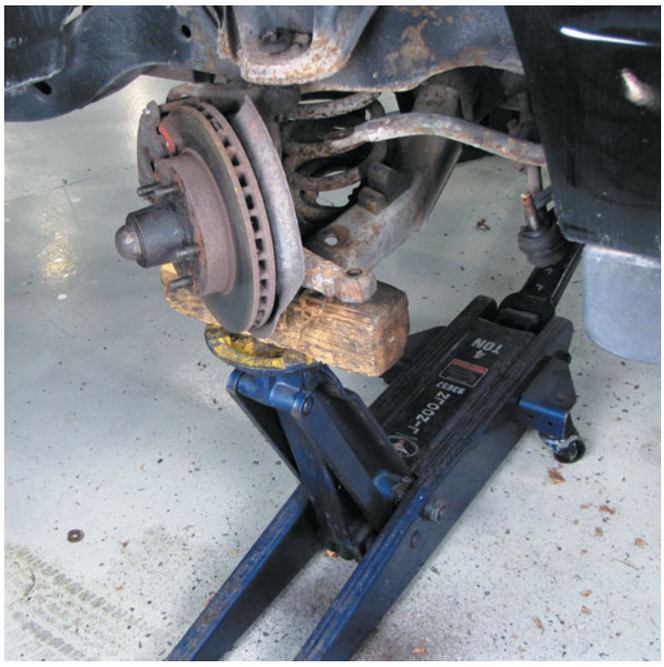


FIGURE 113–47 The steering knuckle has been disconnected from the lower ball joint. The lower control arm and coil spring are being held up by a floor jack.

It is normal for the rear of a vehicle to sag when a heavy load is carried, but it can permanently damage the spring by exceeding the yield point of the steel spring material.

REPLACEMENT The only solution recommended by the vehicle manufacturer is to replace the damaged springs in pairs (both front and both rear, or all four). Several aftermarket alternatives include the following:

- **Helper or auxiliary leaf springs.** These helper springs are usually designed to increase the load-carrying capacity of leaf springs or to restore the original ride height to sagging springs.
- **Spring inserts for coil springs.** Hard rubber or metal spacers are *not recommended* because they create concentrated pressure points on the coils that can cause the spring to break. Hard rubber stabilizers that bridge the gap between two coils without raising the ride height stiffen the ride by locking two coils together. With two coils connected, the spring rate increases and the spring becomes stiffer.
- **Air shocks or airbag devices.** Air shocks or airbags are generally used to restore or increase the load-carrying capacity to the rear of the vehicle. While these devices do allow the ride height to be maintained, the extra load is still being supported by the tires and rear axle bearings. Caution should be used not to overload the basic chassis or powertrain of the vehicle.

There are two designs for vehicles that use coil springs. The most commonly used design places the coil spring between the vehicle frame and the lower control arm.

Both front-suspension designs require that the front shock absorbers be removed in order to replace the coil springs. This first step in the coil spring removal procedure can be performed on the ground or on any type of hoist. After removing the shock absorber, use a coil spring compressor and install it through the center of the coil spring. ● **SEE FIGURE 113–46.** Hook the arms of the coil spring compressor over the rungs of the coil spring and rotate the adjusting nut on the spring compressor with a wrench to shorten the spring. Coil spring clips or the use of a floor jack can also be used to retain the coil spring.

CAUTION: When compressed, all springs contain a great deal of stored energy. If a compressed spring were to become disconnected from its spring compressor or clips, it could be projected outward with enough force to cause injury or death.

After the coil spring is compressed and retained, the control arm can be separated from the steering knuckle and the coil spring can be removed as shown in ● **FIGURES 113–47 AND 113–48.**

Replacement springs should be compressed and installed using the reverse procedure.

NOTE: Many automotive experts recommend that new coil insulators be installed every time the coil springs are replaced.

Make sure that the spring is positioned correctly in the control arm and that the spring insulators are installed correctly. ● **SEE FIGURE 113–49.** Most control arms use two holes for the purpose of coil spring seating. The end of the spring should cover one hole completely and partially cover the second hole. ● **SEE FIGURE 113–50.**

STEERING KNUCKLES

DIAGNOSIS Most steering knuckles are constructed of cast or forged cast iron. The steering knuckle usually incorporates the wheel spindle and steering arm. The steering knuckle/steering arm can become bent if the vehicle is in an accident or hits a curb sideways. Often this type of damage is not apparent until vehicle handling or excessive



FIGURE 113–48 A rubber mallet is being used to support the upper control arm as the lower control is being lowered using a floor jack. After all of the tension has been removed from the coil spring it can be removed and the replacement installed.



FIGURE 113–50 The holes in the lower arm are not only used to allow water to drain from the spring seat, but also are used as a gauge to show the service technician that the coil spring is correctly seated.

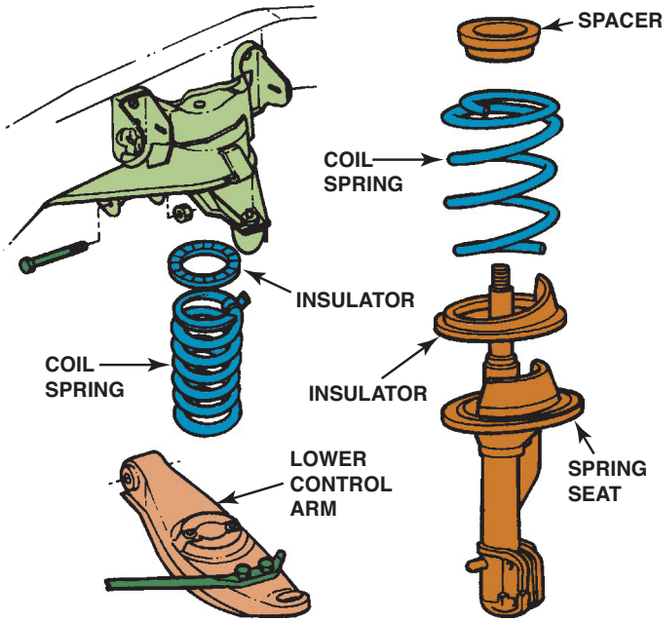


FIGURE 113–49 Spring insulators install between the spring seat and the coil spring to reduce noise.

tire wear is noticed. Unless a thorough inspection is performed during a wheel alignment, a bent steering knuckle is often overlooked.

REPLACEMENT If the steering knuckle is bent or damaged, it must be replaced. It should *not* be bent back into shape or repaired. To replace the steering knuckle, the ball joint(s) must be disconnected from the knuckle and the brake components removed. Be sure to support the control arm and spring properly during the procedure. See a factory service manual for the exact procedure and fastener torque for the vehicle you are servicing.

TORSION BARS

ADJUSTMENT Most torsion bar suspensions are designed with an adjustable bolt to permit the tension on the torsion bar to be increased or decreased to change the ride height. Unequal side-to-side ride height can be corrected by adjusting (turning) the torsion bar tension bolt. ● **SEE FIGURE 113–51.**

Torsion bar adjustment should be made if the difference in ride height from one side to another exceeds 1/8 in. (0.125 in. or 3.2 mm). If the ride height difference side to side is greater than 1/8 in., the vehicle will tend to wander or be unstable, with constant steering wheel movements required to maintain straight-ahead direction.

TORSION BAR REPLACEMENT Torsion bars do not need to be replaced as part of regular service. If the vehicle height is lower than specified, the adjustment bolt can be rotated to restore proper suspension height. The torsion bar can be removed to gain access to parts of the vehicle or to replace a torsion bar damaged in a collision. To replace a torsion bar, check service information for the

REAL WORLD FIX

The Rock-Hard Problem

The owner of a six-month-old full-size pickup truck complained that occasionally when the truck was driven up into a driveway, a loud grinding sound was heard. Several service technicians worked on the truck, trying to find the cause for the noise. After the left front shock absorber was replaced, the noise did not occur for two weeks, and then started again. Finally, the service manager told the technician to replace anything and everything in the front suspension in an attempt to solve the customer's intermittent problem. Five minutes later, a technician handed the service manager a small, deformed rock. This technician had taken a few minutes to *carefully* inspect the entire front suspension. Around the bottom coil spring seat, the technician found the rock. Apparently, when the truck made a turn over a bump, the rock was forced between the coils of the coil spring, making a very loud grinding noise. But the rock did not always get between the coils. Therefore, the problem occurred only once in a while. The technician handed the rock to the very happy customer.

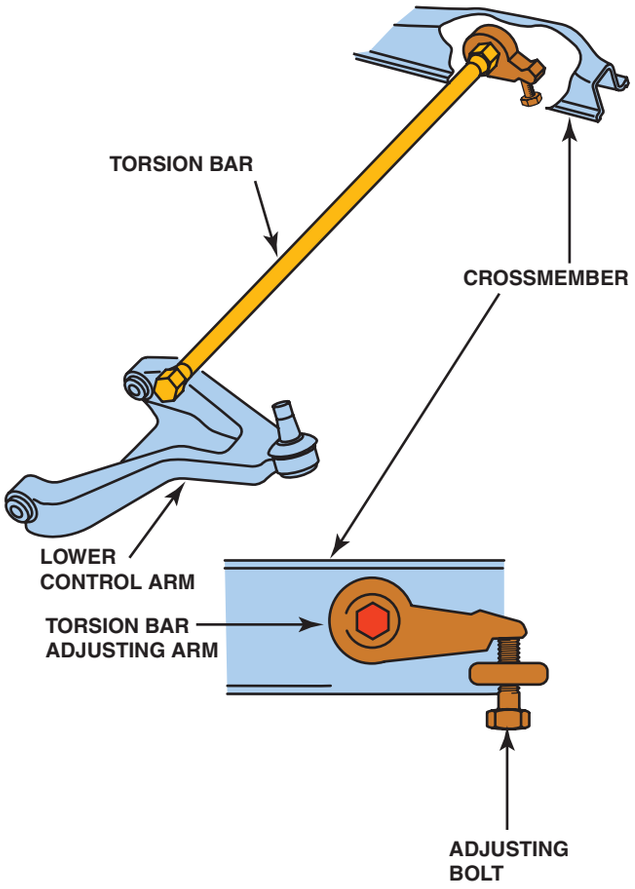


FIGURE 113–51 By rotating the adjusting bolt, the vehicle can be raised or lowered.

exact procedure to follow. Most published procedures include the following steps:

STEP 1 Hoist the vehicle safely.

STEP 2 Attach a holding fixture or large "C" clamp to the torsion bar adjusting arm. Check service information for the exact procedure and locations.

STEP 3 Loosen the torsion bar adjusting bolt until all of the tension has been relieved.

STEP 4 Slide the torsion toward the front of the vehicle (longitudinal torsion bar) until the spline or hexagonal end slips out of the adjusting arm.

STEP 5 Lower the rear of the torsion bar slightly and move the torsion bar toward the rear of the vehicle out of the lower control arm.

To install, reverse the removal procedure.

NOTE: Torsion bars should never be switched from one side of the vehicle to the other as they are twisted and work hardened in one direction and can break if installed on the opposite side of the vehicle.

CONTROL ARM BUSHINGS

DIAGNOSIS Defective control arm bushings are a common source of vehicle handling and suspension noise problems. Most suspension control arm bushings are constructed of three parts: an inner metal sleeve, the rubber bushing itself, and an outer steel sleeve. (Some vehicles use a two-piece bushing that does not use an outer sleeve.)

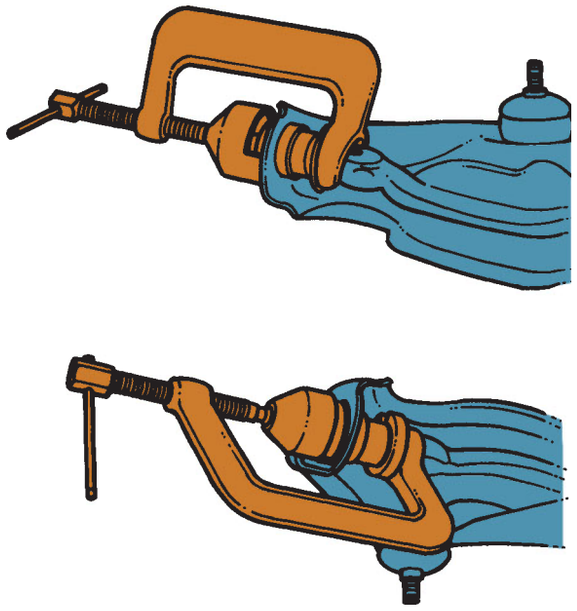


FIGURE 113–52 An adapter and a press or large clamp are used to remove the old bushing from the control arm and to install a new bushing.

REPLACEMENT To remove an old bushing from a control arm, the control arm must first be separated from the suspension and/or frame of the vehicle. Several methods can be used to remove the bushing from the control arm, but all methods apply force to the *outer* sleeve. While an air chisel is frequently used to force the steel sleeve out of the suspension member, a puller tool is most often recommended by General Motors. ● **SEE FIGURE 113–52.** The puller can be used to remove the old bushing and install the replacement bushing without harming the control arm or the new bushing. All bushings should be tightened with the vehicle on the ground and the wheels in a straight-ahead position; this prevents the rubber bushing from exerting a pulling force on the suspension.

NOTE: Some replacement control arm bushings have a higher durometer, or hardness, rating than the original. Urethane bushings are often used in sporty or race-type vehicles and deflect less than standard replacement bushings. These harder bushings also transfer more road noise, vibration, and harshness to the body.

The upper control arm bushings can be replaced in most vehicles that use a short/long-arm-type suspension by following just four easy steps:

STEP 1 Raise the vehicle and support the lower control arm with a safety stand or floor jack.

STEP 2 Disconnect the upper control arm from the frame by removing the frame-attaching nuts or bolts.

STEP 3 Using the upper ball joint as a pivot, rotate the upper control arm outward into the wheel well area. With the control arm accessible, it is much easier to remove and replace the upper control arm pivot shaft and rubber bushings.

STEP 4 After replacing the bushings, simply rotate the upper control arm back into location and reattach the upper control arm pivot shaft to the vehicle frame.

NOTE: An alignment should always be performed after making any suspension-related repairs.



1 The tools needed to replace a front strut assembly include several sockets and a ball-peen hammer, plus a strut compressor.



2 After safely hoisting the vehicle to elbow height and removing the wheel covers, mark and remove the front tire/wheel assembly.



3 Remove the two strut retaining nuts.



4 Before using a hammer to drive the retaining bolts from the steering knuckle, thread the nut into the bolt backwards to prevent causing damage to the threads.



5 Remove the retaining bolts and separate the strut from the steering knuckle.



6 Lower the vehicle and remove the upper strut retaining fasteners.

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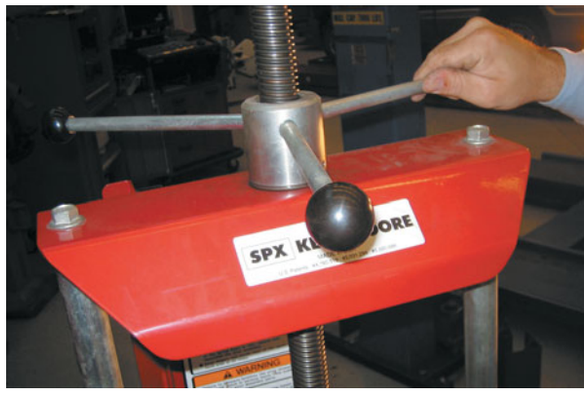
7 Hold the strut while removing the last upper retaining nut and then remove the strut assembly.



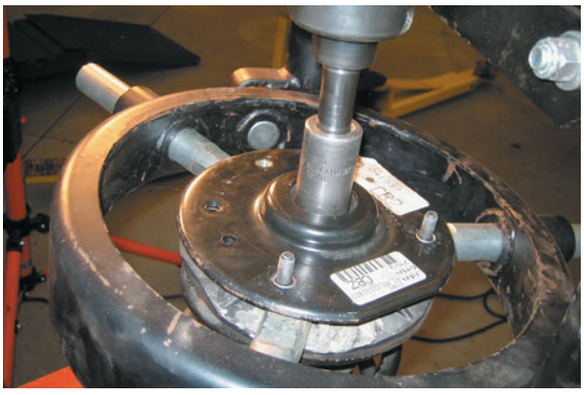
8 After the strut has been removed from the vehicle, install the assembly into a strut compressor.



9 Position the jaws of the compressor under the bearing assembly as per the vehicle manufacturer's instructions. Mark the relationship of spring to strut before disassembly.



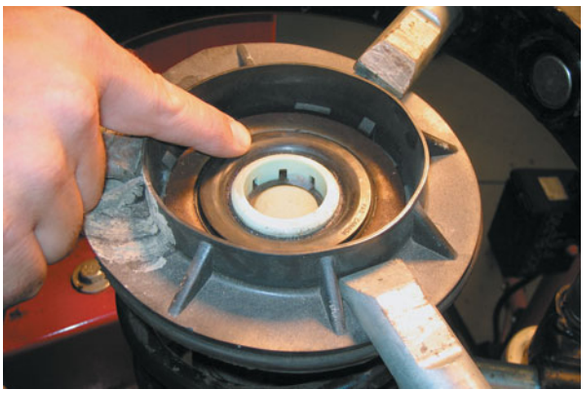
10 Turn the compressor wheel until all tension of the spring has been relieved from the upper bearing assembly.



11 Remove the strut retaining nut.



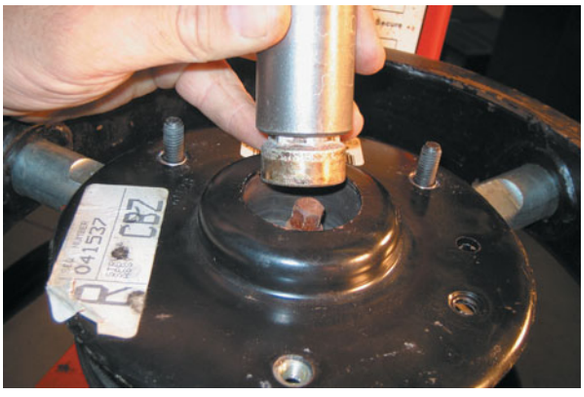
12 Remove the strut assembly.



13 Before installing the replacement strut, check the upper bearing by exerting a downward force on the bearing while rotating and check for roughness. Replace if necessary.



14 Install the strut from underneath the spring compressor fixture.



15 Install the strut retaining nut. Most vehicle manufacturers specify that the strut retaining nut be replaced and the old one discarded.



16 Before loosening the tension, check that the coil spring is correctly located at both the top and the bottom, then release the tension on the spring.



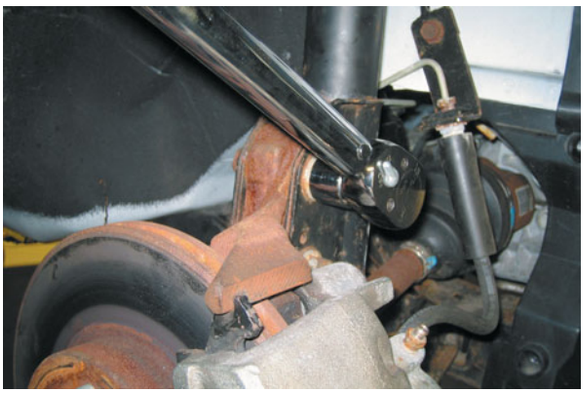
17 Remove the strut assembly from the compressor and place back into the vehicle and install the upper fasteners. Do not torque to specifications until the lower fasteners have been installed.



18 Attach the lower strut to the steering knuckle using the original hardened bolts and nuts.

CONTINUED ▶

STRUT REPLACEMENT (CONTINUED)



19 Using a torque wrench, torque all fasteners to factory specifications.



20 Install the tire/wheel assembly, lower the vehicle, and torque the lug nuts to factory specifications. Align the vehicle before returning it to the customer.

REVIEW QUESTIONS

1. Describe how to perform a proper road test for the diagnosis of suspension-related problems.
2. List four symptoms of worn or defective shock absorbers.
3. Explain the procedure for replacing front shock absorbers on an SLA-type suspension vehicle.
4. Describe the testing procedure for ball joints.
5. Describe the correct general procedure to remove and replace tapered suspension components.

CHAPTER QUIZ

1. Unusual noise during a test drive can be caused by _____.
   - **a.** Defective wheel bearings or stabilizer bar links
   - **b.** Defective or worn control arm bushings or ball joints
   - **c.** Worn or defective CV joints
   - **d.** All of the above
2. Two technicians are discussing non-indicator-type ball joint inspection. Technician A says that the vehicle should be on the ground with the ball joints *loaded,* then checked for freeplay. Technician B says that the ball joints should be *unloaded* before checking for freeplay. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
3. Most manufacturers specify a maximum axial play for ball joints of about _____.
   - **a.** 0.003 in. (0.076 mm)
   - **b.** 0.010 in. (0.25 mm)
   - **c.** 0.030 in. (0.76 mm)
   - **d.** 0.050 in. (1.27 mm)
4. The preferred method to separate tapered chassis parts is to use _____.
   - **a.** A pickle fork tool
   - **b.** A torch to heat the joint until it separates
   - **c.** A puller tool or two hammers to shock and separate the taper
   - **d.** A drill to drill out the tapered part
5. A light film of oil is observed on the upper area of a shock absorber. Technician A says that this condition should be considered normal. Technician B says that a rod seal may bleed fluid during cold weather, causing the oil film. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B

6. Before the strut insert can be removed from a typical MacPherson strut assembly, which operation is necessary to prevent possible personal injury?
   a. The brake caliper and/or brake hose should be removed from the strut housing
   b. The coil spring should be compressed
   c. The upper strut mounting bolts should be removed
   d. The lower attaching bolts should be removed
7. What should the technician do when replacing stabilizer bar links?
   a. The stabilizer bar should be removed from the vehicle before replacing the links.
   b. The links can be replaced individually, yet the manufacturer often recommends that the links at both ends be replaced together.
   c. The stabilizer bar must be compressed using a special tool before removing or installing stabilizer bar links.
   d. Both b and c are correct.
8. A noise and a pull toward one side during braking is a common symptom of a worn or defective _____.
   a. Shock absorber
   b. Strut rod bushing
   c. Stabilizer bar link
   d. Track rod bushing
9. To help prevent vehicle wandering on a vehicle with torsion bars, the ride height (trim height) should be within _____ side to side.
   a. 0.003 in. (0.076 mm)
   b. 0.050 in. (1.27 mm)
   c. 0.100 in. (2.5 mm)
   d. 0.125 in. (3.2 mm)
10. Two technicians are discussing suspension bushings. Technician A says that replacing control arm bushings usually requires special tools. Technician B says using high-performance urethane bushings may cause excessive noise to be transferred to the passenger compartment. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

chapter 114 REAR SUSPENSIONS AND SERVICE

OBJECTIVES: **After studying Chapter 114, the reader will be able to:** • Prepare for ASE Suspension and Steering (A4) certification test content area "B" (Suspension System Diagnosis and Repair). • Describe the various types and styles of rear suspension. • Explain the purpose and function of Panhard rods, Watt's links, and shackles. • List the steps necessary to replace rear shock absorbers. • Explain how to replace rear leaf and coil springs.

KEY TERMS: Axle windup 1336 • Chapman strut 1339 • Hotchkiss drive 1336 • IRS 1338 • Live axle 1336 • Panhard rod 1337 • Semi-independent suspension 1339 • Semi-trailing arm 1338 • Solid axle 1335 • Torque arm 1337 • Track rod 1337 • Trailing arm 1337 • Watts linkage 1338

All suspensions have two basic jobs: keeping the tires on the ground and providing a smooth ride.

SOLID REAR AXLES

A **solid axle** can be used at the rear of either a rear-wheel-drive or front-wheel-drive vehicle. ● **SEE FIGURE 114–1.** On a rear-wheel-drive vehicle, a solid rear axle consists of the differential gears and axle shafts inside a solid housing. On a front-wheel-drive vehicle, a solid axle is usually a simple U-shaped or tubular beam that may contain a torsion bar, rod, or tube to allow some twisting action.

Certain characteristics apply to any solid rear axle, while other characteristics vary by the type of suspension used to attach the axle to the frame.

Solid axles have some handling characteristics that are inferior to those of an independent suspension. Disadvantages of a solid axle include the following:

- Increased proportion of unsprung weight
- Side-to-side road shock transference
- Poorer tire adhesion

Increasing the proportion of unsprung weight decreases ride quality. Transferring road shock from side-to-side causes wheel tramp and shimmy, and poor tire adhesion accelerates tire wear. ● **SEE FIGURE 114–2.**

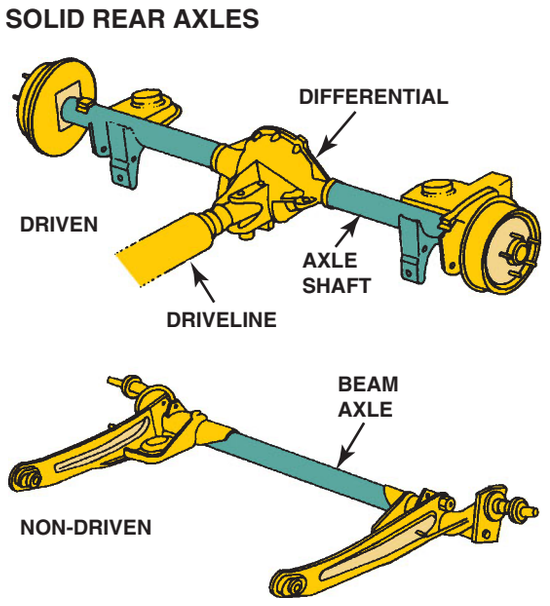


FIGURE 114–1 Solid axles are used on rear-wheel-drive vehicles as well as front-wheel-drive vehicles.

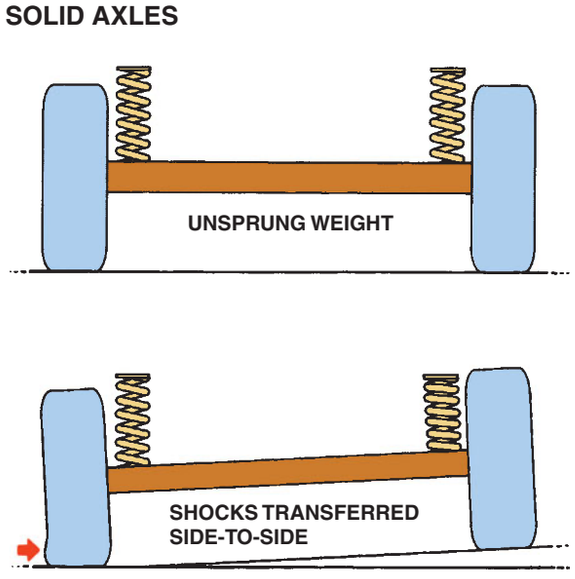


FIGURE 114–2 A solid axle supports the springs, so the axle and suspension components are unsprung weight. When one wheel rides over a bump, the force of impact transfers through the solid axle to the opposite side, leading to unstable handling.

FREQUENTLY ASKED QUESTION

What Is Axle Windup?

Axle windup is a product of the law of physics, which states that every action produces an equal and opposite reaction. As the axle shafts rotate in one direction to drive the wheels, the axle housing attempts to rotate in the opposite direction. The force of this reaction tends to lift the front end of the vehicle during acceleration. ● **SEE FIGURE 114–3.** Axle windup is a particular problem with a solid, driven rear axle because the axle housing concentrates the reacting force. Under extreme acceleration, the reacting force can actually tilt the drive shaft upward and lift the front wheels off the ground. Leaf springs, control arms, pinion snubbers, and torque arms all are means of controlling axle windup.

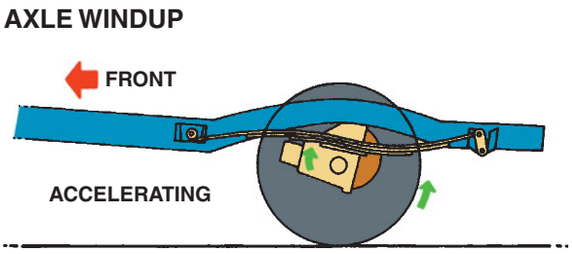


FIGURE 114–3 When the axle housing reacts against the force of axle shaft rotation, the front of the differential tilts upward, creating axle windup.

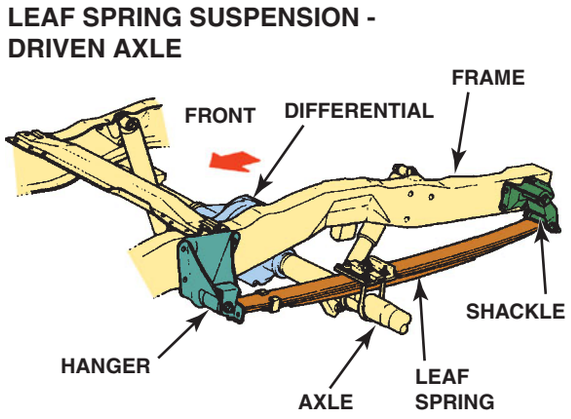


FIGURE 114–4 A typical rear-wheel-drive pickup truck rear suspension equipped with leaf springs. This type of arrangement is called a Hotchkiss drive and the drive train forces are controlled by the rear suspension components.

The sprung weight of the frame and body must be heavy to oppose the unsprung weight of a solid axle, especially on a driven axle. Unsprung weight, wheel tramp, and shimmy all reduce tire adhesion. The effects of these problems are more noticeable in rear-wheel-drive vehicles due to the weight of the rear axle and differential assembly. On a typical front-wheel-drive vehicle, the simple axle beam is not heavy enough to decrease ride quality or cause extreme tire wear. In fact, the rear tires of a front-wheel-drive model always wear more slowly than the front tires because the rear axle is so much lighter than the powertrain.

If engine torque is applied to the rear axle to drive the vehicle, the axle is referred to as a **live axle.**

LEAF SPRING REAR SUSPENSIONS

A leaf spring suspension is a simple system because it does not require control arms to brace and position the axle. The leaf springs link the axle to the frame and effectively serve two purposes:

- Absorbing road shock
- Locating the axle under the vehicle

Most rear-wheel-drive trucks use a solid rear axle with leaf springs in an arrangement called a **Hotchkiss drive.** ● **SEE FIGURE 114–4.** Leaf springs on a driven axle control axle windup

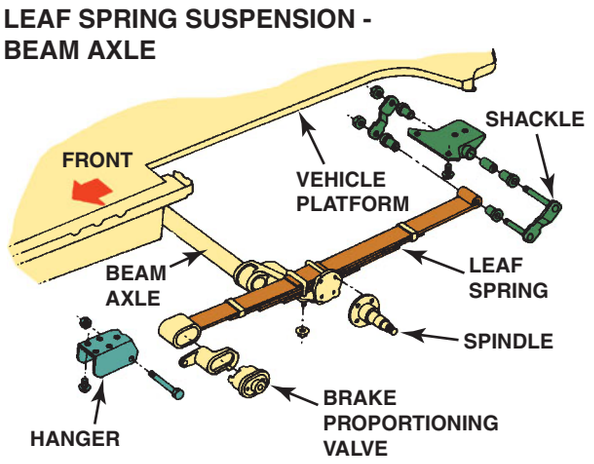


FIGURE 114–5 An exploded view of a beam axle with multi-leaf springs.

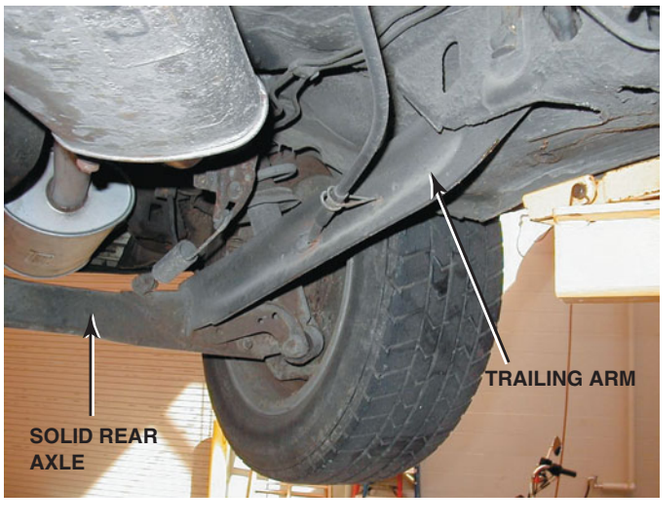


FIGURE 114–6 A trailing arm rear suspension with a solid axle used on a front-wheel-drive vehicle.

by transferring force from the axle housing to the frame. The front portion of the leaf spring, from the axle housing to the frame mount, acts like a trailing control arm. However, if the front section of the leaf spring is too flexible, it may not control axle windup as well. To compensate, some manufacturers make the front section of the spring shorter, and therefore less flexible, than the rear section.

Leaf springs are used on the rear of many light- and medium-duty trucks and vans. ● **SEE FIGURE 114–5.** A shackle attaches the rear of each spring to the unit-body frame, while the front of each spring pivots through a bolt and bushing connected to a hanger that bolts to the body.

TRAILING ARM REAR SUSPENSIONS

A **trailing arm** extends from a frame crossmember located ahead of the rear axle back to the axle housing or a wheel knuckle. Trailing arms run parallel to the centerline of the chassis. ● **SEE FIGURE 114–6.** A trailing arm mounts to the frame with bushings,

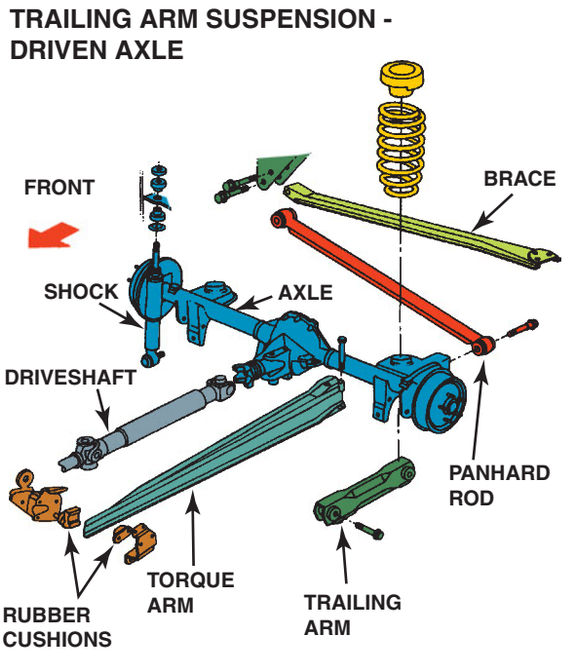


FIGURE 114–7 The Camaro and Firebird rear suspension systems use a torque arm to control axle windup. If the rubber torque arm bushings (cushions) are worn, a loud "bang" could be heard and felt when accelerating suddenly.

which allows the arm to pivot as the wheel rides over bumps. Some rear suspensions use two sets of trailing arms, one set positioned higher in the chassis than the other. Although the arms in this type of arrangement are commonly referred to as the *upper control arms* and *lower control arms,* they are usually called trailing arms. The word *trailing* applies to any link where the supported member trails the arm. Trailing arms may be used to brace either a driven or nondriven solid rear axle against front-to-rear forces, but they do not provide much resistance to side-to-side, or lateral, forces. The axle itself is one means of locating the wheels side-to-side, and solid rear suspensions frequently use another rod to provide additional support. Trailing arms transfer axle windup force to the frame and control front-to-rear axle movement. On a few models, especially those with a high-performance suspension, a **torque arm** provides additional resistance to axle windup. ● **SEE FIGURE 114–7.** The torque arm extends parallel to the drive shaft between the rear axle and the transmission. One end of the torque arm is rigidly bolted to the differential housing, while the other end attaches to the transmission through a cushioned bracket to allow some flex.

A trailing arm rear suspension on a nondriven solid axle virtually always includes a **track rod,** also called a **Panhard rod.** A track rod is a rod attached to the body or frame on one end and the rear axle on the other. The purpose of the track rod is to keep the rear axle centered under the vehicle. The suspension may use either coil springs or struts.

The rear axle is a U-shaped steel beam that is open on the bottom. ● **SEE FIGURE 114–8.** Flat metal axle end plates, to which the wheel spindles bolt, are attached to each end of the beam. A torsion tube or rod fits inside the beam and is welded to the axle end plates.

The trailing arms, which are welded to the outboard ends of the axle, extend forward and attach to the frame with pivot bushing mounts. A bracket on top of the beam axle locates the ring-type lower strut mount, and the upper strut mount attaches to a reinforced area of the wheel well.

TRAILING ARM SUSPENSION - BEAM AXLE

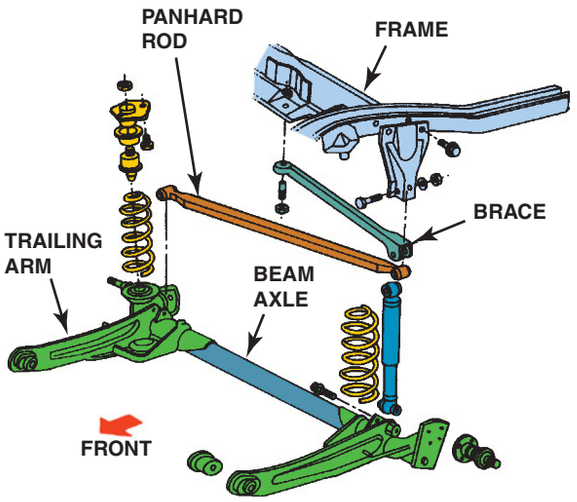


FIGURE 114–8 A typical beam axle rear suspension, which uses trailing arms and coil springs along with a track rod, also called a Panhard rod, to control side-to-side axle movement.

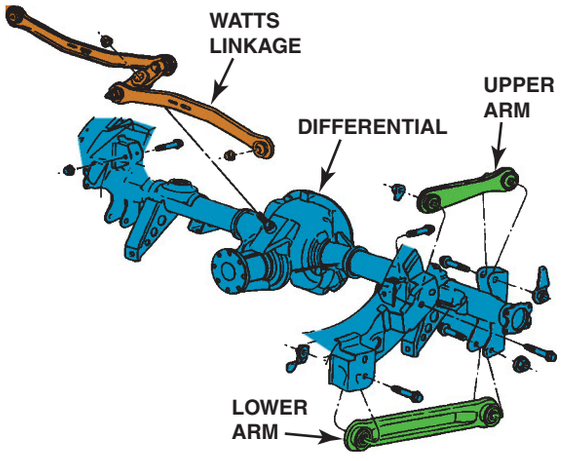


FIGURE 114–9 This Ford rear suspension uses upper and lower semi-trailing arms to mount the rear axle and a watts linkage to control side-to-side movement.

INDEPENDENT SUSPENSION

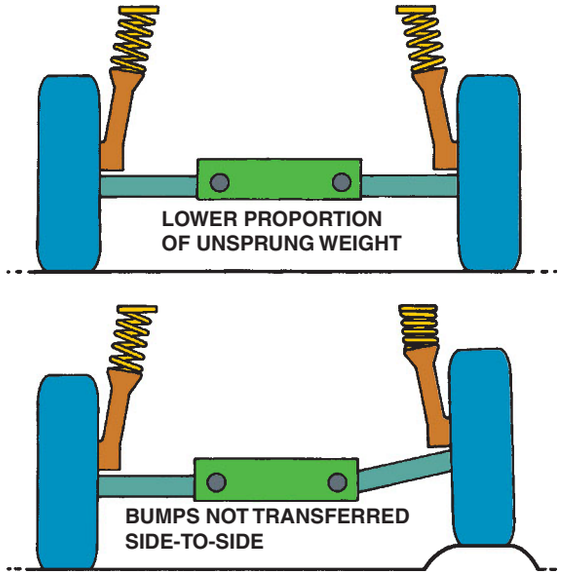


FIGURE 114–10 An independent rear suspension provides a better ride because less weight is unsprung and the suspension is able to react quickly to bumps in the road without affecting the opposite side.

SHORT-LONG-ARM (SLA) SUSPENSION

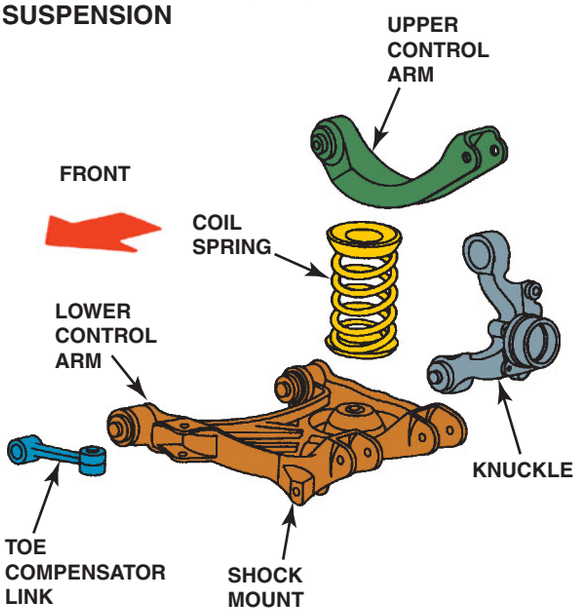


FIGURE 114–11 A typical short/long-arm independent rear suspension.

SEMI-TRAILING ARM REAR SUSPENSIONS

A **semi-trailing arm** is similar to a trailing arm in that it extends back from a frame member to the axle. However, a trailing arm is parallel to the vehicle centerline whereas a semi-trailing arm pivots at an angle to the vehicle centerline. Semi-trailing arms have an advantage over trailing arms because they control both side-to-side and front-to-rear motion. Typically, a semi-trailing arm suspension uses coil springs, air springs, or pivot-base struts.

A semi-trailing arm suspension may be used with either a solid axle or an independent suspension.

The Ford suspension uses two pairs, upper and lower, of semi-trailing arms and a center pivot arrangement to locate the driven rear axle. This axle centering pivot bracket and linkage is called a **watts linkage.** ● **SEE FIGURE 114–9.**

INDEPENDENT REAR SUSPENSIONS

The use of **independent rear suspension,** called **IRS,** has grown dramatically over the past several decades to the point where such systems are now fairly common, especially on front-wheel-drive vehicles and some rear-wheel-drive vehicles. Although rarely used on trucks, a number of rear-wheel-drive vehicles do feature an independent rear suspension.

The reduction in unsprung weight is particularly noticeable for driven axles, which are constructed to transfer the weight of the differential and axles to the frame. ● **SEE FIGURE 114–10.** A vehicle with an independent rear suspension rides and handles better than a similar vehicle equipped with a solid rear axle. An SLA-type of independent suspension may be used at the rear of a rear-wheel-drive vehicle. ● **SEE FIGURE 114–11.**

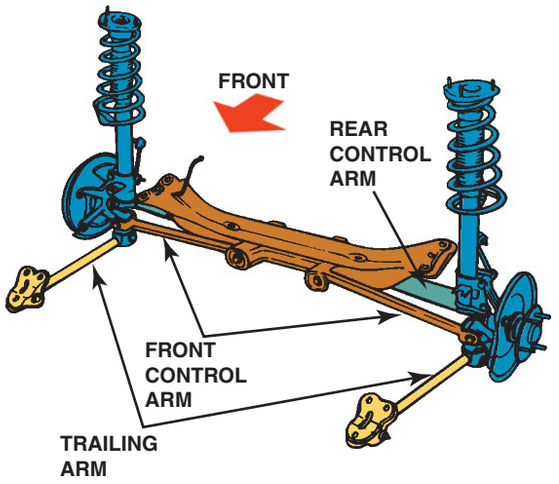


FIGURE 114–12 This independent rear suspension uses a MacPherson strut, two parallel lower transverse control arms, and a trailing arm.

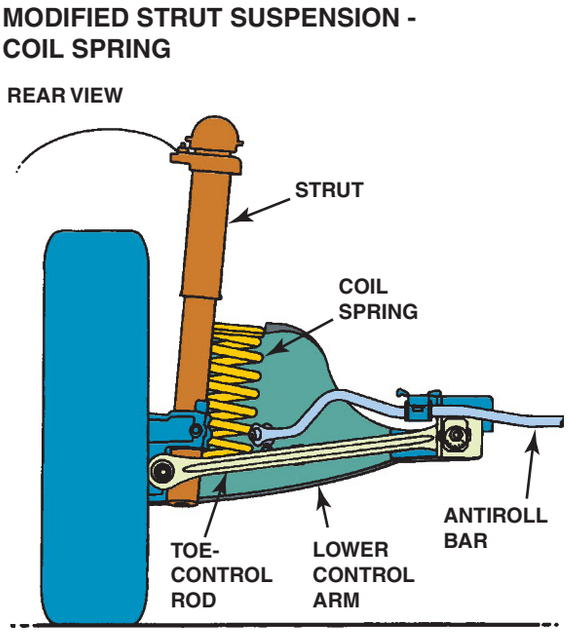


FIGURE 114–13 The toe-control rod provides an extra brace to keep the rear wheels straight ahead during braking and acceleration on this modified-strut-type independent rear suspension.

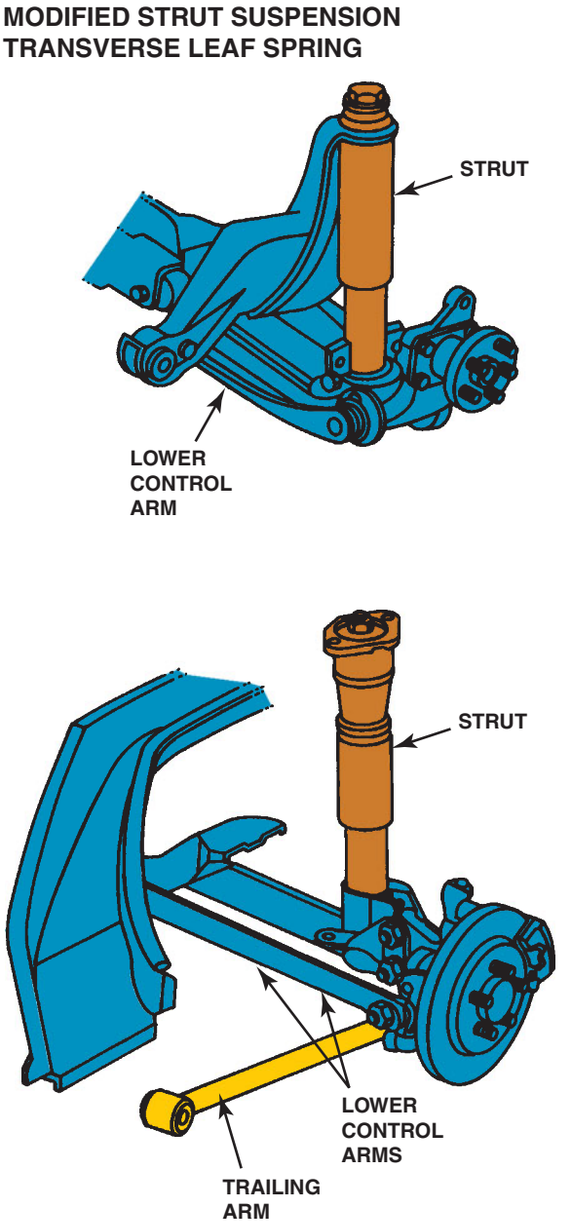


FIGURE 114–14 The upper drawing shows a transverse-leaf-spring-type independent rear suspension that uses an "H"-shaped lower control arm. The lower drawing shows a transverse leaf spring suspension that uses two parallel lower links and a trailing arm.

The differential carrier bolts to the rear subframe, which bears the weight of the axle. Equal-length axle shafts with constant-velocity (CV) joints at either end connect the differential to the rear wheels, and allow the wheels to move independently of each other.

The main benefit of an SLA suspension is that it reduces tire scrub and improves traction. The positioning of the control arms determines the suspension roll center location. In general, the lower the roll center, the less body roll.

Unit-body front-wheel-drive vehicles frequently use strut suspensions at the rear axle. Typically, the strut mounts to the knuckle and replaces the upper control arm. The first designer to put MacPherson-type struts in a rear suspension was an Englishman, Colin Chapman. For this reason, a rear strut suspension is often referred to as a **Chapman strut** suspension by European manufacturers and engineers.

The MacPherson strut system is the most popular independent rear suspension for late-model front-wheel-drive vehicles. ● **SEE FIGURE 114–12.** Modified strut rear suspensions are found on a variety of front-wheel-drive models from a number of different manufacturers. ● **SEE FIGURE 114–13.**

General Motors produced two different rear modified strut systems with transverse leaf springs. ● **SEE FIGURE 114–14.** A transverse leaf spring is also used on the Chevrolet Corvette and the Cadillac XLR.

SEMI-INDEPENDENT REAR SUSPENSIONS

A **semi-independent suspension** is used only at a nondriven rear axle. The semi-independent design is based on a crossbeam that is similar to the beam axle of a solid, nondriven rear suspension.

SEMI-INDEPENDENT SUSPENSIONS

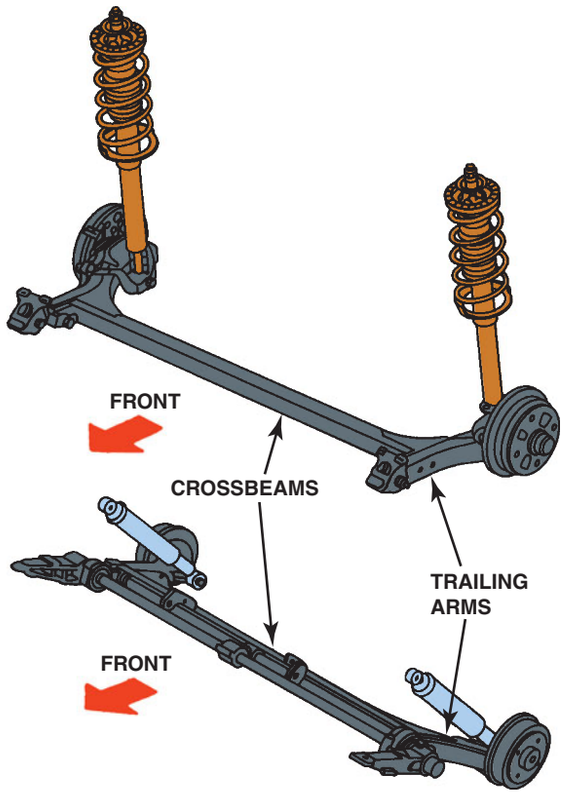


FIGURE 114–15 The crossbeam is placed toward the front of the vehicle rather than the centerline of the rear wheels on a semi-independent-type rear suspension.

SEMI-INDEPENDENT SUSPENSION-STRUT

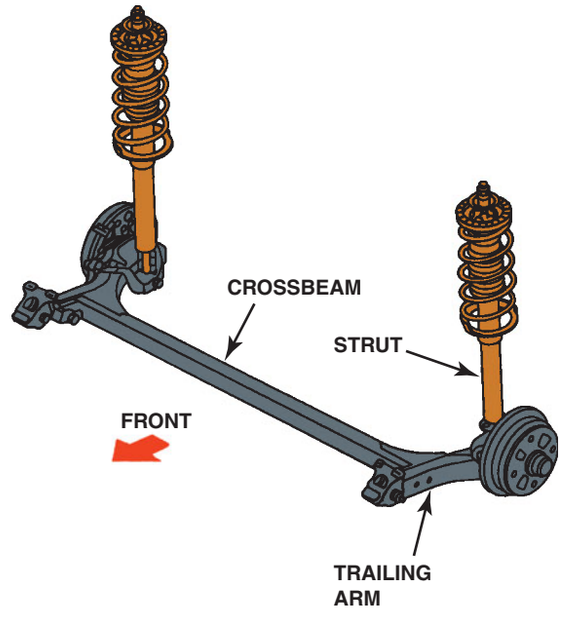


FIGURE 114–16 A semi-independent rear suspension with MacPherson struts.

However, on a semi-independent design the crossbeam is placed ahead, rather than at the centerline, of the wheels. ● **SEE FIGURE 114–15.** Trailing arms extend rearward from the crossbeam to the wheels. The name *semi-independent* indicates that although an axle does not directly link the wheels, the wheels are not completely independent of each other because they are indirectly connected through the crossbeam.

Some semi-independent rear suspensions use struts. ● **SEE FIGURE 114–16.**



FIGURE 114–17 Check all rubber bushings for excessive cracking.

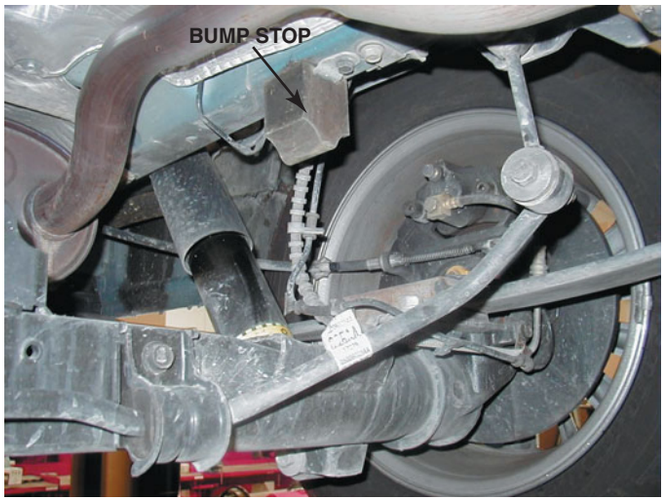


FIGURE 114–18 Carefully inspect the bump stops for damage during a thorough visual inspection.

REAR SUSPENSION SERVICE

Rear suspension service starts with a thorough test drive, to observe any unusual noises or vibrations that may be caused by a fault with a rear suspension component.

After a test drive, safely hoist the vehicle and perform a thorough visual inspection. Use an appropriate prybar and move all of the bushings and joints, checking for deterioration or freeplay. ● **SEE FIGURE 114–17.**

Inspect the shock absorber or struts for leakage or damage. Inspect the bump stops for damage. ● **SEE FIGURE 114–18.** If the bump stops are damaged, this may indicate that the springs are fatigued and the vehicle is at lower-than-normal ride height, or that the shocks or studs are unable to control the springs. ● **SEE FIGURE 114–19.**



FIGURE 114–19 A broken spring was discovered during a routine under-vehicle visual inspection. Notice the witness marks that show that the spring coils have been hitting each other.



FIGURE 114–20 The shock absorber needs to be disconnected before removing the coil spring. Installation is the reverse of removal procedure.

REAR SHOCK REPLACEMENT

PRECAUTIONS Before removing the rear shock absorbers, the rear axle must be supported to prevent stretching of the rear brake flexible hose. Shocks are attached to the frame or body of the vehicle at the top and to a bracket on the rear axle housing at the bottom. Often, the top of the rear shock absorber is fastened *inside* the vehicle. Consult the vehicle manufacturer's service information for exact procedures and fastener torque values.

NOTE: Shock absorbers and/or struts should always be replaced as a pair.

AIR SHOCK INSTALLATION Air-adjustable shock absorbers are a popular replacement for conventional rear shock absorbers. Air shocks can be used to level the vehicle while towing a trailer or when heavily loaded. When the trailer or load is removed, air can be released from the air shocks to return the vehicle height to normal.

Most replacement air shocks are directional and are labeled *left* and *right.* This ensures that the plastic air hose line exits the shock absorber toward the center or rear of the vehicle and is kept away from the wheels.

The plastic air shock line attaches to the shock absorber with an O-ring or brass ferrule and nut. An air leak can result if this O-ring or ferrule is not installed according to the manufacturer's recommendations. Route the plastic air line along the body, keeping it away from the exhaust and any other body parts where the line could be damaged. Attach the line to both shocks to a junction at a convenient location for adding or releasing air.

REAR SPRING REPLACEMENT

REAR COIL SPRINGS

REPLACEMENT. Coil springs in the rear are easily replaced on both front-wheel-drive and rear-wheel-drive vehicles. The procedure includes the following steps:

1. Raise the vehicle safely on a hoist.
2. Remove both rear wheels.
3. Support the rear axle assembly with tall safety stands.
4. Remove the lower shock absorber mounting bolts/nuts and disconnect the shock absorber from the rear axle assembly.
5. Slowly lower the rear axle assembly by either lowering the height of the adjustable safety stands or raising the height of the vehicle on the hoist.
6. Lower the rear axle just enough to remove the coil springs. ● **SEE FIGURE 114–20**.

CAUTION: The shock absorber is usually the only component that limits the downward movement of the rear axle to allow removal of the rear coil springs. Some vehicles may be equipped with rear suspension height sensors for the adjustable suspension system or an adjustable rear proportioning valve for the rear brakes. Some vehicles also require that the rear stabilizer bar or track rod be disconnected or removed before lowering the rear axle assembly. Always consult service information for the exact procedure and torque specifications for the vehicle being serviced.

REAR LEAF SPRINGS

REPLACEMENT. Rear leaf springs often need replacement due to one of the following common causes:

1. **Individual leaves of a leaf spring often crack, then break.** When a leaf spring breaks, the load-carrying capacity of the vehicle decreases and it often sags on the side with the broken spring. Metal fatigue, corrosion, and overloading are three of the most common causes of leaf spring breakage. ● **SEE FIGURE 114–21**.

   NOTE: When one rear spring on one side sags, the opposite front end of the vehicle tends to *rise.* For example, if the right rear spring breaks or sags down, the left front of the vehicle tends to rise higher than the right front. This unequal vehicle height can make the vehicle difficult to handle, especially around corners or curves.

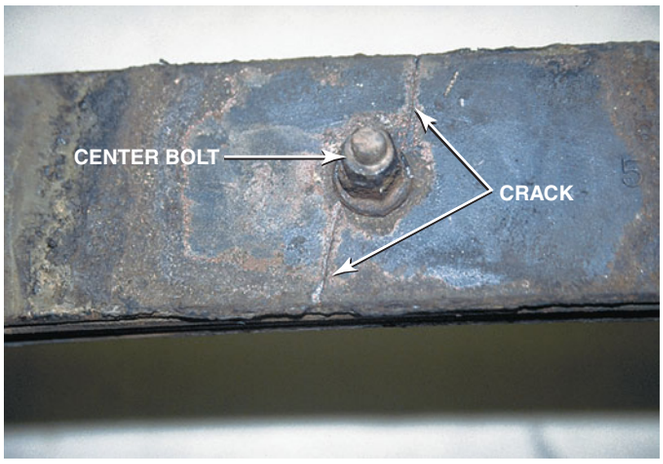


FIGURE 114–21 The center bolt is used to hold the leaves of the leaf spring together. However, the hole for the center bolt also weakens the leaf spring. The crack shown is what a technician discovered when the leaf spring was removed during the diagnosis of a sagging rear suspension.

2. **If the center bolt breaks,** the individual leaves can move and the rear axle is no longer held in the correct location. When one side of the rear axle is behind the other side, the vehicle will *dog track.* Dog tracking refers to the sideways angle of the vehicle while traveling straight. It is commonly caused by the rear axle steering the vehicle toward one side, while the driver controls the direction of the vehicle with the front wheels.

NOTE: Leaf springs should be replaced in pairs.

To replace leaf springs in the rear of a rear-wheel-drive vehicle, follow these steps:

1. Raise the vehicle safely on a hoist.
2. Support the rear axle with safety stands.
3. Remove the rear shackle bolts and forward mounting bolt or mounting bracket.
4. Remove the U-bolts.
5. Being careful of any nearby brake line, remove the spring.
6. Install the new spring, being careful to position the center bolt correctly into the hole on the axle pedestal.

REVIEW QUESTIONS

1. What are the disadvantages of a solid rear axle?
2. What is the purpose of a torque arm?
3. What must be done to ensure safety when replacing the rear shock absorbers?

CHAPTER QUIZ

1. A vehicle equipped with a coil spring front suspension and a leaf spring rear suspension "dog tracks" while driving on a straight, level road. Technician A says that a broken center bolt could be the cause. Technician B says defective rear shock absorbers could be the cause. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. When axle windup is controlled by the rear-leaf spring during acceleration, this system is called _____.
   a. Trailing arm **c.** Torque arm
   b. Semi-trailing arm **d.** Hotchkiss drive
3. A loud "bang" is heard and felt every time the accelerator is depressed or released on a rear-wheel-drive vehicle. Technician A says that a leaking shock absorber could be the cause. Technician B says a broken torque arm could be the cause. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
4. Technician A says that leaf springs are mounted lengthwise on the rear of many vehicles. Technician B says that some vehicles use a transversely mounted leaf spring on the rear. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
5. A strut-type suspension is used _____.
   a. In the front only
   b. In the rear only
   c. In both the front and rear
   d. In rare vehicles no longer in production
6. Two technicians are discussing rear shock absorbers. Technician A says that if one shock is leaking, then both rear shock absorbers should be replaced. Technician B says that the rear axle should be supported before removing rear shock absorbers. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. A "witness mark" is a _____.
   a. Type of fastener
   b. Type of tool
   c. Mark where two parts have rubbed or touched
   d. Identification mark
8. The left front of the vehicle is higher than the right front and the right rear is lower than the left rear. What is the most likely cause of this problem?
   a. A weak right-rear shock absorber
   b. A broken track rod
   c. A broken left-front shock absorber
   d. A sagging right-rear spring
9. One rear leaf spring is broken. Technician A says that both rear leaf springs should be replaced. Technician B says that only the broken spring needs to be replaced. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
10. A track rod is also called a _____.
    a. Panhard rod **c.** Handing link
    b. Control rod **d.** Semi-independent rod

chapter 115

ELECTRONIC SUSPENSION SYSTEMS

OBJECTIVES: After studying Chapter 115, the reader will be able to: • Prepare for ASE Suspension and Steering (A4) certification test content area "B" (Suspension System Diagnosis and Repair). • Discuss the various types of electronic suspension systems. • Describe how suspension height sensors function. • Explain the use of the various sensors used for electronic suspension control. • Discuss the steering wheel position sensor. • Explain how solenoids and actuators are used to control the suspension.

KEY TERMS: Actuator 1343 • Air suspension 1345 • Armature 1349 • AS 1350 • Automatic level control (ALC) 1350 • CCVRTMR 1355 • Computer command ride (CCR) 1347 • Desiccant 1355 • Driver selector switch 1347 • EBCM 1346 • ECU 1343 • Electromagnet 1348 • Handwheel position sensor 1345 • Height sensor 1343 • Input 1343 • Lateral accelerometer sensor 1346 • LED 1343 • Magneto-rheological (MR) 1355 • Mode select switch 1350 • Motor 1349 • MRRTD 1355 • Output 1343 • Perform ride mode 1352 • Photocell 1343 • Phototransistor 1343 • Pulse width 1349 • Pulse-width modulation 1349 • Real-time dampening (RTD) 1345 • RPO 1352 • RSS 1345 • Selectable ride (SR) 1347 • Solenoid 1345 • Solenoid controlled damper 1352 • Stabilitrak 1352 • Steering wheel position sensor 1345 • Touring ride mode 1352 • Vehicle stability enhancement system (VSES) 1346 • VS sensor 1346 • Yaw rate sensor 1346

THE NEED FOR ELECTRONIC SUSPENSIONS

Since the mid-1980s, many vehicle manufacturers have been introducing models with electronic suspension controls that provide a variable shock stiffness or spring rate. The main advantage of electronic controls is that the suspension can react to different conditions. The system provides a firm suspension feel for fast cornering and quick acceleration and braking, with a soft ride for cruising. ● **SEE FIGURE 115–1.**

ELECTRONIC SUSPENSION CONTROLS AND SENSORS

PURPOSE AND FUNCTION Sensors and switches provide **input** to the electronic control module (ECM), or system computer. The ECM, which may also be referred to as the **electronic control unit (ECU),** is a small computer that receives input in the form of electrical signals from the sensors and switches and provides **output** electrical signals to the system actuators. ● **SEE FIGURE 115–2.** The electrical signal causes an **actuator** to perform some type of mechanical action.

HEIGHT SENSORS Sensors, which are the input devices that transmit signals to the ECM, monitor operating conditions and component functions. A **height sensor** senses the vertical relationship between the suspension component and the body. Its signal indicates to the ECM how high the frame or body is, or how compressed the suspension is. A number of sensor designs are used to determine ride height, including a **photocell** type of sensor. ● **SEE FIGURE 115–3.**

Four height sensors, one at each wheel, deliver an input signal to the ECM. All four sensors are similar and use a control link, lever, slotted disc, and four photo interrupters to transmit a signal. Each photo interrupter consists of a **light-emitting diode (LED)** and a **phototransistor,** which reacts to the LED.

Inside the sensor, the LEDs and phototransistors are positioned opposite each other on each side of the slotted disc. ● **SEE FIGURE 115–4.** When the system is activated, the ECM applies voltage to the LEDs, which causes them to illuminate. Light from an LED shining on the phototransistor causes the transistor to generate a voltage signal. Signals generated by the phototransistors are delivered to the ECM as an input that reflects ride height.

As suspension movement rotates the disc, the slots or windows on the disc either allow light from the LEDs to shine on the phototransistors or prevent it. The windows are positioned in such a manner that, in combination with the four LEDs and transistors, the sensor is capable of generating 16 different levels of voltage. This variable voltage, which is transmitted to the ECM as an input signal, directly corresponds to 1 of 16 possible positions of the suspension. This input signal tells the ECM the position of the suspension in relation to the body. Whether the input voltage signal is increasing or decreasing allows the ECM to determine if the suspension is compressing or extending.

The ECM can also determine the relative position of the body to the suspension, or the attitude of the vehicle, from the four height sensors. Comparing front-wheel input signals to those of the rear wheels determines the amount of pitch caused by forces of acceleration or deceleration. A side-to-side comparison allows the ECM to determine the amount of body roll generated by cornering force.

GENERAL MOTORS ELECTRONIC SUSPENSION SENSORS There are five different sensors found on electronic suspension systems, and GM vehicles can have between one and four of these sensors, depending on the system.

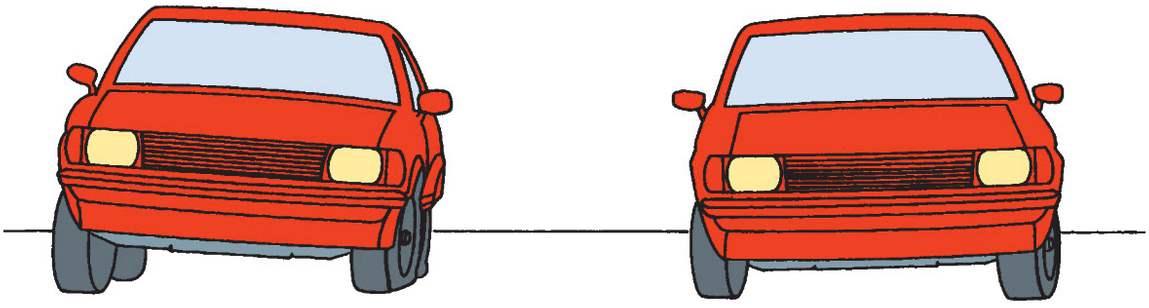


FIGURE 115–1 An electronically controlled suspension system can help reduce body roll and other reactions better than most conventional suspension systems.

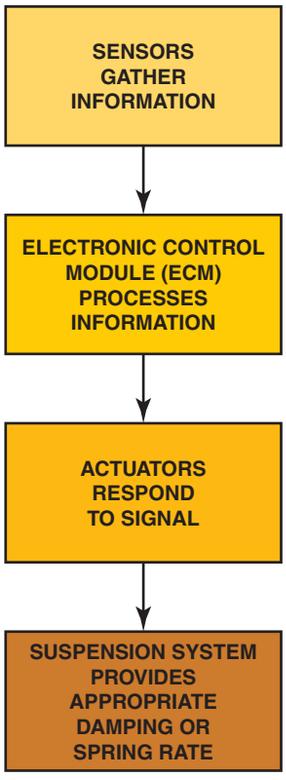


FIGURE 115–2 Input devices monitor conditions and provide information to the electronic control module, which processes the information and operates the actuators to control the movement of the suspension.

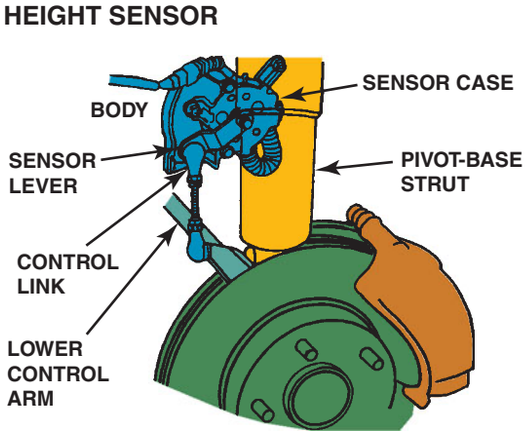


FIGURE 115–3 A typical electronic suspension height sensor, which bolts to the body and connects to the lower control arm through a control link and lever.

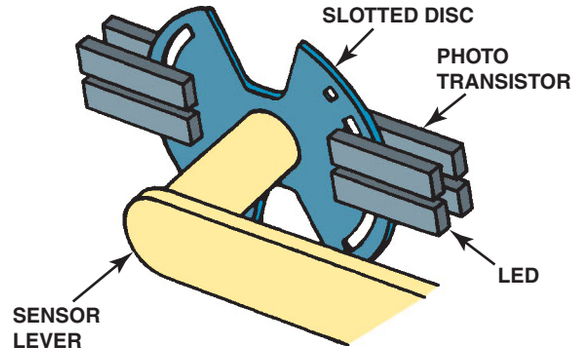


FIGURE 115–4 When suspension action moves the lever, it rotates the slotted disc and varies how much of the photo transistor is exposed to the LEDs, which vary the input signal.

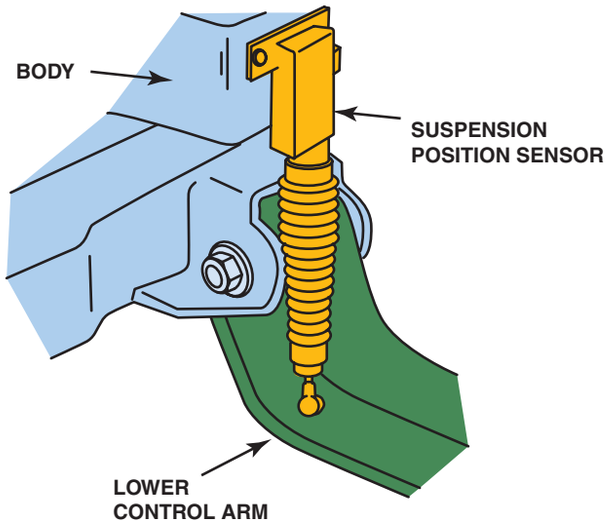


FIGURE 115–5 Typical suspension position sensor.

Depending on the vehicle, the *suspension position sensor* may be called by a different name. It can be called:

- An automatic level control sensor
- An electronic suspension position sensor
- A position sensor
- An air suspension sensor

The sensor provides the control module with information regarding the relative position and movement of suspension components. The common mounting location is between the vehicle body and the suspension control arm. ● **SEE FIGURE 115–5.**

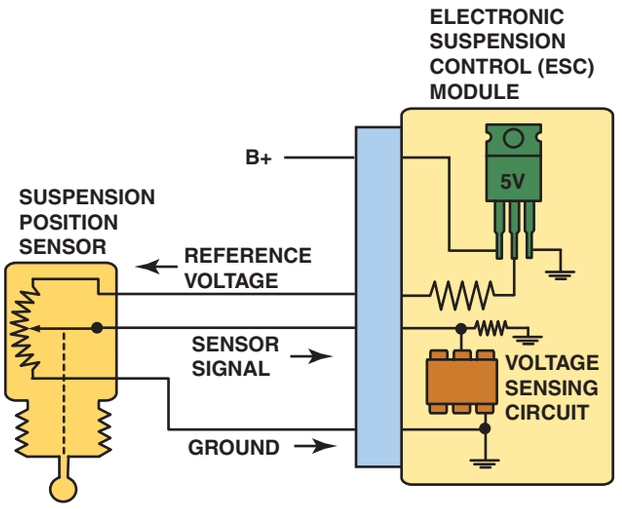


FIGURE 115–6 A three-wire suspension position sensor schematic.

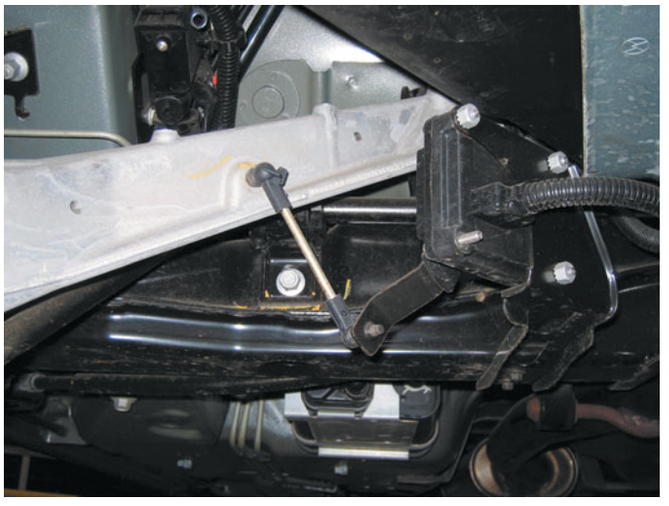


FIGURE 115–7 A suspension height sensor.

POSITION SENSOR OPERATION

The operation of the sensor is either an air suspension sensor two-wire type or a potentiometer three-wire type. The **air suspension** sensor is also known as a *linear Hall-effect* sensor. The air suspension sensor operation consists of a moveable iron core linked to the components. As the core moves, it varies the inductance of the internal sensor coil relative to suspension position.

The suspension control module energizes and de-energizes the coil approximately 20 times a second, thereby measuring sensor inductance as it relates to suspension position. The potentiometer three-wire sensor requires reference and ground voltage. Similar to the throttle position (TP) sensor, it produces a variable analog voltage signal. ● **SEE FIGURE 115–6.**

As the suspension moves up or down, an arm moves on the suspension position sensor through a ball-and-cup link. ● **SEE FIGURE 115–7.**

Suspension position sensor voltage changes relative to this movement. The sensor receives a 5-volt reference signal from the control module. The position sensor returns a voltage signal between 0 and 5 volts depending on suspension arm position.

NOTE: Some systems may require sensor learning or "reprogramming" after replacement. For instance, the sensor used on the Tahoe or Suburban needs to be programmed if replaced. Always check service information for the details and procedures to follow when replacing a sensor on the suspension.

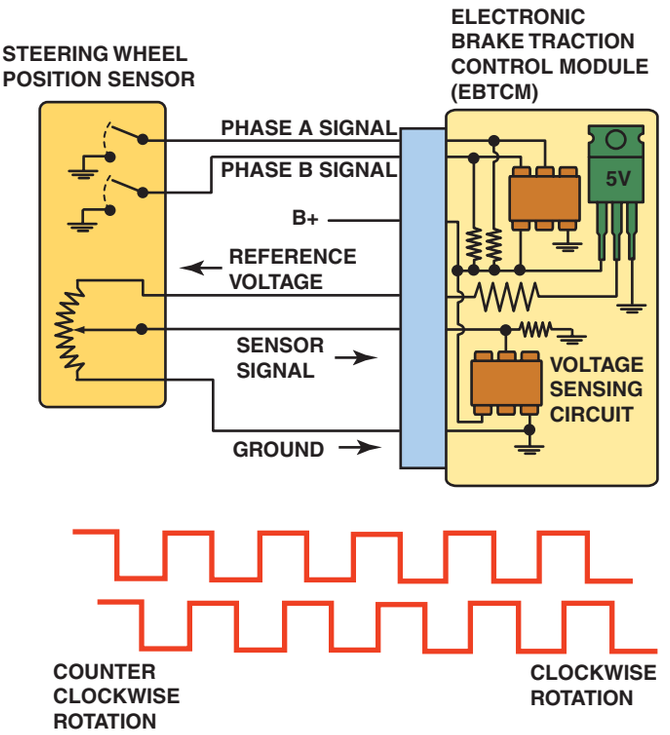


FIGURE 115–8 The steering wheel position (handwheel position) sensor wiring schematic and how the signal varies with the direction that the steering wheel is turned.

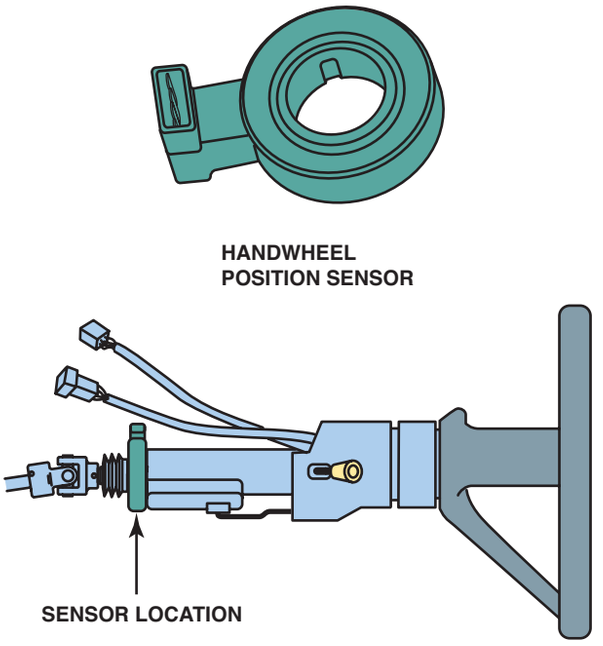


FIGURE 115–9 The handwheel position sensor is located at the base of the steering column.

STEERING WHEEL POSITION SENSOR

Depending on the vehicle, the **steering wheel position sensor** may also be called a **handwheel position sensor.** The function of this sensor is to provide the control module with signals relating to steering wheel position, the speed and direction of handwheel position.

The sensor is found on most **real-time dampening (RTD)** and **road-sensing suspension (RSS)** applications. The sensor is typically located at the base of the steering column. Always refer to service information for vehicle-specific information. ● **SEE FIGURES 115–8 AND 115–9.**

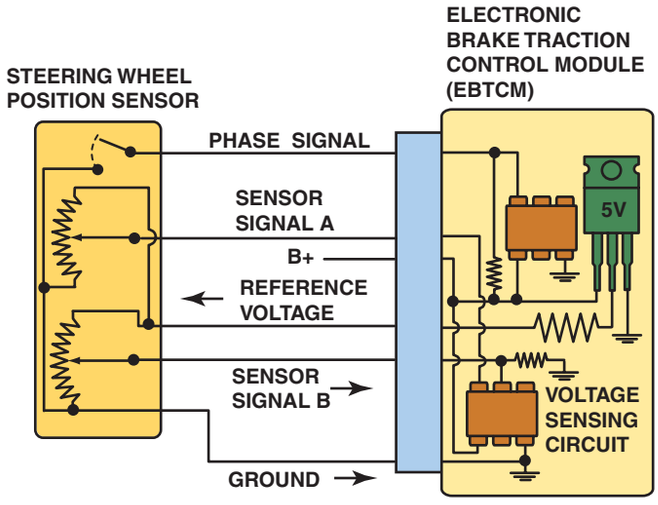


FIGURE 115–10 Steering wheel (handwheel) position sensor schematic.

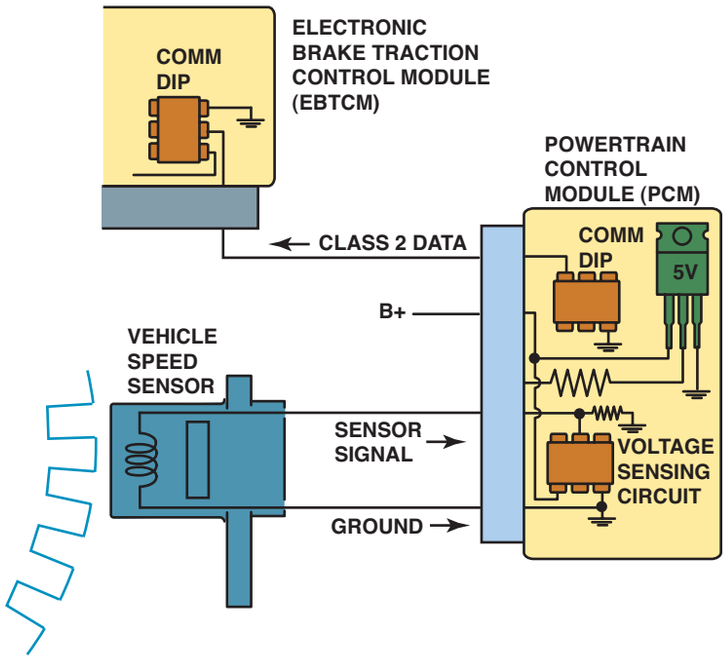


FIGURE 115–11 The VS sensor information is transmitted to the EBCM by Class 2 serial data.

The handwheel sensor produces two digital signals, which are used by the **electronic brake control module (EBCM).** These signals are produced as the steering wheel is rotated. The sensor can also produce more than two signals. As an example, the Cadillac Escalade handwheel sensor produces one analog and three digital signals.

The sensor uses a 5-volt signal reference. Analog signal voltage values increase or decrease, between 0 and 5 volts, as the steering wheel is moved left and right of center. The digital signal is also a standard power-to-ground circuit as shown in the schematic.

There are three possible digital signals:

- Phase A
- Phase B
- Index pulse

These signals provide the suspension control module with steering wheel speed and direction information. Digital signals are either high or low, 5 volts or 0 volts. ● **SEE FIGURE 115–10.**

A scan tool provides diagnostic trouble code (DTC) faults for this sensor. If there is an intermittent concern with a steering wheel position sensor, select the movie mode or snapshot features on a scan tool and slowly turn the steering wheel lock to lock. After the snapshot is complete, plot the analog sensor voltage to see if the signal dropped out. Any dropout is an indication of an intermittent problem.

VEHICLE SPEED SENSOR

The **vehicle speed (VS) sensor** is used by the EBCM to help control the suspension system. The vehicle speed sensor is a magnetic sensor and generates an analog signal whose frequency increases as the speed increases. The ride is made firmer at high speeds and during braking and acceleration and less firm at cruise speeds. ● **SEE FIGURE 115–11.**

PRESSURE SENSOR

A pressure transducer (sensor) is typically mounted on the compressor assembly. This sensor is typically found on suspension systems that use a compressor assembly. The main function of the pressure sensor is to provide feedback to the suspension control module about the operation of the compressor. The sensor assures both that a minimum air pressure is maintained in the system and that a maximum value is not exceeded. A pressure transducer (sensor) is typically mounted on the compressor assembly. This sensor is typically found on systems such as air suspension, real-time damping, and road-sensing suspension that use a compressor assembly. ● **SEE FIGURE 115–12.**

The operation of the pressure sensor requires a 5-volt reference, a ground, and a signal wire to provide feedback to the control module. The voltage output on the signal wire will vary from 0 to 5 volts based upon pressure in the system. A high voltage indicates high pressure and low voltage indicates a low pressure.

LATERAL ACCELEROMETER SENSOR

The function of the **lateral accelerometer sensor** is to provide the suspension control module with feedback regarding vehicle cornering forces. This type of sensor is also called a G-sensor, with the letter "G" representing the force of gravity. For example, when a vehicle enters a turn, the sensor provides information as to how hard the vehicle is cornering. This information is processed by the suspension control module to provide appropriate damping on the inboard and outboard dampers during cornering events. The lateral accelerometer sensor is found on the more complex suspensions systems, that incorporate the **vehicle stability enhancement system (VSES).**

This sensor can be either a stand-alone unit or combined with the yaw rate sensor. Typically, the sensor is mounted in the passenger compartment under a front seat, center console, or package shelf.

The sensor produces a voltage signal of 0 to 5 volts as the vehicle maneuvers left or right through a curve. The signal is an input to the EBCM. If zero lateral acceleration, the sensor input is 2.5 volts. Check service information for specific codes that can be set.

If driving the vehicle and the voltage values increase or decrease during cornering events, this indicates proper operation. ● **SEE FIGURE 115–13.**

YAW RATE SENSOR

The **yaw rate sensor** provides information to the suspension control module and the EBCM. This information is used to determine how far the vehicle has deviated from the driver's intended direction. The yaw sensor is used on vehicles equipped with Electronic Stability Control (ESC).

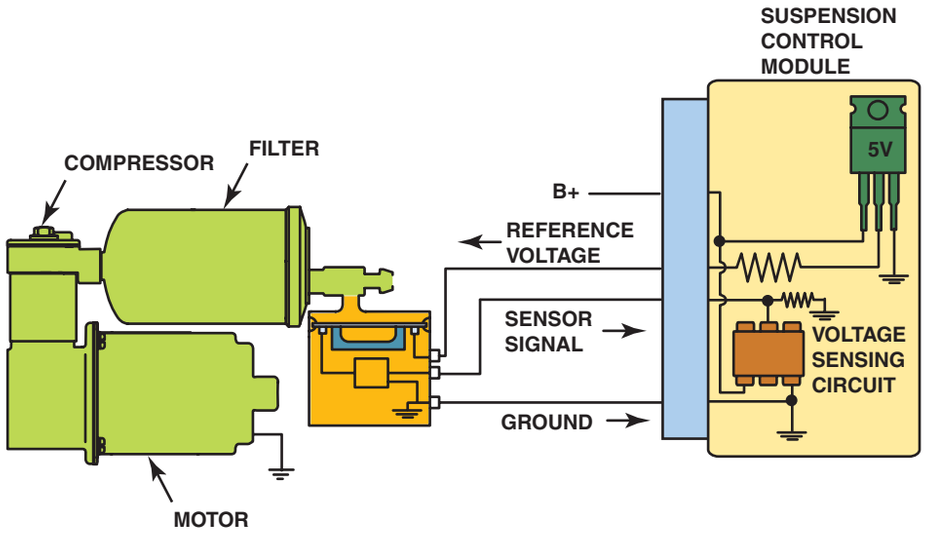


FIGURE 115–12 An air pressure sensor.

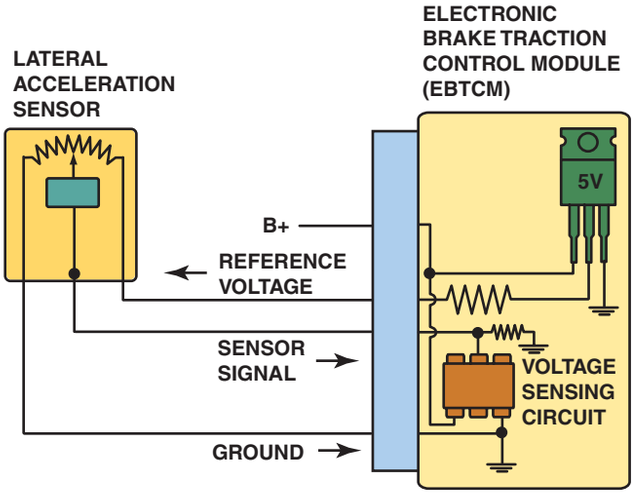


FIGURE 115–13 A schematic showing the lateral acceleration sensor and the EBCM.



FIGURE 115–14 A visual inspection showed a liquid had spilled. This lead to finding the lateral acceleration sensor connector terminals were corrorded.

TECH TIP

A Visual Inspection Is Often the Key to Success.

An ABS amber warning light and a stored U0124 code (lost communications with lateral acceleration sensor) lead to looking at service information for the location of the sensor. It was found to be located under the center console. A visual check of the area showed that a sticky soft drink had likely spilled from the cup holder. ● **SEE FIGURE 115–14.** The liquid had gotten into the electrical connector and caused the fault.

This sensor can be either a stand-alone unit or combined with the lateral accelerometer sensor. Typically, the sensor is mounted in the passenger compartment under the front seat, center console, or on the rear package shelf.

The sensor produces a voltage signal of 0 to 5 volts as the vehicle yaw rate changes. The voltage signal is an input to the EBCM. The yaw rate input to the EBCM indicates the number of degrees that the vehicle deviates from its intended direction.

For example, with a 0-degree yaw rate, the sensor output is 2.5 volts. During an emergency maneuver, the signal will vary above or below 2.5 volts. This sensor does set DTC codes. These codes can be found in service information. ● **SEE FIGURE 115–15.**

DRIVER SELECTOR SWITCH

The **driver selector switch** is a two- or three-mode switch, usually located in the center console, and is an input to the suspension control module.

The switch that is used to select either touring (soft) or performance (firm) ride is found on the **Selectable Ride (SR)** and the **Computer Command Ride (CCR)** systems. The mode select switch status is generally displayed on a scan tool. The three-position switch is used on the Corvette RTD system, and allows the driver to select three modes of operation:

- Tour
- Sport
- Performance

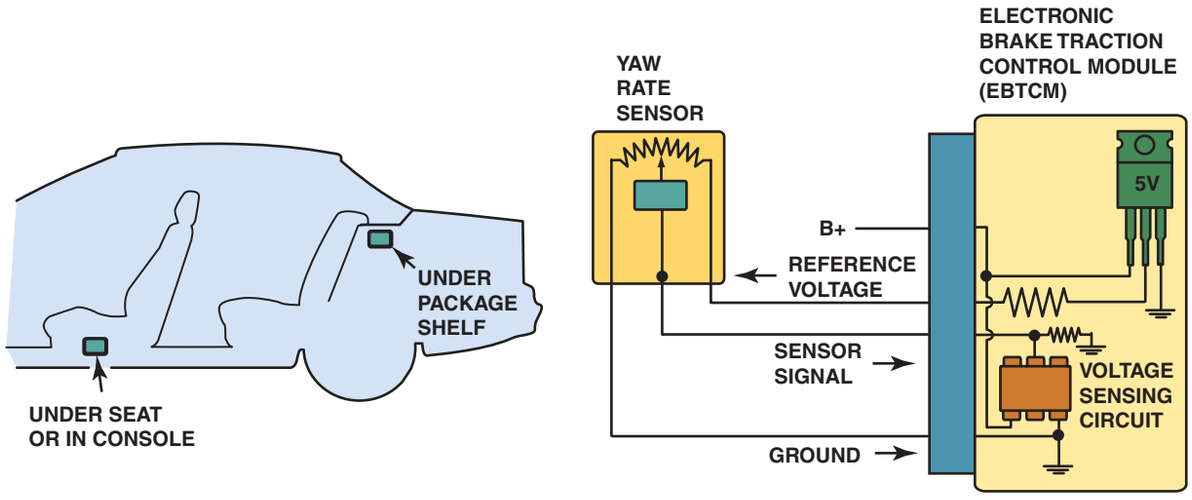


FIGURE 115–15 Yaw rate sensor showing the typical location and schematic.

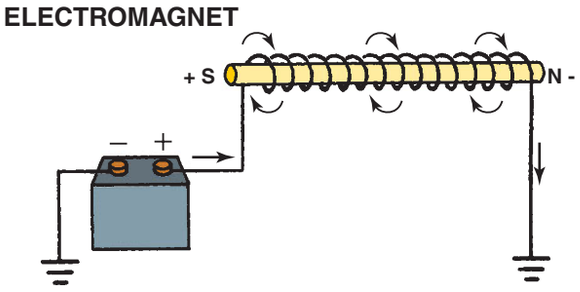


FIGURE 115–16 A magnetic field is created whenever an electrical current flows through a coil of wire wrapped around an iron core.

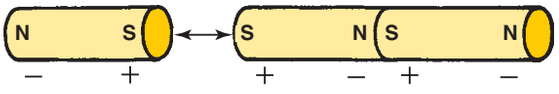


FIGURE 115–17 When magnets are near each other, like poles repel and opposite poles attract.

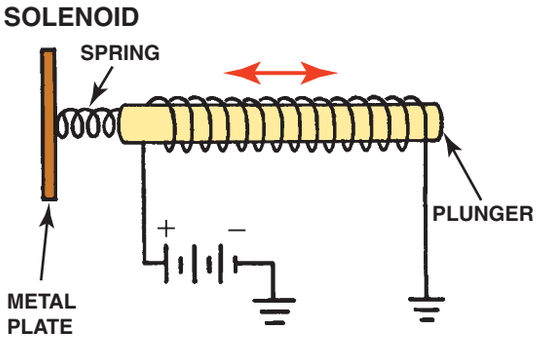


FIGURE 115–18 When electrical current magnetizes the plunger in a solenoid, the magnetic field moves the plunger against spring force. With no current, the spring pushes the plunger back to its original position.

ELECTRONIC SUSPENSION SYSTEM ACTUATORS

PURPOSE AND FUNCTION Each actuator in an electronically controlled suspension system receives output signals from the ECM and responds to these signals, or commands, by performing a mechanical action. Actuators are usually inductive devices that operate using an electromagnetic field. A simple **electromagnet** consists of a soft iron core with a coil of wire, usually copper, wrapped around it. ● **SEE FIGURE 115–16.**

Electrical current traveling through the coiled wire creates a magnetic field around the core. All magnets are polarized; that is, they have a north, or positive, and a south, or negative, pole. When the opposite poles of two magnets are placed near each other—positive-to-negative—the magnets attract each other. Place the same poles together, positive-to-positive or negative-to-negative, and the magnets repel each other. ● **SEE FIGURE 115–17.** Magnets also attract and are attracted to certain types of metals, especially iron and steel.

When an electromagnet has more than one coil, the stronger primary coil can induce voltage into the weaker secondary coil. This inductive transfer occurs even though there is no physical connection between the two coils.

SOLENOIDS In a **solenoid,** the core of the electromagnet also acts as a plunger to open and close a passage or to move a linkage. Solenoids are cylindrically shaped with a metal plate at one end and open at the other end to allow the plunger to move in and out. The electromagnetic coils are placed along the sides of the cylinder. A preload spring forces the plunger toward one end of the device when the solenoid is de-energized, or there is no current in the coil.

When the solenoid is energized, current passes through the coil and magnetizes the core. The magnetized core is attracted to the metal plate and the strength of the magnetic field overcomes spring force to pull the plunger inward. ● **SEE FIGURE 115–18.** When the electrical current switches off, the solenoid de-energizes and spring force returns the plunger to its rest position.

An airflow control valve is an example of a solenoid used in an electronically controlled suspension. ● **SEE FIGURE 115–19.** As the solenoid plunger extends and retracts, it opens and closes air passages between the system air-pressure tank and the air springs. The position of the plunger determines whether the springs receive more pressure or whether pressure bleeds out of them. Increasing the pressure in the air springs lifts the body higher, and decreasing the pressure by bleeding air from the springs lowers the body.

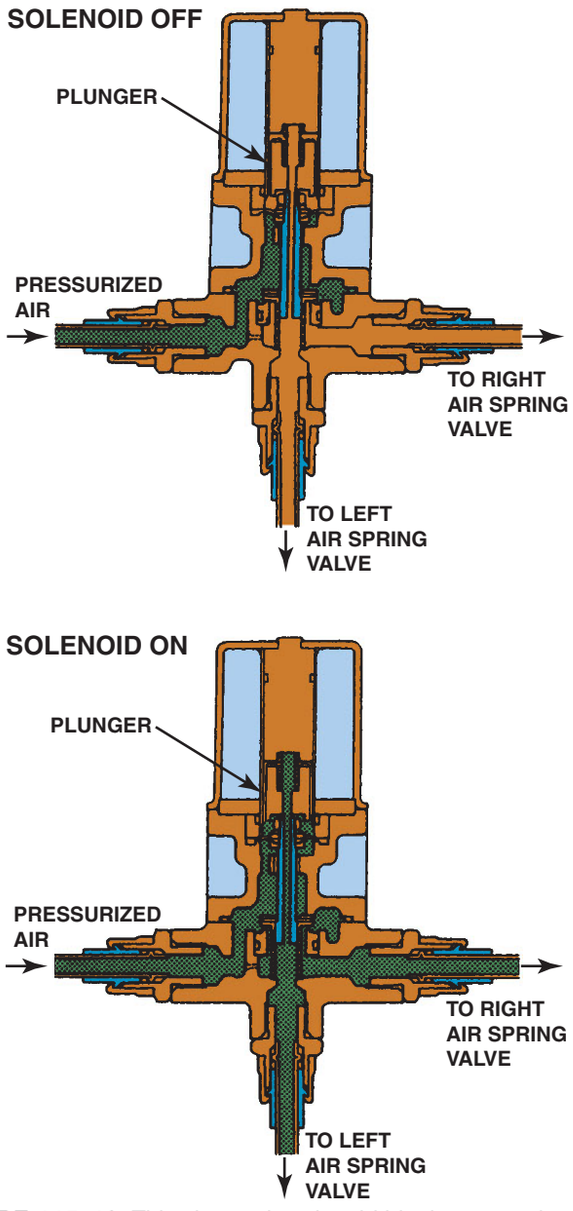


FIGURE 115–19 This air supply solenoid blocks pressurized air from the air spring valves when off. The plunger pulls upward to allow airflow to the air spring valves when the solenoid is energized.

Solenoids are digital devices that are either on or off. However, the ECM can vary the amount a solenoid opens by pulsing the output signal to the coil. If the signal is rapidly switched on and off, spring and magnetic forces do not have enough time to react and effectively move the plunger between the signal changes. The amount of time the current is on compared to the amount of time it is off is called **pulse width,** and the control of a solenoid using this pulsing-on-and-off method is called **pulse-width modulation.**

ACTUATOR MOTORS If a current-carrying conductor is placed in a magnetic field, it tends to move from the stronger field area to the weaker field area. A **motor** uses this principle to convert electrical energy into mechanical movement. Electrical current is directed through the field coils on the motor frame to create a magnetic field within the frame. By applying an electrical current to the **armature,** which is inside the motor frame, the armature rotates from a strong field area to a weaker field area. Armature movement can in turn move another part, such as a gear, pulley, or shaft, attached to it.

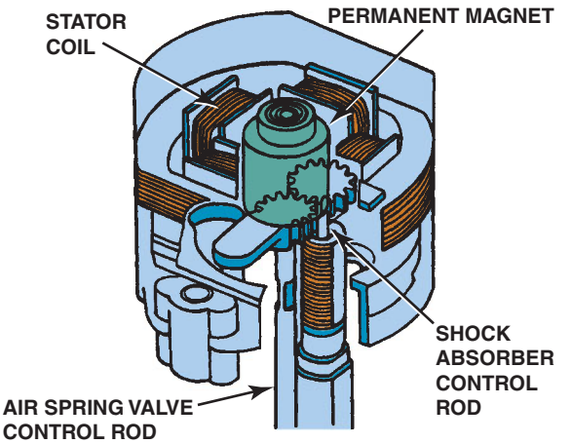


FIGURE 115–20 An actuator motor uses a permanent magnet and four stator coils to drive the air spring control rod.

Located at the top mount of the air spring variable shock assembly of each wheel, the suspension control actuator moves a control rod that regulates air pressure to the spring, which determines ride height. The actuator is an electromagnetic device consisting of four stator coils and a permanent magnet core. ● **SEE FIGURE 115–20.**

The ECM applies current to two stator coils at a time to create opposing magnetic fields around the core, which causes the core to rotate into a new position. Which coils are energized determines how far and in which direction the core rotates. ● **SEE FIGURE 115–21.** By switching current from one pair of coils to the other, the ECM moves the core into a new position, and a third position is available by reversing the polarity of the coils.

A gear at the base of the permanent magnet connects to a rod that operates the air valve to the air spring. The gear also drives another gear, which operates the control rod of the variable shock absorber. Therefore, the three positions of the suspension control actuator motor provide three shock absorber stiffness settings in addition to a variable air spring.

TYPES OF ELECTRONIC SUSPENSION

The types of electronic suspension systems used on General Motors vehicles, as examples, include:

1. Selectable Ride
2. Automatic Level Control
3. Air Suspension
4. Computer Command Ride
5. Real-Time Dampening/Road-Sensing Suspension
6. Vehicle Stability Enhancement System
7. Magneto-Rheological Suspension (F55)

SELECTABLE RIDE (SR) The Selectable Ride (SR) system is the most basic of the electronic systems offered by General Motors. Selectable Ride (SR) allows the driver to choose between two distinct damping levels:

- Firm
- Normal

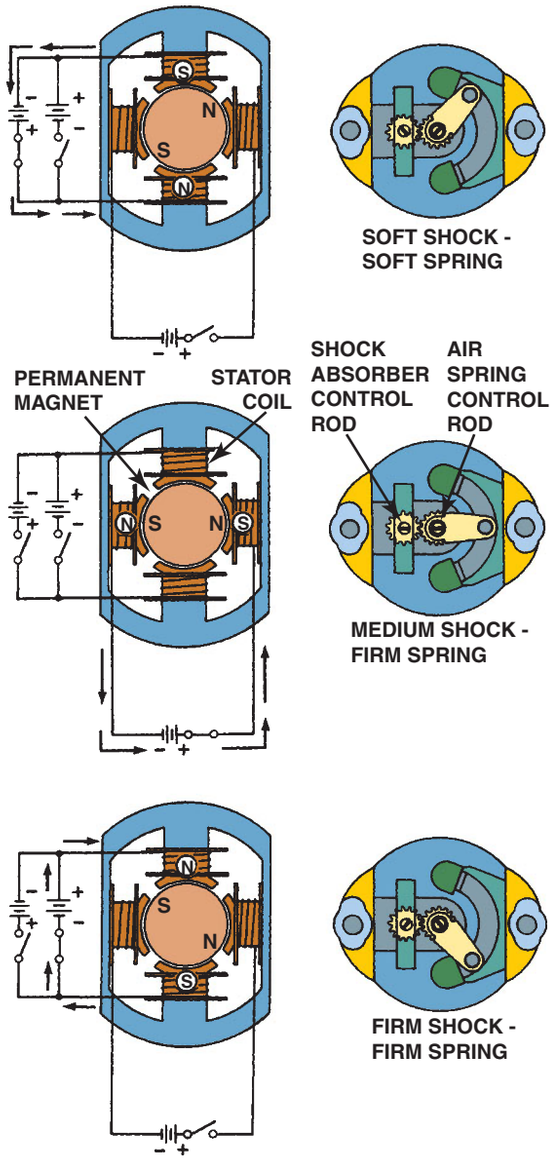


FIGURE 115–21 The stator coils of the actuator are energized in three ways to provide soft, medium, or firm ride from the air springs and shock absorbers.

SR is found on Chevrolet and GMC full-size pickup trucks. ● **SEE FIGURE 115–22.**

A switch is used to control four electronically controlled gas-charged dampers. The **mode select switch** activates the bi-state (two settings) dampers at all four corners of the vehicle, allowing the driver to select vehicle ride characteristics. The system is either energizing or de-energizing the bi-state dampers to provide a firm or normal ride.

AUTOMATIC LEVEL CONTROL

The **Automatic Level Control (ALC)** system automatically adjusts the rear height of the vehicle in response to changes in vehicle loading and unloading. Automatic Level Control is found on many General Motors vehicles. ALC controls rear leveling by monitoring the rear suspension position sensor and energizing the compressor to raise the vehicle or energizing the exhaust valve to lower the vehicle. ALC has several variations across the different platforms. ● **SEE FIGURE 115–23.**

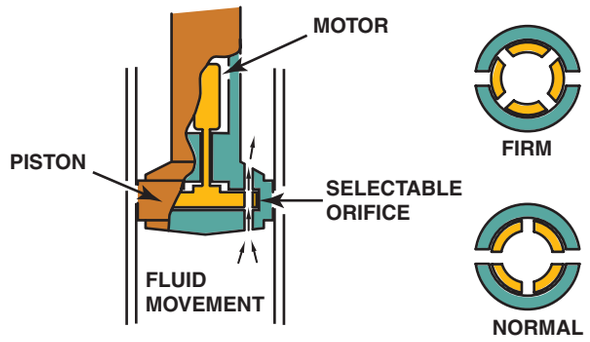


FIGURE 115–22 Selectable Ride as used on Chevrolet and GMC pickup trucks.

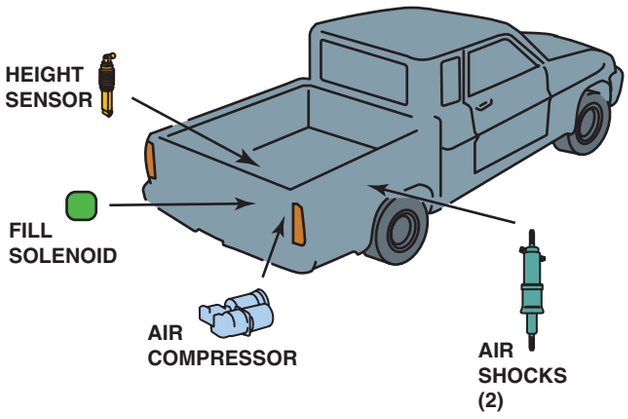


FIGURE 115–23 ALC maintains the same ride height either loaded or unloaded by increasing or decreasing the air pressure in the rear air shocks.

AIR SUSPENSION (AS)

Air Suspension (AS) is a system very similar to the ALC system. The purpose of the AS system includes:

1. Keep the vehicle visually level
2. Provide optimal headlight aiming
3. Maintain optimal ride height

The AS system includes the following components:

- An air suspension compressor assembly
- Rear air springs
- Air suspension sensors

The AS system is designed to maintain rear trim height within 3/16 inch (4 mm) in all loading conditions, and the leveling function will deactivate if the vehicle is overloaded.

The AS system also includes an accessory air inflator found in the rear cargo area. ● **SEE FIGURE 115–24.**

VARIABLE-RATE AIR SPRINGS

In an air spring system with ordinary shock absorbers, the ECM uses the air springs to control trim height and is used on many Ford, Mercury, and Lincoln vehicles.

The three height sensors transmit a signal to the ECM that reflects trim height at each axle. ● **SEE FIGURE 115–25.** The ignition and brake light switches tell the ECM whether the ignition switch is on or off, and if the brake pedal is depressed. The dome light switch indicates whether any doors are open. The on/off switch disables the air spring system to avoid unexpected movement while towing or servicing the vehicle.

CAUTION: Failure to turn off the system will cause the air springs to be vented when the vehicle is hoisted. This will cause the vehicle to drop almost to the ground when the vehicle is lowered. This can cause damage to the air springs and/or to the vehicle. The shut-off switch is usually located in the trunk.

The ECM receives information from the height sensors indicating that the trim height is too high or too low, and it energizes the actuators to add or bleed air from the air springs. The system actuators can still operate for up to an hour after the ignition is switched off.

Any time the ignition is switched to the "run" position, the ECM raises the vehicle, if necessary, within the first 45 seconds. If trim height is too high and the vehicle must be lowered, the ECM delays doing so for 45 seconds after the ignition is switched on.

An air compressor with a regenerative dryer provides the air change required to inflate the air springs on the air suspension system, and a vent solenoid is used to relieve air pressure and deflate the springs. ● **SEE FIGURE 115–26.**

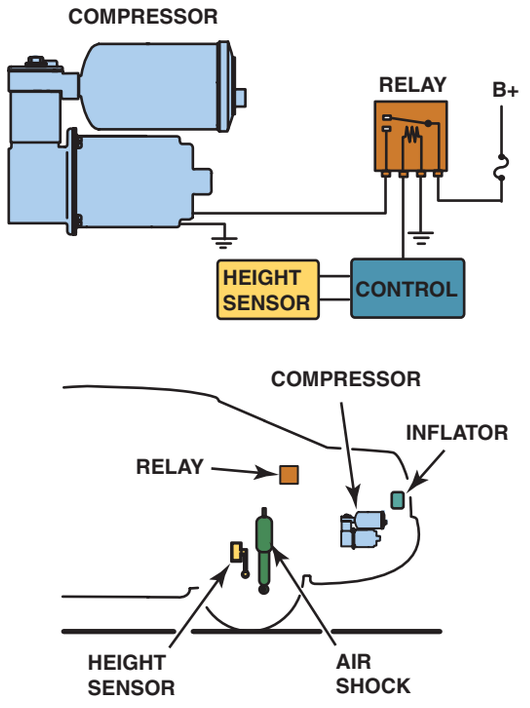


FIGURE 115–24 A typical schematic showing the air suspension compressor assembly and sensor.

By energizing the compressor relay, the ECM directs current to turn on the compressor motor when trim height needs to be raised. The ECM command to lower the vehicle is an electrical signal that opens the vent solenoid to bleed air pressure out of the system. ● **SEE FIGURE 115–27.**

GENERAL MOTORS COMPUTER COMMAND RIDE The General Motors Computer Command Ride (CCR) system controls ride firmness by automatically controlling an actuator in each of the four struts to increase ride firmness as speed increases.

The three damping modes are:

- Comfort
- Normal
- Sport

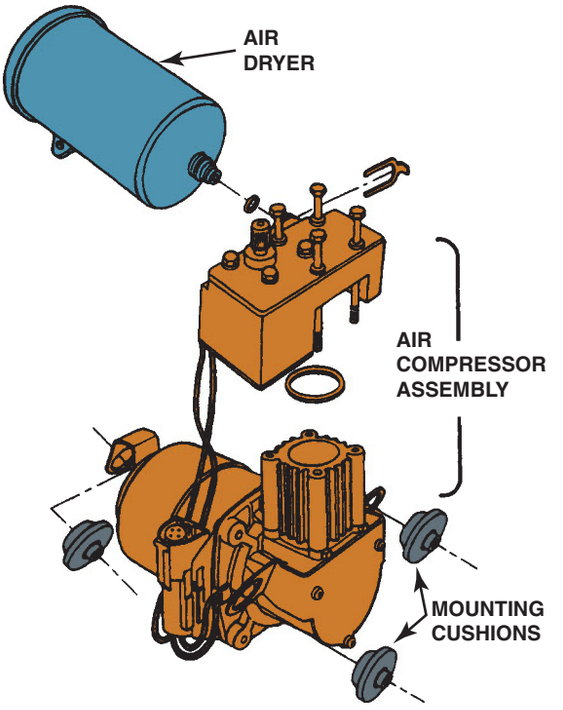


FIGURE 115–26 The air spring compressor assembly is usually mounted on rubber cushions to help isolate it from the body of the vehicle. All of the air entering or leaving the air springs flows through the regenerative air dryer.

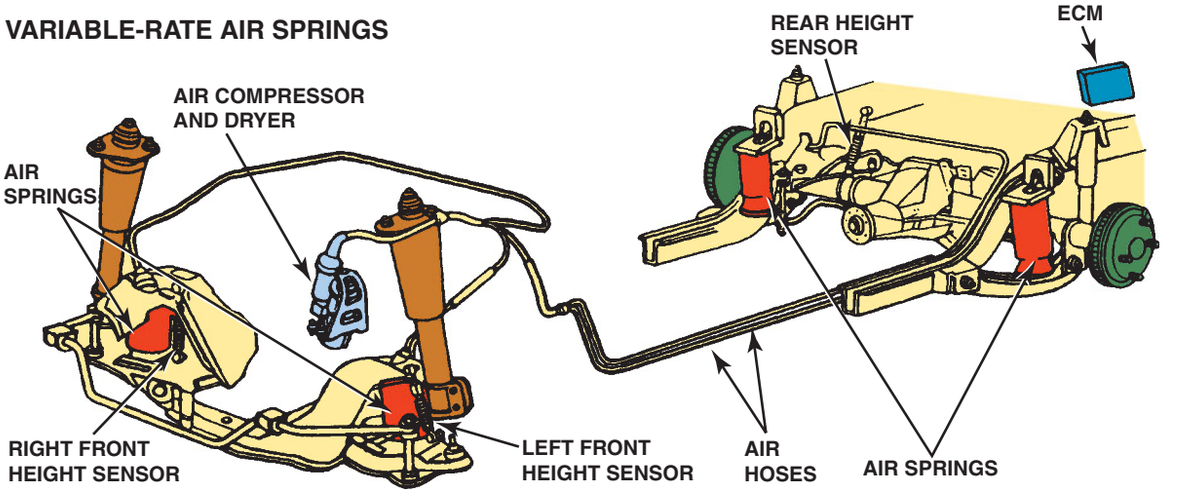


FIGURE 115–25 The typical variable-rate air spring system uses three height sensors, two in the front and one in the rear, to monitor trim height and to provide input signals to the ECM.

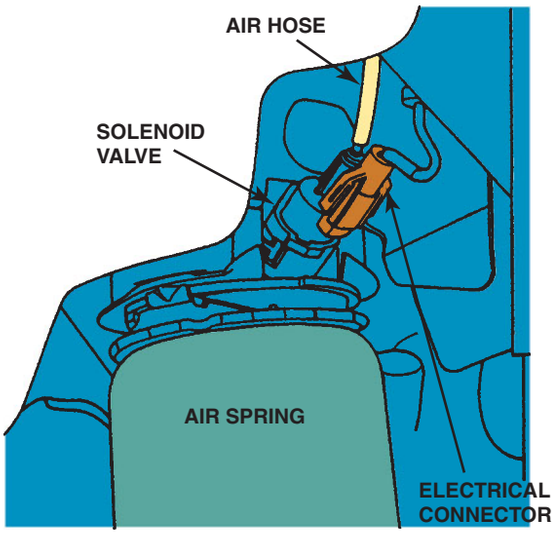


FIGURE 115–27 A solenoid valve at the top of each spring regulates airflow into and out of the air spring.

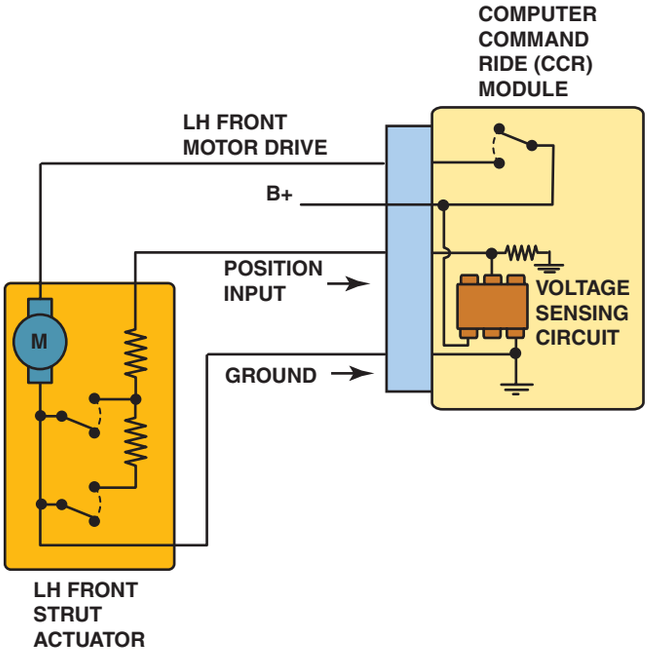


FIGURE 115–28 Schematic showing Computer Command Ride (CCR) system.

Damping mode selection is controlled by the CCR control module according to vehicle speed conditions, driver select switch position, and any error conditions that may exist.

In the **perform ride mode,** the system will place the damping level in the firm mode regardless of vehicle speed.

In the **touring ride mode,** the damping level depends on vehicle speed. ● **SEE FIGURE 115–28.**

REAL-TIME DAMPENING AND ROAD-SENSING SUSPENSION

Real-time dampening (RTD) independently controls a solenoid in each of the four shock absorbers in order to control the vehicle ride characteristics and is capable of making changes within milliseconds (0.001 second).

Road-sensing suspension (RSS), along with ALC, controls damping forces in the front struts and rear shock absorbers in response to various road and driving conditions.

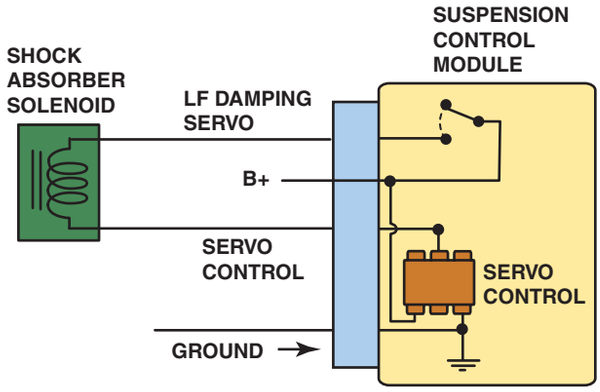


FIGURE 115–29 Schematic showing the shock control used in the RSS system.

TECH TIP

Check the RPO Code

Whenever working on the suspension system check the **RPO (regular production option)** code for the type of suspension used. For example, the F55 RPO may be called by a different name depending on the make and model of vehicle. Also, service procedures will be different on the same vehicle depending on whether it is equipped with an F45 or an F55 system. The General Motors vehicle RPO codes are on a sticker on the spare tire cover in the trunk or in the glove compartment.

RTD and RSS incorporate the following components:

- An electronic suspension control module,
- Front and rear suspension position sensors,
- Bi-state dampers,
- A ride select switch, and
- An air compressor is used on some models.

● **SEE FIGURES 115–29 AND 115–30.**

BI-STATE AND TRI-STATE DAMPERS

The bi-state damper is also known as a **solenoid controlled damper.** Bi-state dampers are found on the RTD, RSS, and SR systems. Each of the suspension dampers used in these systems have an integral solenoid. The solenoid valve provides various amounts of damping by directing hydraulic damping fluid in the suspension shock absorber or strut. ● **SEE FIGURE 115–31.**

The General Motors version of ESC is called the vehicle stability enhancement system (VSES) and includes an additional level of vehicle control to the EBCM. VSES is also known as **Stabilitrak.**

The purpose of the vehicle stability enhancement system along with the antilock brake system (ABS) is to provide vehicle stability enhancement during oversteer or understeer conditions.

The pulse-width modulation (PWM) voltage signal from the suspension control module controls the amount of current flow through each of the damper solenoids. With a low PWM signal de-energized, more hydraulic damping fluid is allowed to bypass the main suspension damper passage, resulting in a softer damping mode.

As the PWM signal increases, or is energized, the damping mode becomes more firm. ● **SEE FIGURE 115–32.**

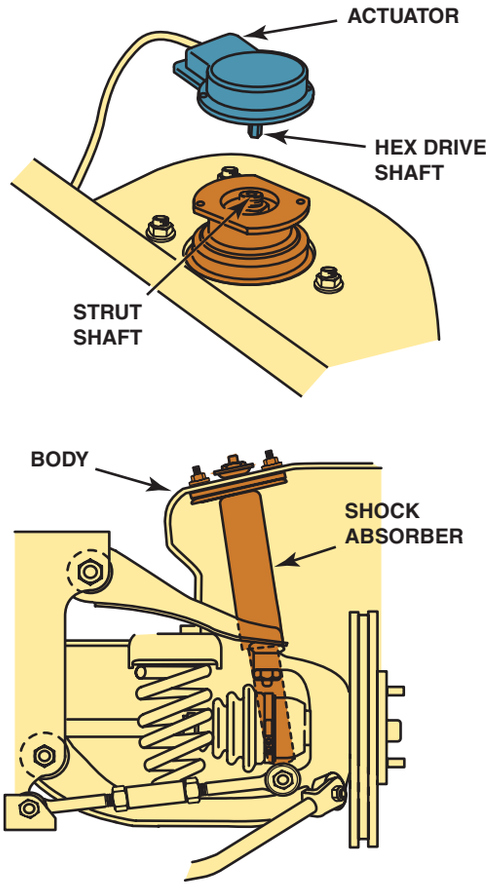


FIGURE 115–30 Bi-state dampers (shocks) use a solenoid to control fluid flow in the unit to control compression and rebound actions.

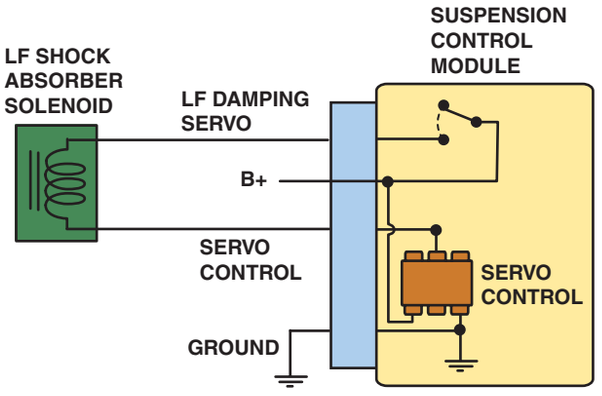


FIGURE 115–31 Solenoid valve controlled shock absorber circuit showing the left front (LF) shock as an example.

NOTE: If the suspension module does not control the shock absorber solenoid, a full soft damping mode results. In some system malfunctions, the module may command one or all of the damper solenoids to a full soft damping.

The main difference between a tri-state damper and a bi-state damper is that the tri-state damper uses an electrical actuator, whereas the bi-state damper is solenoid controlled.

The three damping modes include:

- Comfort
- Normal
- Sport

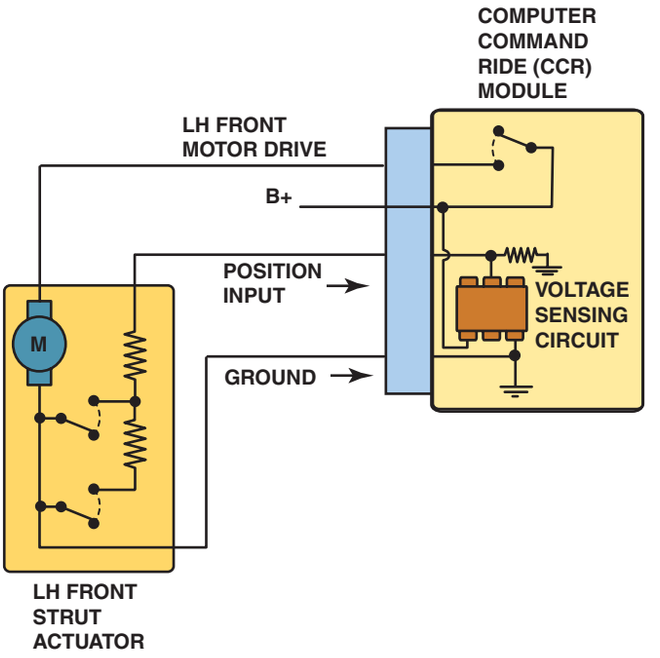


FIGURE 115–32 A typical CCR module schematic.

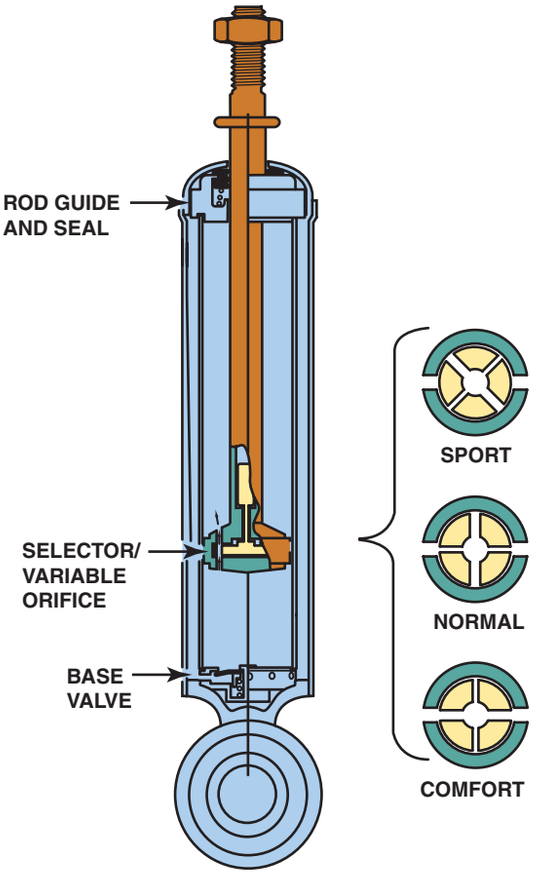


FIGURE 115–33 The three dampening modes of a CCR shock absorber.

A tri-state damper has an integral electrical strut actuator that rotates a selector valve to change the flow of hydraulic damping fluid. ● **SEE FIGURE 115–33.**

The CCR module controls the operation of the strut actuators to provide the three damping modes.

The strut position input provides feedback to the CCR module. The strut position input is compared to the commanded actuator position to monitor system operation. ● **SEE FIGURE 115–34.**

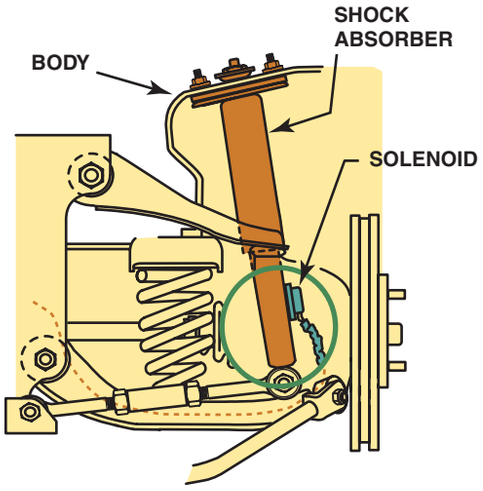


FIGURE 115–34 Integral shock solenoid.

FREQUENTLY ASKED QUESTION

What Are Self-Leveling Shocks?

A German company, ZF Sachs, supplies a self-leveling shock absorber to several vehicle manufacturers, such as Chrysler for use on the rear of minivans, plus BMW, Saab, and Volvo. The self-leveling shocks are entirely self-contained and do not require the use of height sensors or an external air pump. ● **SEE FIGURE 115–35.**

The shock looks like a conventional shock absorber but contains the following components:

- Two reservoirs in the outer tube
- An oil reservoir (low-pressure reservoir)
- A high-pressure chamber

Inside the piston rod is the pump chamber containing an inlet and an outlet valve. When a load is placed in the rear of the vehicle, it compresses the suspension and the shock absorber. When the vehicle starts to move, the internal pump is activated by the movement of the body. Extension of the piston rod causes oil to be drawn through the inlet valve into the pump. When the shock compresses, the oil is forced through the outlet valve into the high-pressure chamber. The pressure in the oil reserve decreases as the pressure in the high-pressure chamber increases. The increasing pressure is applied to the piston rod, which raises the height of the vehicle.

When the vehicle's normal height is reached, no oil is drawn into the chamber. Because the shock is mechanical, the vehicle needs to be moving before the pump starts to work. It requires about 2 miles of driving for the shock to reach the normal ride height. The vehicle also needs to be driven about 2 miles after a load has been removed from the vehicle for it to return to normal ride height.

AUTOMATIC LEVEL CONTROL (ALC)

Vehicles that have an air inflator system as part of the ALC system also have an air inflator switch. The air inflator switch is an input to the ALC and AS system. The inflator switch is used to control the air inflator system operation and provides a signal to the ALC or AS module to initiate compressor activation.



FIGURE 115–35 A typical ZF Sachs self-leveling shock, as used on the rear of a Chrysler minivan.

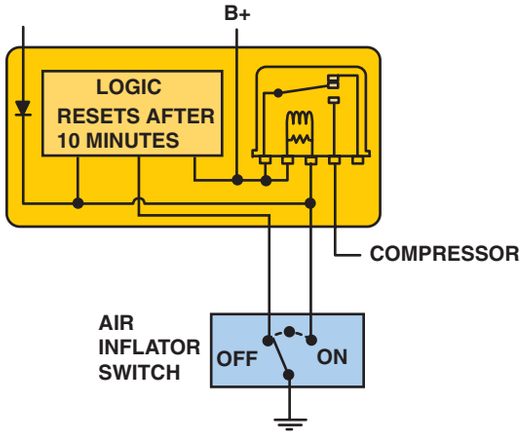


FIGURE 115–36 Schematic of the ALC system.

With the ignition on, the driver can turn the system to ON. The switch will command the compressor to run for up to 10 minutes, allowing time to inflate a tire or other items requiring air.

NOTE: There are no DTCs associated with compressor assembly.

INFLATOR OR COMPRESSOR RELAY The suspension control module energizes the relay to activate the compressor motor. This adjusts the rear trim height as needed. The suspension control module controls the compressor relay for normal operation or for the accessory air inflator.

To avoid compressor overheating, the timer within the suspension control module limits the compressor run time to 10 minutes. ● **SEE FIGURE 115–36.**

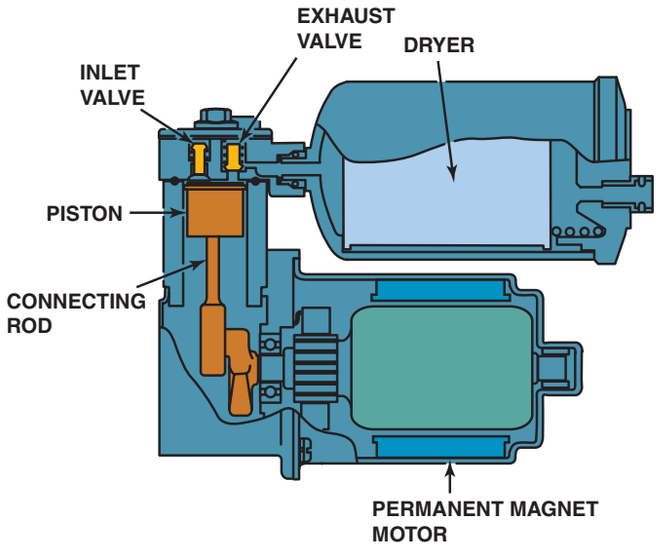


FIGURE 115–37 Air compressor assembly can be located at various locations depending on the vehicle.

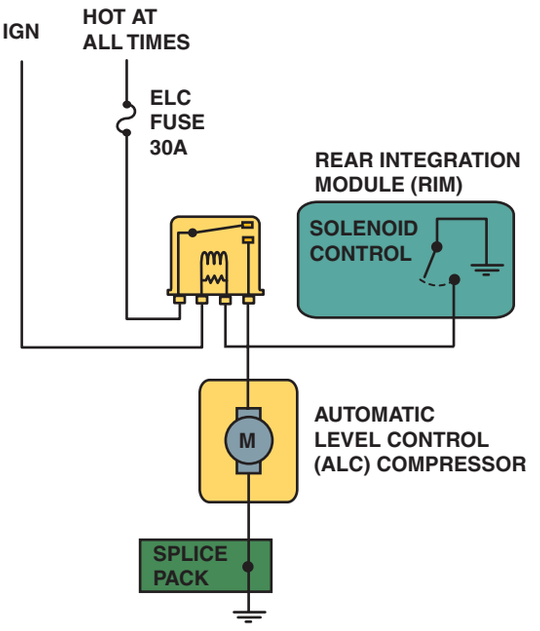


FIGURE 115–39 Schematic showing the rear integration module (RIM) and how it controls the ALC compressor.

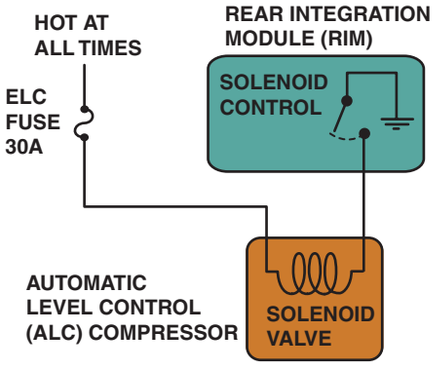


FIGURE 115–38 The exhaust solenoid is controlled by the rear integration module (RIM).

On RTD or RSS systems with a compressor, the scan tool may display DTCs associated with compressor relay operation. On some vehicle applications, the scan tool will display data relating to relay operation and can be used to command the relay to verify proper operation.

COMPRESSOR The compressor is a positive-displacement air pump and can generate up to 150 lbs. of pressure per square inch (PSI). The compressor is found on the ALC, AS, RTD, and RSS systems. A 12-volt permanent magnet motor drives the compressor. The compressor supplies compressed air to the rear air shock absorbers or struts to raise the vehicle. ● **SEE FIGURE 115–37.**

AIR DRYER. Within the compressor is an air dryer. The air dryer is responsible for removing moisture from the compressor system. Improper air dryer operation can cause a premature failure in the system if an air line restriction occurs due to excessive moisture build-up. A dryer on the output side of the compressor contains silica gel **desiccant,** which removes moisture from the discharge air before it travels through the nylon air hoses to the air chamber of the rear shocks.

EXHAUST SOLENOID. The exhaust solenoid, which is located on the compressor, relieves pressure in the system. The ground-side switched exhaust solenoid has three main functions:

1. It releases compressed air from the shock absorbers or air springs to lower the vehicle body.
2. It relieves compressor head pressure. By exhausting air, it protects compressor start-up from high head pressure, which can possibly cause fuse failure.
3. The solenoid acts as a pressure relief valve, which limits overall system pressure.

The special functions on many scan tools can be used to command the solenoid and to verify its operation. ● **SEE FIGURES 115–38 AND 115–39.**

MAGNETO-RHEOLOGICAL (MR) SUSPENSION

MR fluid shocks use a working fluid inside the shock that can change viscosity rapidly depending on electric current sent to an electromagnetic coil in each device. The fluid is called **magneto-rheological (MR)** and is used in monotube-type shock absorbers. This type of shock and suspension system is called the **magneto-rheological real-time damping (MRRTD)** or **chassis continuously variable real-time dampening magneto-rheological suspension (CCVRTMR).**

Under normal operating conditions, the fluid flows easily through orifices in the shock and provides little dampening. When a large or high-frequency bump is detected, a small electrical current is sent from the chassis controller to an electromagnetic coil in each shock and the iron particles in the fluid respond within 3 milliseconds (ms), aligning themselves in fiberlike strands. ● **SEE FIGURES 115–40 AND 115–41.**



FIGURE 115–40 Vehicles that use magneto-rheological shock absorbers have a sensor located near each wheel, as shown on this C6 Corvette.



FIGURE 115–41 The controller for the magneto-rheological suspension system on a C6 Corvette is located behind the right front wheel.

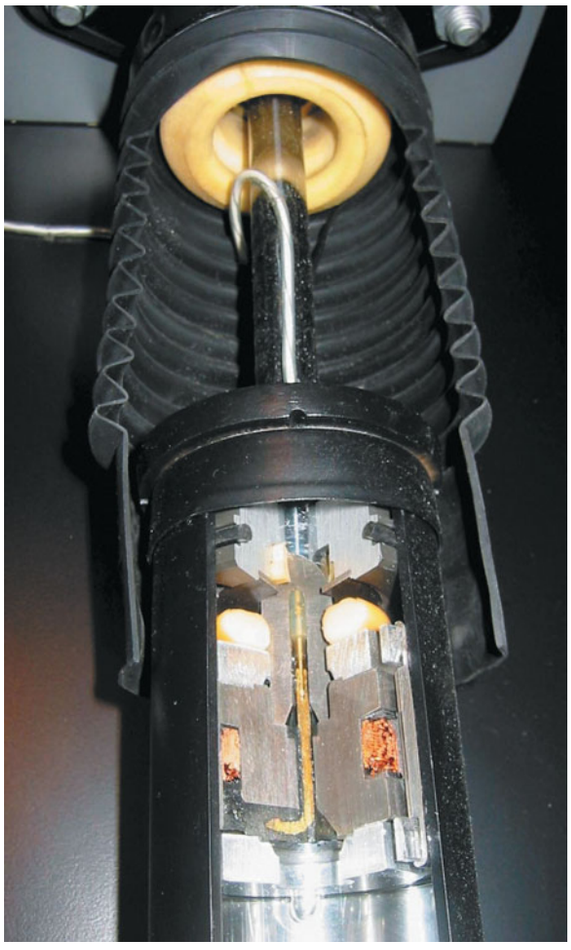


FIGURE 115–42 A cutaway of a magneto-rheological shock absorber as displayed at the Corvette Museum in Bowling Green, Kentucky.

This causes the MR fluid to become thick like peanut butter and increases the firmness of the shock. This type of shock absorber is used to control squat during acceleration and brake dive as well as to reduce body roll during cornering by the chassis controller. ● **SEE FIGURE 115–42.**

? FREQUENTLY ASKED QUESTION

Can Computer-Controlled Shock Absorbers and Struts Be Replaced with Conventional Units?

Maybe. If the vehicle was manufactured with or without electronic or variable shock absorbers, it may be possible to replace the originals with the standard replacement units. The electrical connector must be disconnected, and this may cause the control system to store a diagnostic trouble code (DTC) and/or turn on a suspension fault warning light on the dash. Some service technicians have used a resistor equal in resistance value of the solenoid or motor across the terminals of the wiring connector to keep the controller from setting a DTC. All repairs to a suspension system should be done to restore the vehicle to like-new condition, so care should be exercised if replacing electronic shocks with nonelectronic versions.

TROUBLESHOOTING REAR ELECTRONIC LEVELING SYSTEMS

The first step with any troubleshooting procedure is to check for normal operation. Some leveling systems require that the ignition key be on (run), while other systems operate all the time. Begin troubleshooting by placing approximately 300 lb (135 kg) on the rear of the vehicle. If the compressor does not operate, check to see if the sensor is connected to a rear suspension member and that the electrical connections are not corroded.

Also check the condition of the compressor ground wire. It must be tight and free of rust and corrosion where it attaches to the vehicle body. If the compressor still does not run, check to see if 12 volts are available at the power lead to the compressor. If

necessary, use a fused jumper wire directly from the positive (+) of the battery to the power lead of the compressor. If the compressor does not operate, it must be replaced.

If the ride height compressor runs excessively, check the air compressor, the air lines, and the air shocks (or struts) with soapy water for air leaks. Most air shocks or air struts are not repairable and must be replaced. Most electronic leveling systems provide some adjustments of the rear ride height by adjusting the linkage between the height sensor and the rear suspension. ● **SEE FIGURE 115–43.**

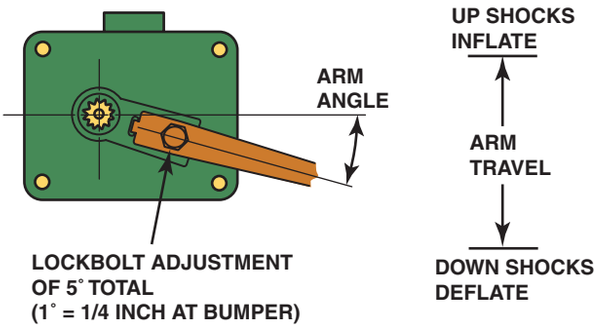


FIGURE 115–43 Most electronic level-control sensors can be adjusted, such as this General Motors unit.

REVIEW QUESTIONS

1. What type of sensor is usually used on electronically controlled suspensions to sense the height of the vehicle?
2. Why is the vehicle speed sensor used as input for many electronic suspension systems?
3. What is a lateral accelerometer sensor and why is it used?
4. Why does the output side of the suspension air compressor contain a desiccant?

CHAPTER QUIZ

1. What type of sensor is used as a height sensor on vehicles equipped with an electronically controlled suspension?
   a. Hall-effect
   b. Photo cell
   c. Potentiometer
   d. All of the above
2. Which sensors do most vehicles use if equipped with electronic suspension?
   a. Height sensors
   b. Steering wheel position sensors
   c. Lateral accelerometer sensors
   d. All of the above
3. A lateral acceleration sensor is used to provide the suspension control module with feedback regarding _____ force.
   a. Cornering
   b. Acceleration
   c. Braking
   d. All of the above
4. A steering wheel position sensor is being discussed. Technician A says that the sensor is used to determine the direction the steering wheel is turned. Technician B says that the sensor detects how fast the steering wheel is turned. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
5. Technician A says that an electronic control module used in the suspension system is the same as that used for engine control. Technician B says that most electronically controlled suspension systems use a separate electronic control module. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. What type of actuator is used on electronically controlled suspensions?
   a. Solenoid
   b. Electric motor
   c. Either a or b
   d. Neither a nor b
7. Why is the typical rear load-leveling system connected to the ignition circuit?
   a. To keep the system active for a given time after the ignition is switched off
   b. To prevent the system from working unless the ignition key is on
   c. To keep the compressor from running for an extended period of time
   d. All of the above
8. Which sensor can be tested by unbolting the sensor and with the ignition on, engine off (KOEO), looking at the scan tool data?
   a. "G" sensor
   b. Wheel speed sensor
   c. Vehicle speed sensor
   d. Suspension sensor
9. The *firm* setting is usually selected by the electronic suspension control module whenever which of the following occurs?
   a. High speed
   b. Rapid braking
   c. Rapid acceleration
   d. All of the above
10. Which of the following is the *least likely* sensor to cause an electronic suspension fault?
    a. Yaw sensor
    b. Throttle position (TP) sensor
    c. Steering wheel position sensor
    d. Vehicle speed sensor

chapter 116

STEERING COLUMNS AND GEARS

OBJECTIVES: After studying Chapter 116, the reader will be able to: • Prepare for ASE Suspension and Steering (A4) certification test content area "A" (Steering System Diagnosis and Repair). • Discuss steering columns and intermediate shafts. • Explain how a recirculating ball-nut and worm gear steering gear system works. • Describe how a rack-and-pinion steering gear works.

KEY TERMS: Collapsible column 1360 • Flexible coupling 1360 • Gear lash 1367 • Inflator module 1358 • Kickback 1369 • Lock plate 1363 • Overcenter adjustment 1367 • Pinion torque 1369 • Pitman arm 1363 • Pitman shaft 1363 • Preload 1366 • Rack and pinion 1367 • Rack support 1369 • Sector gear 1363 • Sector shaft 1363 • Steering shaft 1359 • Stub shaft 1361 • Telescoping steering column 1361 • Tilt steering column 1361 • Universal joint 1359 • Variable ratio 1364 • Worm gear 1363

STEERING WHEELS

The steering wheel, which consists of a rigid rim and a number of spokes connecting the rim to a center hub, attaches to the top of the steering shaft at its center. Most steering wheel hubs have internal splines that fit over external splines on the steering shaft. A bolt or nut at the center of the hub secures the wheel to the shaft. The steering wheel may also contain controls for the cruise control and audio controls, as well as the driver's airbag.

HORN OPERATION The horn circuit is in a series circuit in which electricity has one path that it can follow when the circuit is complete. A normally open switch in an electrical circuit is inside the horn button. When the driver pushes the horn button, the contacts on the switch close, allowing electrical current through the circuit to operate the horn. ● **SEE FIGURE 116–1.** A relay circuit is a more common method of wiring the horn. In a relay, closing a switch in a low-current series circuit triggers the high-current circuit that powers the horn.

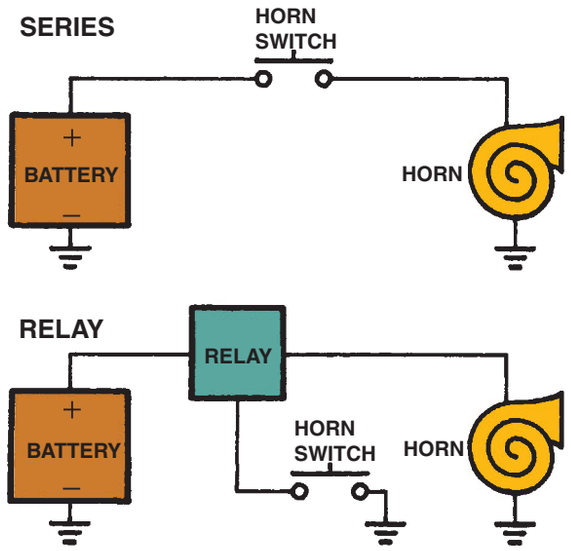


FIGURE 116–1 Most steering columns contain a horn switch. The horn button is a normally open (NO) switch. When the button is depressed, the switch closes, which allows electrical current to flow from the battery to sound the horn. Most horn circuits use a relay to conduct the horn current.

AIRBAGS An airbag is a device made of nylon cloth that is covered with neoprene. The airbag is folded and stored in the front center of the steering wheel. In a front-end collision, the airbag inflates in a fraction of a second to provide a cushion between the driver and the steering wheel and dashboard. ● **SEE FIGURE 116–2.** The part of the steering wheel where the airbag is stored is called the **inflator module.** The module also contains an igniter, a canister of flammable gas, and a number of sodium azide pellets. The sodium azide pellets burn quickly, and rapidly release nitrogen gas while they burn. The nitrogen gas fills the airbag. As it inflates, the airbag tears open the module cover and spreads out across the steering wheel, windshield, and dashboard. The entire process, from sensor reaction to full airbag deployment, takes 30 to 65 milliseconds. Within a second of inflating, the bag deflates partially as the nitrogen gas escapes through exhaust vents in the side of the airbag. Once deployed, an airbag cannot be reused.

The module fits in front of the nut that secures the steering wheel to the steering shaft. Bolts at the back of the steering wheel fasten the airbag module to the steering wheel. Electrical current is provided to the airbag through the spiral cable, which is also known as a clockspring or coil. The spiral cable connects to the airbag module with two wire leads. The spiral cable is a tightly coiled metal strip that allows steering wheel rotation while maintaining electrical continuity. ● **SEE FIGURE 116–3.**

CAUTION: Whenever working on the steering column, consult service information for the recommended airbag disarming procedure.

STEERING COLUMNS

The steering shaft transmits rotary motion from the steering wheel to the steering gear, while the column jacket that encases it attaches to the vehicle body and offers a stationary mounting

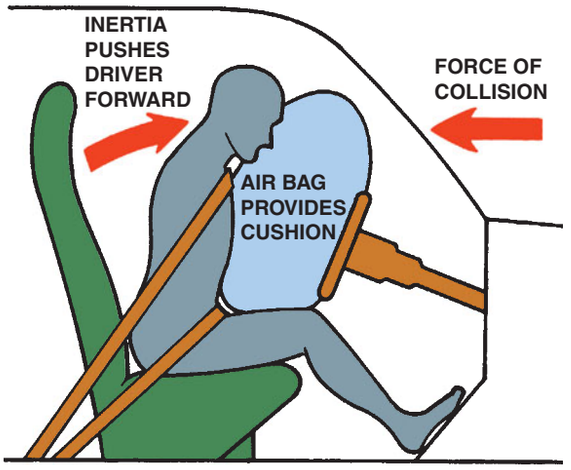


FIGURE 116–2 The airbag inflates at the same time the driver moves toward the steering wheel during a front-end collision and supplements the protection of the safety belt.

point for a number of switches and mechanisms. ● **SEE FIGURE 116–4.**

STEERING SHAFT The **steering shaft** extends from the steering wheel to the steering gear. A bolt or nut secures the shaft to the steering wheel, and a flexible coupling joins it to the steering gear input shaft. The coupling can be a simple rubber or fabric insert, a universal joint (U-joint), or a pot joint. In addition to allowing a directional change of the shaft, a pot joint permits a limited amount of plunging motion. ● **SEE FIGURE 116–5.**

UNIVERSAL JOINT A **universal joint,** or U-joint, consists of two yokes with a steel crosspiece joining them together. ● **SEE FIGURE 116–6.** Universal joints allow changes in the angle between two rotating shafts. In a steering shaft, U-joints allow rotary motion transfer between the steering wheel and the steering gear even though the steering shaft meets the steering gear input shaft at an angle. On

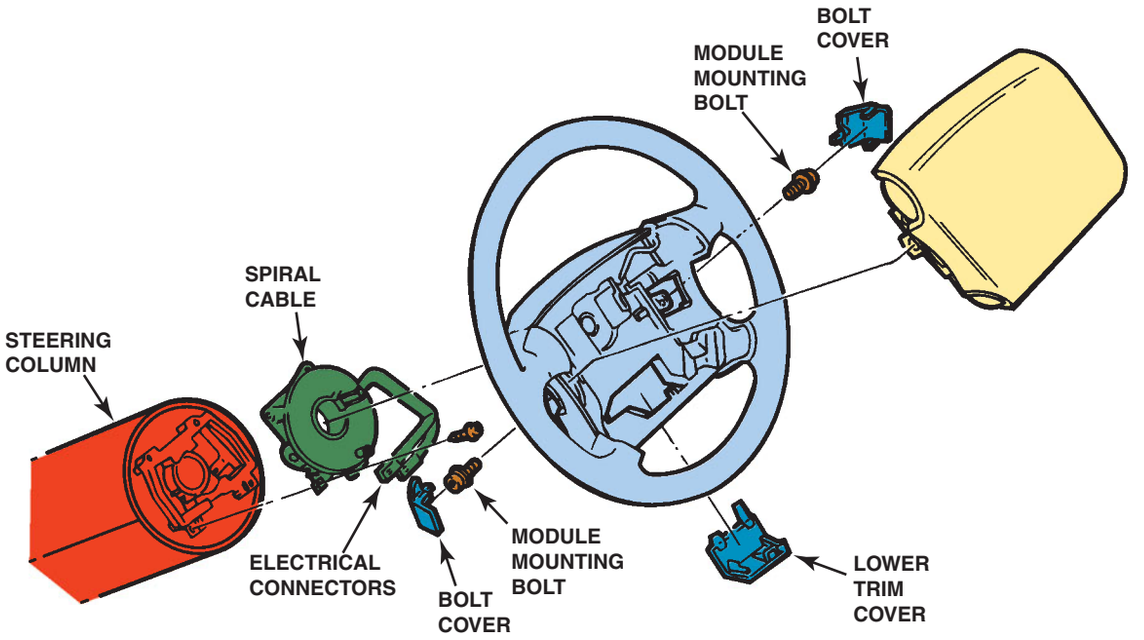


FIGURE 116–3 The airbag module attaches to the steering wheel and is removed as an assembly to service the steering wheel and column.

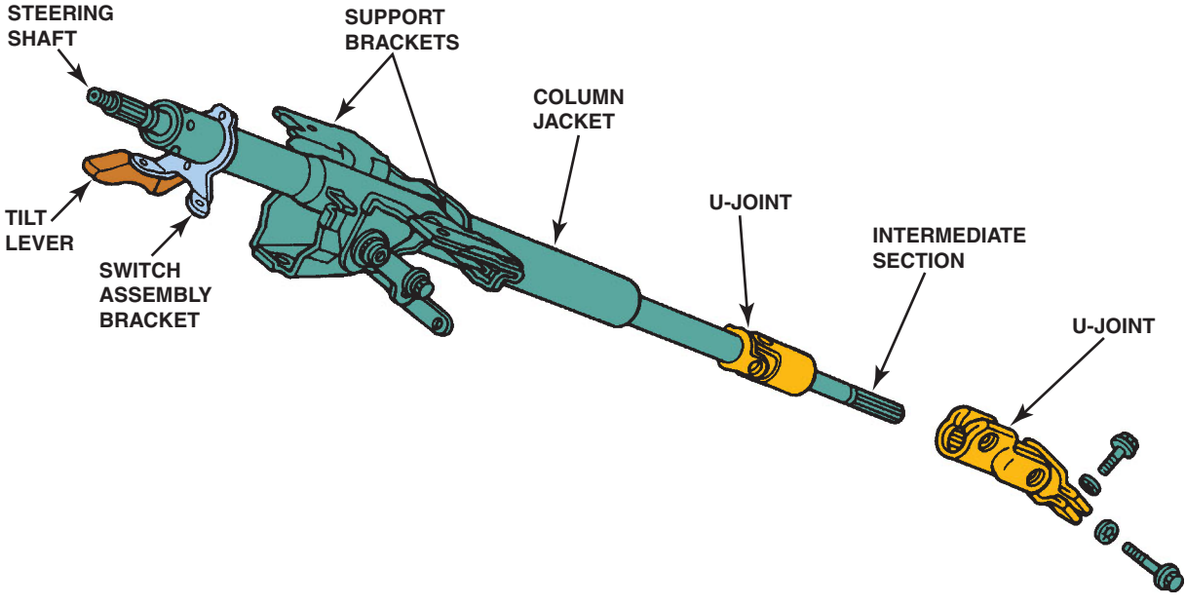


FIGURE 116–4 The steering shaft links the steering wheel to the steering gear while the column jacket, which surrounds part of the shaft, holds support brackets and switches. This steering shaft has a small intermediate section between the main section and the steering gear.

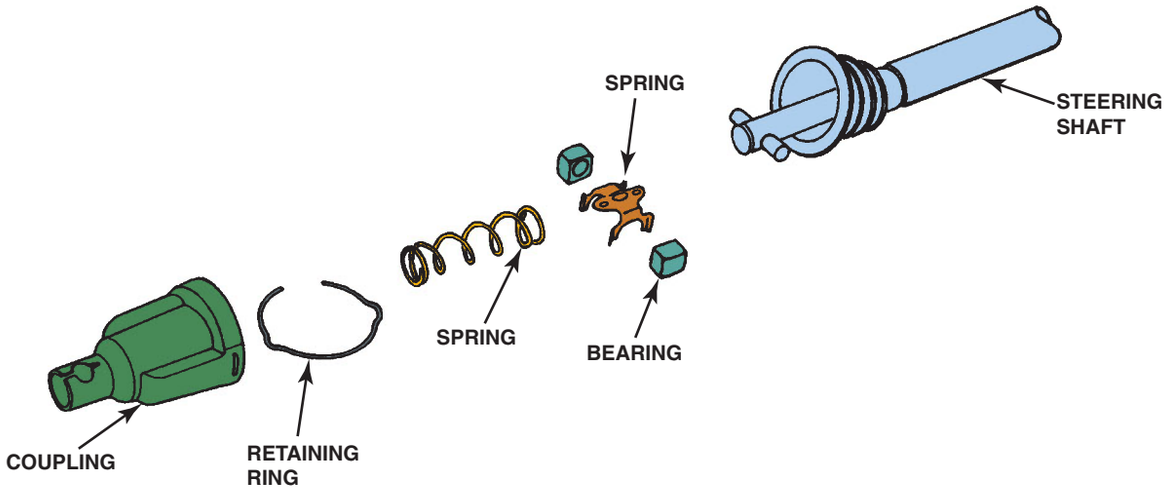


FIGURE 116–5 A pot joint is a flexible coupling used to join two shafts that allow plunging motion.

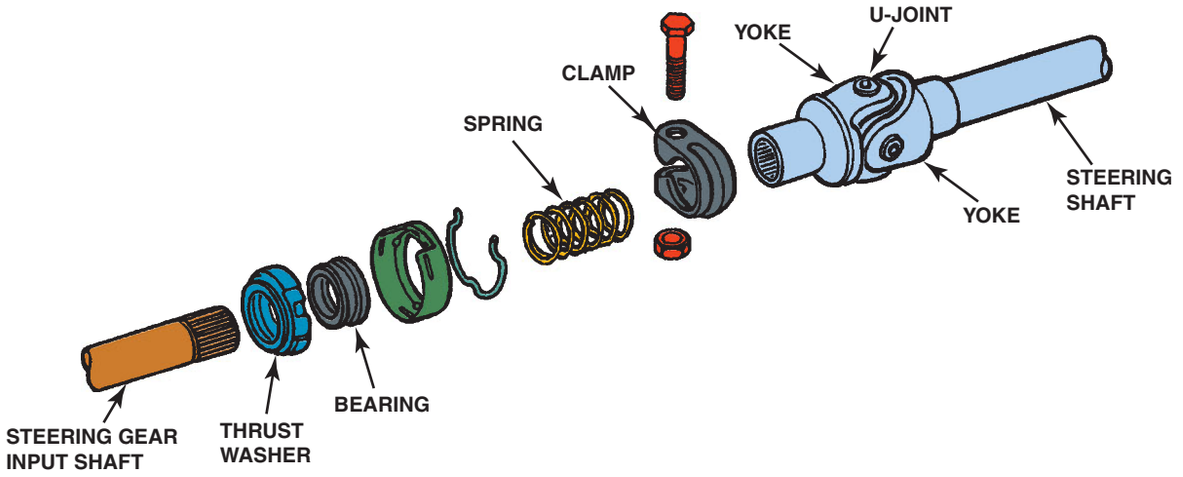


FIGURE 116–6 A typical intermediate steering shaft assembly showing a U-joint and related components.

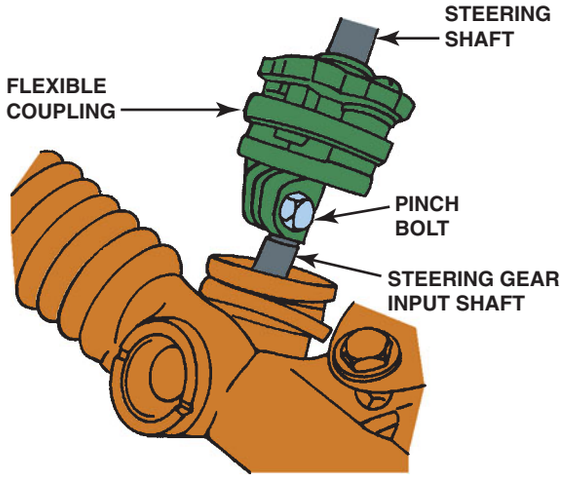


FIGURE 116–7 A flexible coupling is used to isolate road noise and vibration from the steering shaft.

some models the steering shaft itself is assembled in sections that are connected by U-joints. This permits the steering shaft to bend around obstacles between the steering wheel and the steering gear.

FLEXIBLE COUPLING A **flexible coupling** is a simple device made of rubber, or rubber reinforced with fabric, that is placed between two shafts to allow for a change in angle between them. ● **SEE FIGURE 116–7.** The rubber in a steering shaft flexible coupling absorbs vibrations and helps keep the steering wheel from shaking. A fail-safe connection between the steering shaft and the steering gear input shaft keeps the two shafts linked should the rubber coupling wear out or break. This allows the driver to maintain steering control, although the steering feels loose when this happens.

COLUMN COVER To keep the wiring from the jacket-mounted switches out of sight, the part of the steering column that extends into the passenger compartment is shrouded by the column cover. ● **SEE FIGURE 116–8.** The column cover is usually at least two separate pieces, top and bottom. A knee bolster that mounts under the steering column is a safety feature designed to keep the driver from sliding forward during a collision. Knee bolsters are part of the passive restraint system required to meet U.S. federal safety standards on certain vehicles.

COLLAPSIBLE COLUMN Federal law requires that all vehicles sold in the United States have steering columns and shafts that collapse, called **collapsible columns,** during a head-on collision to absorb some of the energy of the crash and lessen the danger of injury to the driver. ● **SEE FIGURE 116–9.** One early method used a section of the steering column constructed out of mesh, which would collapse easily during a crash. Another method is to use a two-piece column. One section of the column has a smaller diameter so that it fits inside the other and rides on a roller bearing. During a

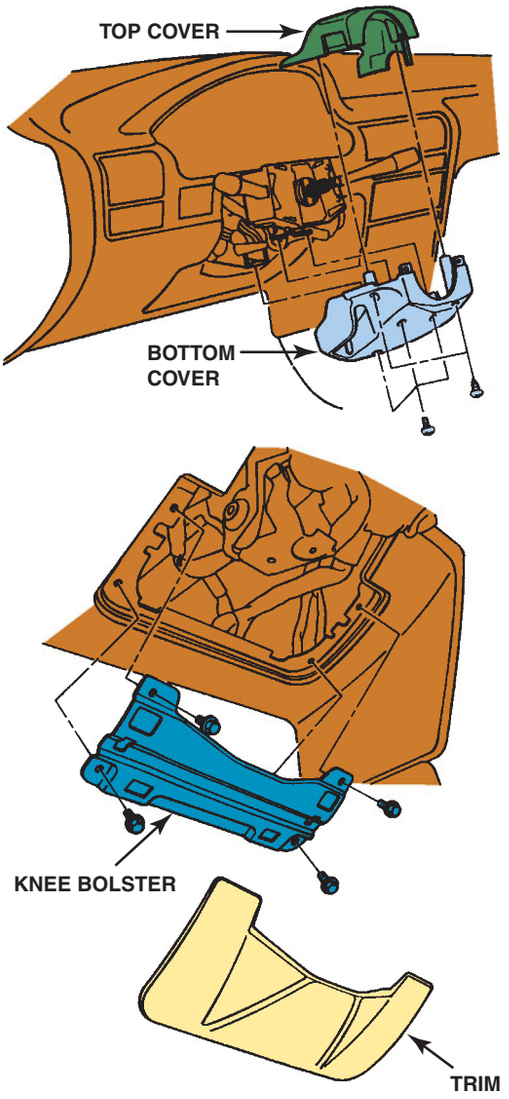


FIGURE 116–8 Steering column covers are often part of the interior trim.

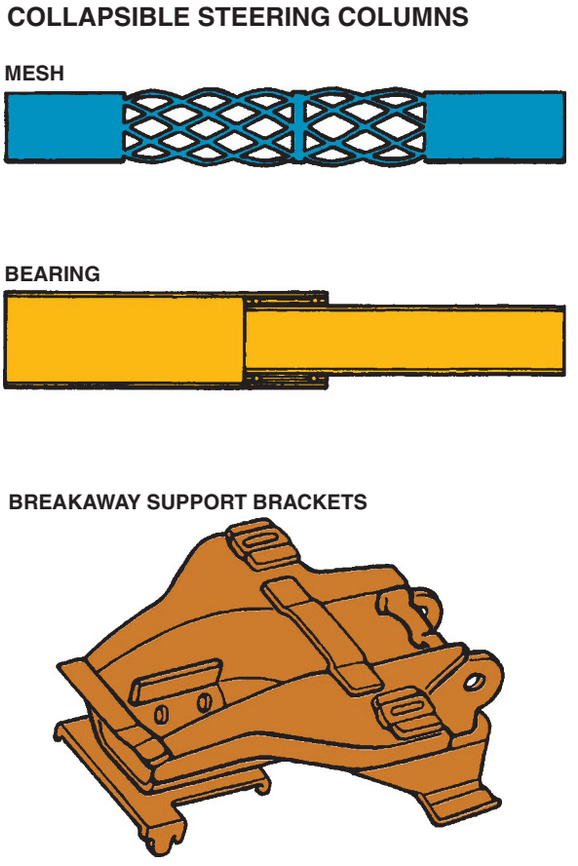


FIGURE 116–9 Collapsible steering columns include a mesh design that crushes easily, a bearing design that allows one section of the column to slide into the other, and a breakaway device that separates the steering column from the body of the vehicle in the event of a front-end collision.

collision, the smaller section slides down into the larger one to collapse like a telescope.

TILT MECHANISMS Many steering columns have tilt mechanisms, which allow the driver to adjust the angle of the steering wheel relative to the steering column. In a typical **tilt steering column,** the steering shaft has a short section at the top joined to the rest of the steering shaft either by a U-joint or gears. Most tilt mechanisms are some sort of ratchet device that enables the driver to lift the steering wheel and the top section of the shaft and place them in the desired position. ● **SEE FIGURE 116–10.** Usually, spring tension locks the steering wheel in place on the ratchet, and a release lever compresses the spring to allow tilt adjustment.

TELESCOPING STEERING COLUMNS Some steering columns are designed to **telescope,** which means that the top of the steering shaft and jacket can be pulled out toward the driver or pushed in toward the dashboard, and then locked into the new position.

STEERING COLUMN CONSTRUCTION The steering shaft is at the center of the steering column. ● **SEE FIGURES 116–11 AND 116–12.** The top end of the steering shaft splines to the center of the steering wheel, and a large nut fastens the steering wheel to the shaft. The lock housing, which contains the ignition lock cylinder, encases the top part of the steering shaft. The steering column jacket covers the shaft under the ignition lock housing, and the gear selector lever housing fits over a portion of the column jacket.

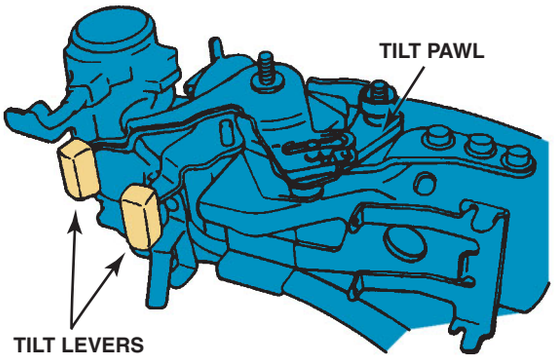
A U-joint connects the lower end of the steering shaft to a small intermediate shaft, often called a **stub shaft.** Because this steering column includes a gear selector lever, the lower end of the column also incorporates an attachment point that connects the shift tube to the gear shift rod. The intermediate shaft extends through a hole in the floor where it is coupled to the steering gear input shaft by a U-joint.

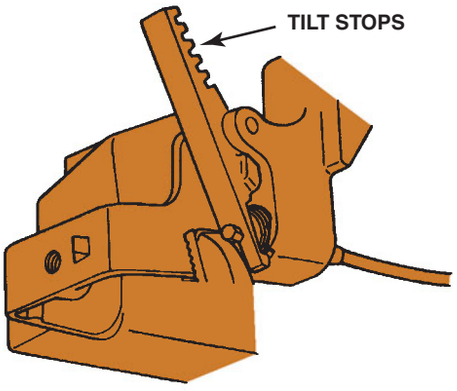
A toe plate bolts to the floor of the passenger compartment to cover the shaft opening and to protect the interior from noise, drafts,

TECH TIP

Do Not Pound on the Steering Column

Always use a steering wheel puller and/or the special tools recommended by the vehicle manufacturer when servicing the steering column. If a hammer is used on the steering shaft in an attempt to remove a steering wheel, the shaft could collapse, requiring the replacement of the entire steering column assembly.





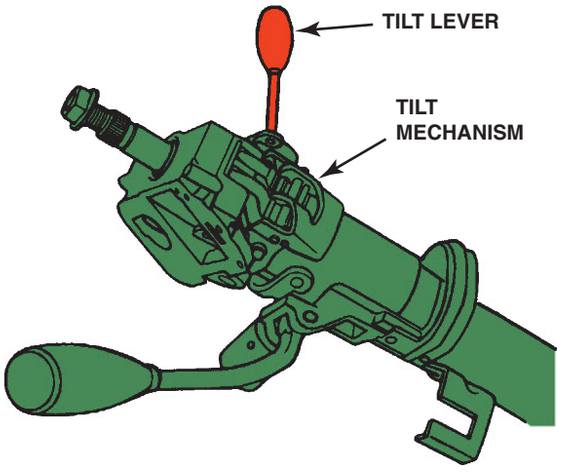


FIGURE 116–10 Tilt mechanisms vary by design and vehicle manufacturer, although most use a ratchet to position the top portion of the steering column.

and dirt. ● **SEE FIGURE 116–13.** The toe plate has a tube for the intermediate shaft, and a seal and silencer fit on top of the tube.

Two sections at the upper end of the steering column house the column-mounted controls. ● **SEE FIGURE 116–14.** The lock housing, seated on top of the column jacket, is the topmost piece and contains the turn signal lever, hazard light control, and ignition lock. The gear selector lever and its housing are just below the lock housing, and the housing encases the top of the steering column jacket.

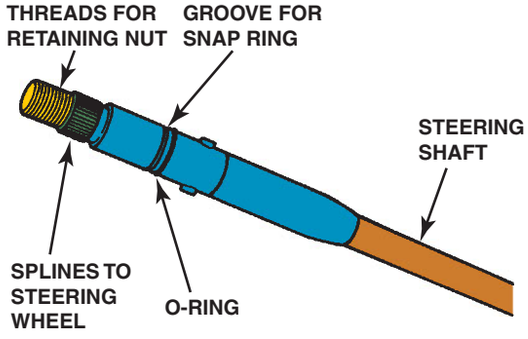


FIGURE 116–12 The steering shaft splines onto the steering wheel.

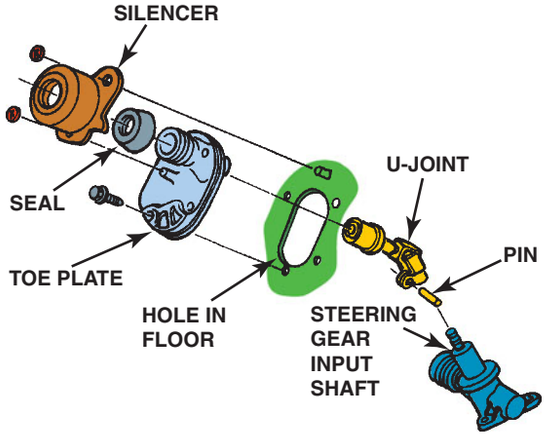


FIGURE 116–13 The toe plate seals the hole from the steering shaft and helps seal out noise and moisture.

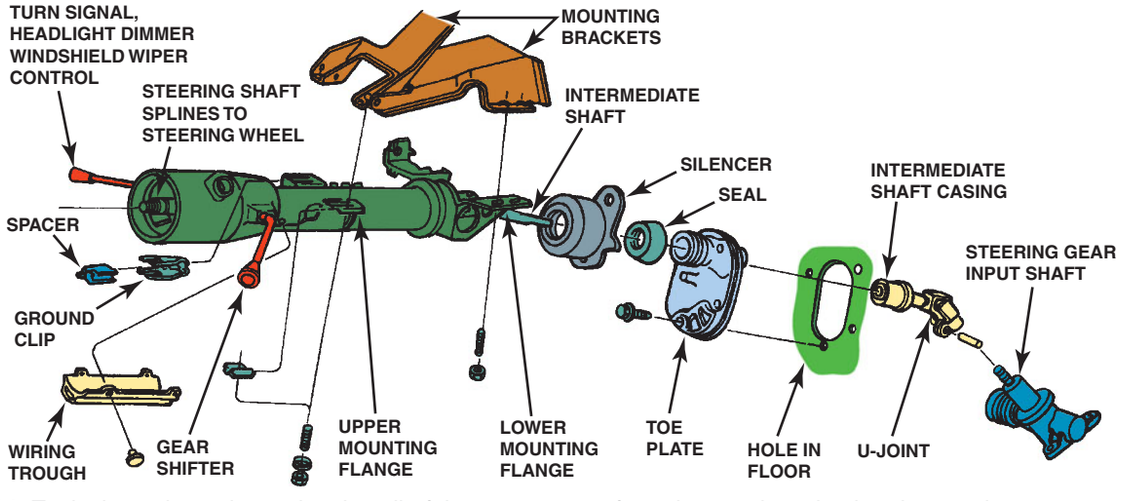


FIGURE 116–11 Typical steering column showing all of the components from the steering wheel to the steering gear.

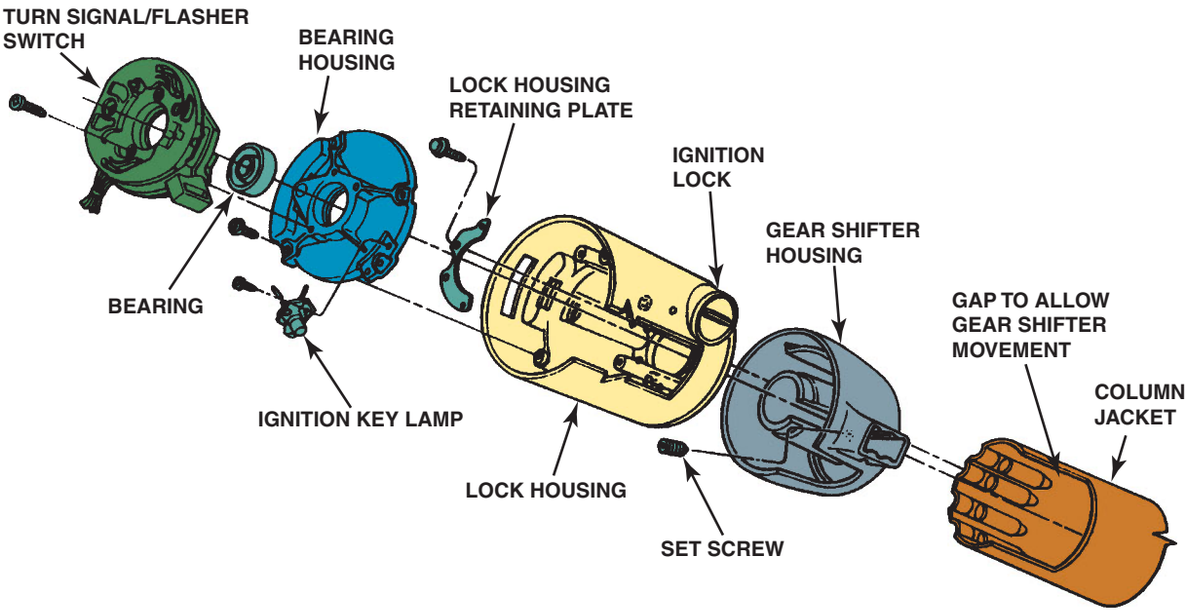


FIGURE 116–14 The upper section of the steering column includes the lock housing and switches.

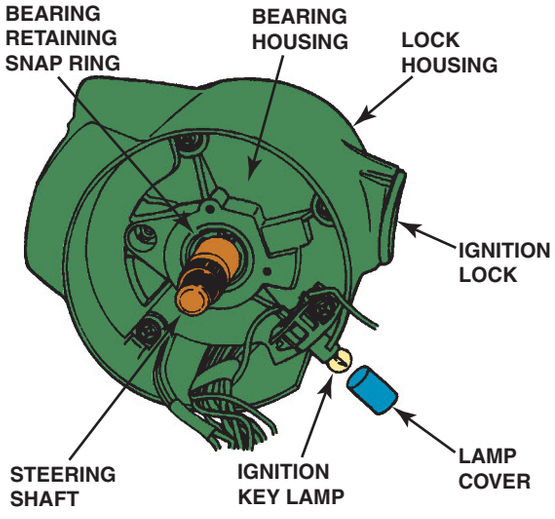


FIGURE 116–15 The upper section of the steering column contains the steering shaft bearing.

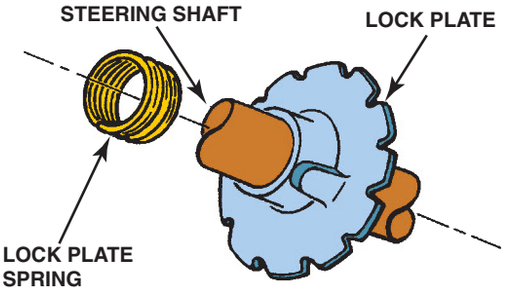


FIGURE 116–16 The lock plate engages an ignition lock pawl to keep the steering wheel in one position when the ignition is off.

The lock housing contains the ignition lock cylinder, several electrical switches, and a steering shaft bearing. Some of the switches have driver-operated controls on the outside of the lock housing.

A multifunction switch operates the turn signals, the windshield wiper and washer switch, and the dimmer switch.

Most steering shafts ride on at least two bearings, one near the top and one near the bottom of the shaft, to allow the shaft to rotate freely without affecting other parts of the steering column. ● **SEE FIGURE 116–15.** A snap ring at the center of the bearing housing rests in a groove on the steering shaft to secure the bearing, and an O-ring on the steering shaft keeps lubricant in the bearing.

Underneath the bearing and housing is a **lock plate** and coil spring that lock the steering shaft into position when the driver removes the ignition key. ● **SEE FIGURE 116–16.** The ignition lock cylinder, which is under the lock plate, moves a bellcrank that in turn operates a spring and lever assembly linked to the ignition switch actuating rod.

CONVENTIONAL STEERING GEARS

PURPOSE AND FUNCTION A conventional steering gear uses steering gear assembly that moves linkages and support arms to steer the vehicle.

All steering gears have an input gear, which transmits rotary movement from the steering wheel into the steering gear, and an output gear, which causes the steering linkage to move laterally. The rotation of the steering wheel is transferred to the front wheels through a steering gear and linkage. The intermediate shaft is splined to a **worm gear** inside a conventional steering gear. Around the worm gear is a nut with gear teeth that meshes with the teeth on a section of a gear called a **sector gear.** The sector gear is part of a **pitman shaft,** also known as a **sector shaft,** as shown in ● **FIGURE 116–17.**

Ball, roller, or needle bearings support the sector shaft and the worm gear shaft, depending on the make and model of the gear assembly.

As the steering wheel is turned, the movement is transmitted through the steering gear to an arm attached to the bottom end of the pitman shaft. This arm is called the **pitman arm.** Whenever the steering wheel is turned, the pitman arm moves.

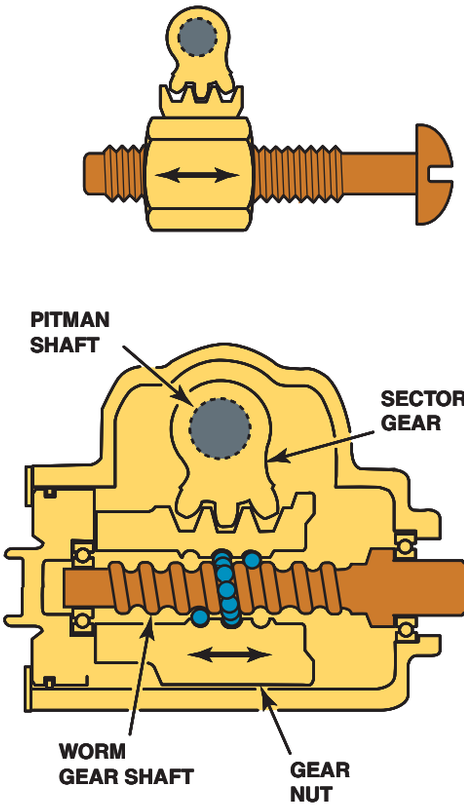


FIGURE 116–17 As the steering wheel is turned, the nut moves up or down on the threads, shown using a bolt to represent the worm gear and the nut representing the gear nut that meshes with the teeth of the sector gear.

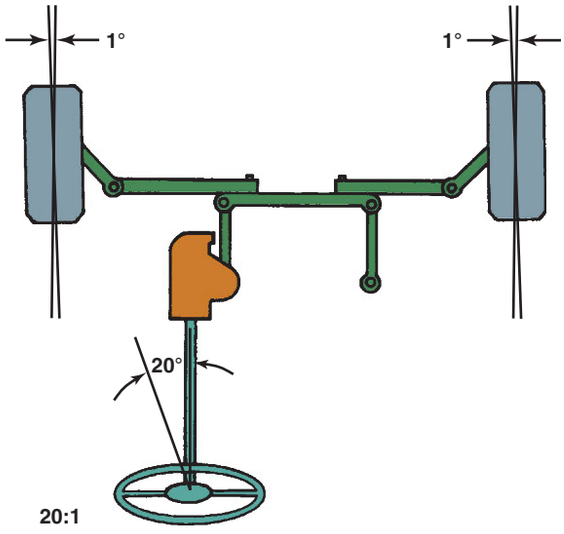


FIGURE 116–18 Steering gear ratio is the ratio between the number of degrees the steering wheel is rotated to the number of degrees the front wheel turns.

STEERING GEAR RATIO When the steering wheel is turned, the front wheels turn on their steering axis. If the steering wheel is rotated 20 degrees and results in the front wheels rotating 1 degree, then the steering gear ratio is 20:1 (read as "20 to 1"). ● **SEE FIGURE 116–18.** The front wheels usually are able to rotate through 60 to 80 degrees of rotation. The steering wheel, therefore, has to rotate 20 times the number of degrees that the wheels move.



FIGURE 116–19 Constant-ratio steering gear sector shaft. Notice that all three gear teeth are the same size.

20 × 60 degrees = 1,200 degrees, or about three full revolutions (360 degrees = 1 full turn) of the steering wheel

20 × 80 degrees = 1,600 degrees, or over four revolutions of the steering wheel

A vehicle that turns three complete revolutions from full left to full right is said to have three turns "lock to lock."

A high ratio, such as 22 to 1 (22:1), means that the steering wheel must be rotated 22 degrees to move the front wheels 1 degree. This high ratio means that the steering wheel is easier to turn than a steering wheel with a lower ratio such as 14:1. The 14:1 ratio is considered to be "faster" than the 22:1 ratio. This fast ratio allows the front wheels to be turned with less movement of the steering wheel, yet more force may be required to turn the wheel. This is considered by some to be more "sporty."

Most steering gears and some rack-and-pinion steering gears feature a **variable ratio.** This feature causes the steering ratio to decrease as the steering wheel is turned from the on-center position. The high on-center ratio (such as 16:1) provides good steering feel at highway speeds while the reduced off-center ratio (13:1) provides fewer steering wheel turns during turning and parking. The ratio is accomplished by changing the length of the gear teeth on the sector gear. ● **SEE FIGURE 116–19** for an example of the teeth of a constant-ratio sector gear.

● **SEE FIGURE 116–20** for an example of the teeth on a variable-ratio sector gear.

The sector gear meshes with the ball nut inside the steering gear, as shown in ● **FIGURE 116–21.**

RECIRCULATING BALL STEERING GEAR

PARTS AND OPERATION A recirculating ball steering gear is the most commonly used conventional steering gear. ● **SEE FIGURE 116–22.**

The end of the steering gear input shaft, or worm shaft, splines to the steering shaft U-joint and provides rotary input to the steering gear. An oil seal prevents fluid leakage where the input shaft enters

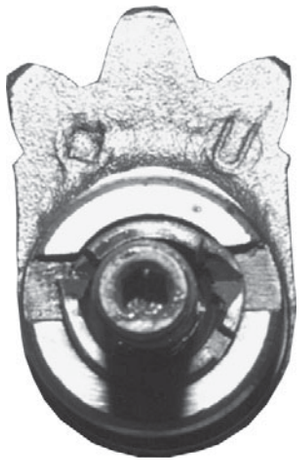


FIGURE 116–20 Variable-ratio steering gear sector shaft. Notice the larger center gear tooth.

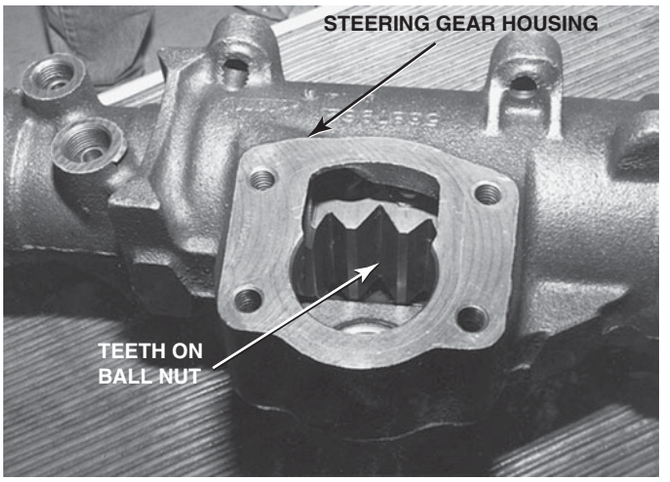
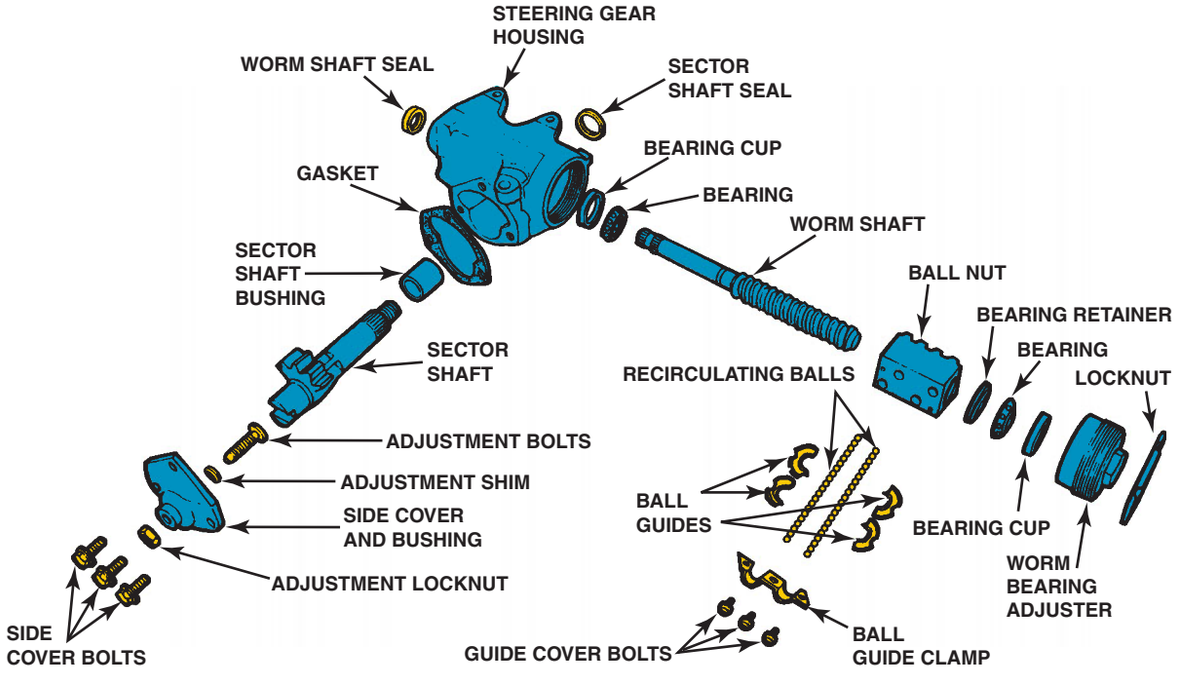


FIGURE 116–21 The sector gear meshes with the gear teeth on the ball nut.



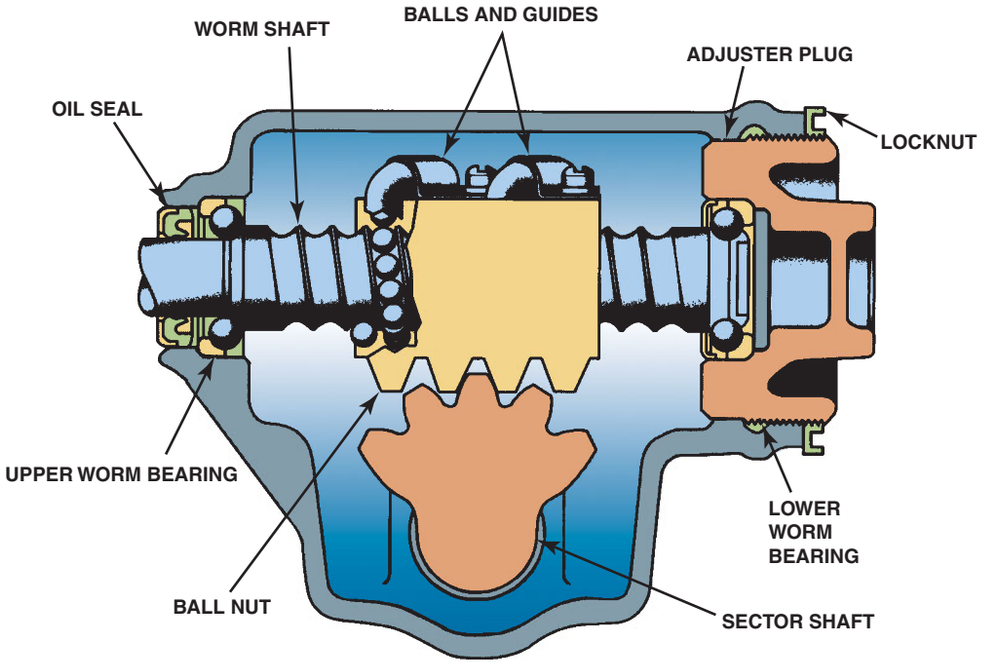


FIGURE 116–22 A typical manual recirculating ball steering gear.

the steering gear housing. At the top and the bottom of the worm gear are the upper and lower thrust bearings. The upper bearing cup seats in the housing, and the lower bearing cup seats in the adjuster plug. The thrust bearings reduce friction between the worm gear and the steering gear housing and control worm endplay.

The adjuster plug at the lower end of the worm gear holds the worm gear, shaft, and bearings inside the steering gear housing.

BALL NUT ASSEMBLY The ball nut, which has internal grooves that match the worm gear thread, fits over the worm gear. Steel balls roll through the tunnels formed by the ball nut grooves and the worm gear thread. Crescent-shaped ball-return guides link the ends of the ball-nut tunnels together, so the balls continuously circulate through the ball nut and worm gear, into the ball-return guides, and back again. These recirculating balls reduce friction and make the steering easier to rotate by the driver. A clamp secured by screws holds the return guides in place on one side of the ball nut. Gear teeth mesh with the teeth of the sector gear machined into the outside of the ball nut on the side opposite the ball-return guides.

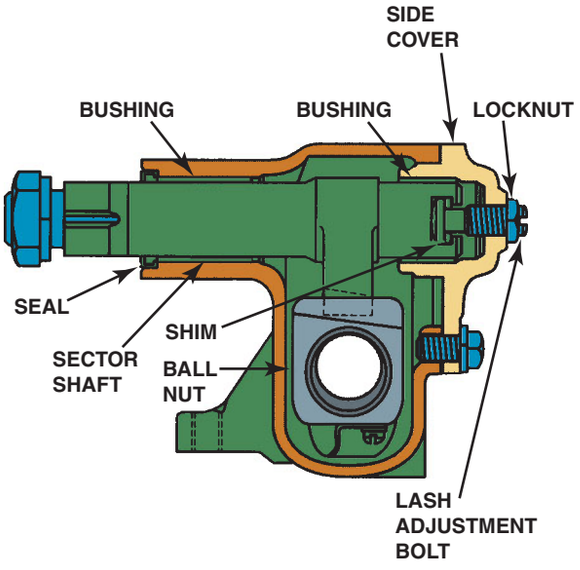


FIGURE 116–23 The sector shaft is supported by bushings, one in the housing and one in the side cover.

SECTOR GEAR The sector gear is an integral part of the sector shaft, which runs through the center of the sector gear, and forms the axis of the gear. One end of the sector shaft extends out of the steering gear housing and splines to the pitman arm. An oil seal prevents lubricant leakage where the sector shaft goes through the opening in the housing. To reduce friction, the sector shaft rides on two bushings. One bushing fits inside the housing and the other is part of the housing side cover. ● **SEE FIGURE 116–23.**

STEERING GEAR ADJUSTMENTS

For the steering gear to operate efficiently, the internal parts must be positioned correctly in relation to the housing and each other. As parts wear, clearances inside the housing and between parts increase, causing looseness and excessive play. The acceptable clearance between any two mechanical parts is called their tolerance. Insufficient tolerance causes binding between parts, increasing steering effort. Excessive tolerance causes delayed reaction to steering input and too much steering wheel freeplay.

Worm bearing preload, also referred to as worm endplay, is a measurement of how much force is required to turn the steering gear input shaft against the force, or **preload,** that the thrust bearings apply to the worm gear and shaft. Worm endplay, which is the distance the worm gear can move end-to-end between the thrust bearings, is directly related to preload. The higher the force the bearings push against the worm gear, the less endplay there is, and the more force it takes to turn the input shaft and worm gear. Worm bearing preload is adjusted by one of two methods: turning an adjustment nut or screw or installing selectively sized shims. Either adjustment method increases or decreases the worm endplay.

Worm endplay is a linear measurement, made in fractions of inches or millimeters, of how far the worm gear and shaft can slide axially. ● **SEE FIGURE 116–24.** Worm bearing preload is a measurement of how much force it takes to overcome bearing pressure in order to turn the input shaft. Preload is a torque, or turning force, measurement made in inch-pounds or Newton-meters. Because endplay and

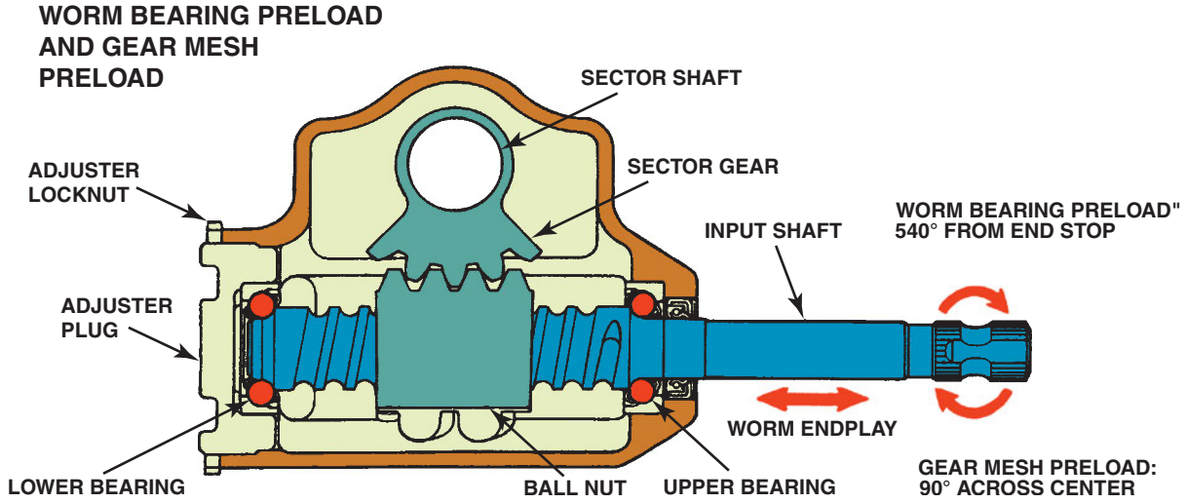


FIGURE 116–24 Worm bearing preload is a turning force measured in in.-lb or N-M, and worm endplay is axial movement measured in fractions of an inch or millimeters.

preload are related, one measurement affects the other. When measuring and adjusting the worm bearing preload, a technician measures preload and adjusts endplay. The endplay is correct when the preload measurement is correct. ● **SEE FIGURES 116–25 AND 116–26.**

Gear mesh preload is a measurement of how closely the teeth of the ball-nut gear and sector gear, or the worm gear and roller, fit together. Gear mesh preload is related to another measurement, called sector lash or **gear lash.**

Gear mesh preload is a measurement of how much turning force must be applied to the input shaft to overcome the resistance of the sector gear and move it. Gear mesh preload is usually measured in a 90-degree turn across the center of the input shaft movement. General Motors calls this adjustment the **overcenter adjustment.** Gear mesh preload (overcenter adjustment) determines how sensitive the steering gear is to small steering wheel movements during straight-ahead driving. Insufficient preload contributes to steering wander.

If there is too much gear lash, the steering becomes unresponsive because the steering gear does not transmit small steering wheel movements to the linkage. Insufficient lash makes the gears bind, offering too much resistance to steering wheel movement. ● **SEE FIGURE 116–27.**

Sector shaft endplay is a measurement of how much room the sector shaft has to slide axially. ● **SEE FIGURE 116–28.** If provision is made to measure sector shaft endplay, the measurement is taken in fractions of inches or millimeters. Some steering gears provide an external adjusting method, but it is more common for sector shaft endplay to be adjusted by internal shims, if it is adjustable.

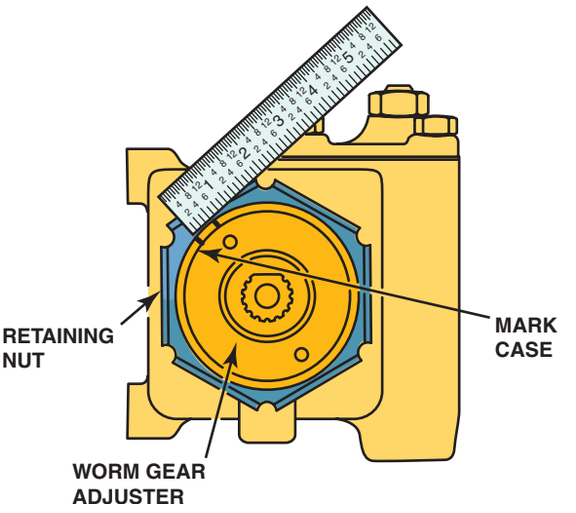


FIGURE 116–26 After the worm gear nut has been tightened, measure 1/2 inch (13 mm) and mark the case. Using the spanner wrench, rotate the worm gear nut counterclockwise 1/2 inch, align the marks, and then tighten the retaining nut. This procedure gives the proper worm gear endplay.

RACK-AND-PINION STEERING GEAR

PARTS AND OPERATION The term "rack and pinion" is simply a description of the basic design of this type of steering gear. The **rack-and-pinion** steering gear is widely used because it is light in weight and takes less space than a conventional steering gear. The input gear of a rack-and-pinion steering gear is a pinion gear that receives rotary input from the steering shaft. The rack is a rod with gear teeth machined into one side. The pinion gear teeth mesh with the teeth on the rack so that when the pinion gear turns, it pushes the rack from side to side. ● **SEE FIGURE 116–29.** The rack connects directly to the tie rod in the steering linkage to move the linkage back and forth in a straight line.

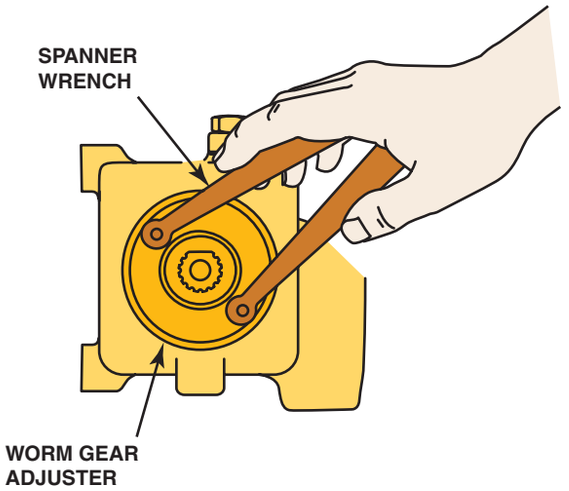


FIGURE 116–25 The first step to adjust worm gear freeplay is to bottom the worm gear nut, using a spanner wrench designed to fit into the two holes in the nut.

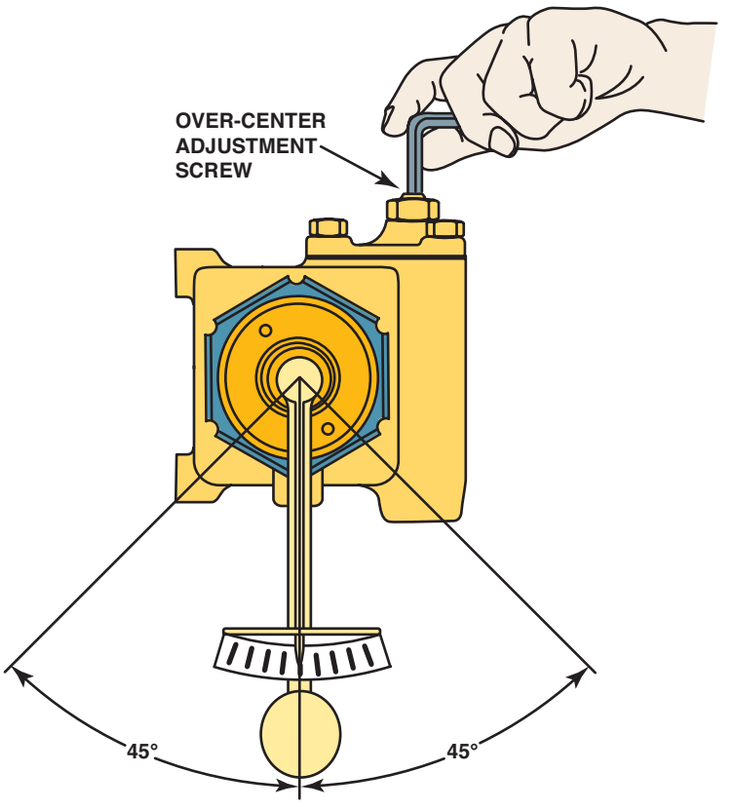


FIGURE 116–27 Performing an overcenter adjustment requires the use of a beam-type inch-lb torque wrench. After the worm bearing preload procedure has been completed, use the torque wrench to measure the rotating torque, which should be 6 to 15 lb-in. If the rotating torque is within the specified range, adjust the overcenter adjustment screw until you achieve 6 to 10 lb-in. additional rotating torque and then tighten the retaining nut.

The steering gear input shaft is splined to the steering shaft U-joint. ● **SEE FIGURE 116–30.** At the end of the steering gear input shaft, which extends into the rack housing, is the pinion gear. Two ball bearings reduce friction between the shaft and the steering gear housing. The upper bearing is a press-fit on the input shaft, and the lower bearing installs inside the housing at the bottom of the pinion gear. A cover, which fits around the shaft and threads into the housing, seats on top of the upper ball bearing to preload it and close the top of the steering gear housing. An oil seal between the top cover and the input shaft keeps lubricant from leaking out of the housing. A lock nut holds the top cover in position.

The teeth of the pinion gear mesh with the teeth of the rack. The teeth are at one end of the rack and the pinion is offset at one side of the housing.

The rack is encased in the long, tubular steering gear housing with a mounting flange on the pinion end. Rubber bushings fit into the mounting flange bolt holes to absorb vibration and isolate the assembly from the frame.

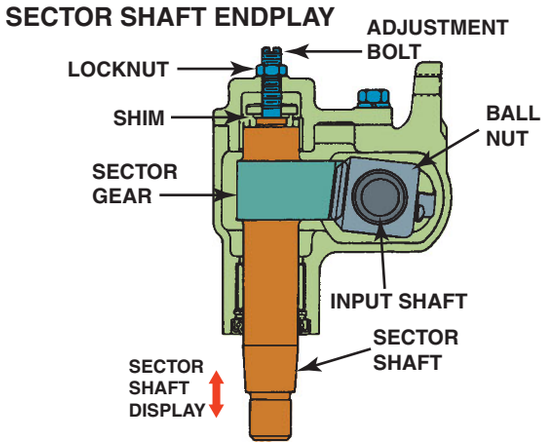


FIGURE 116–28 Sector shaft endplay is the measurement of how far the sector shaft can move axially and is measured in fractions of an inch or millimeters.

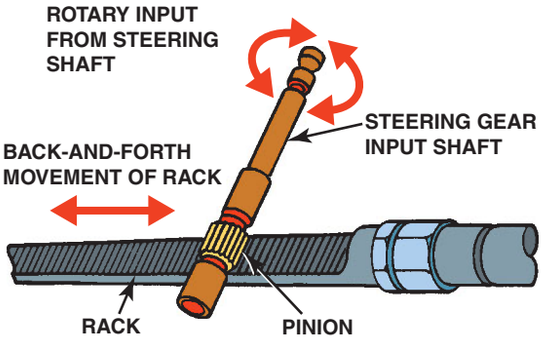


FIGURE 116–29 Rack-and-pinion steering gear operation is simple, direct, and the rack is in a straight line to the front wheels.

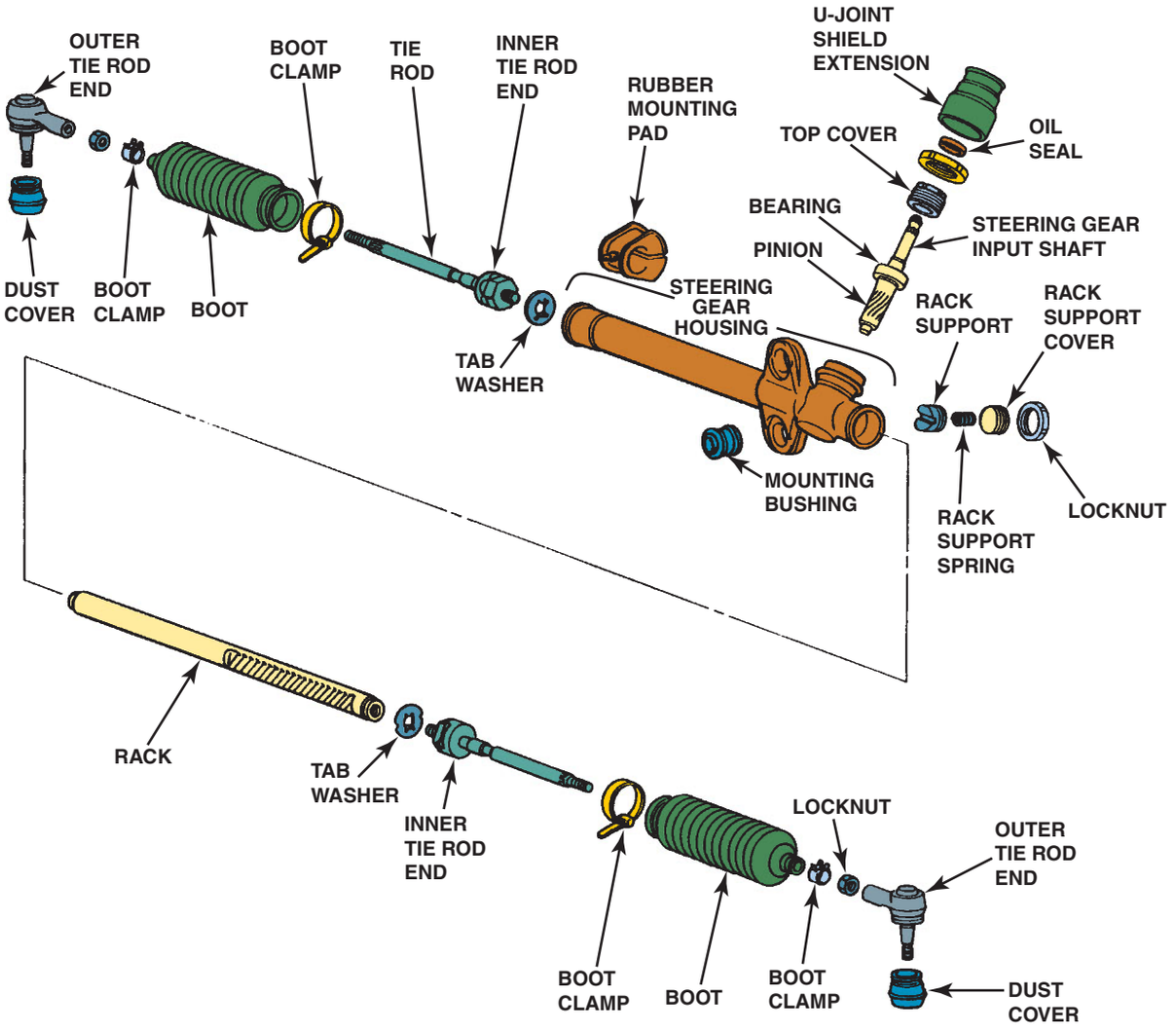


FIGURE 116–30 A typical manual rack-and-pinion steering gear used in a small front-wheel-drive vehicle.

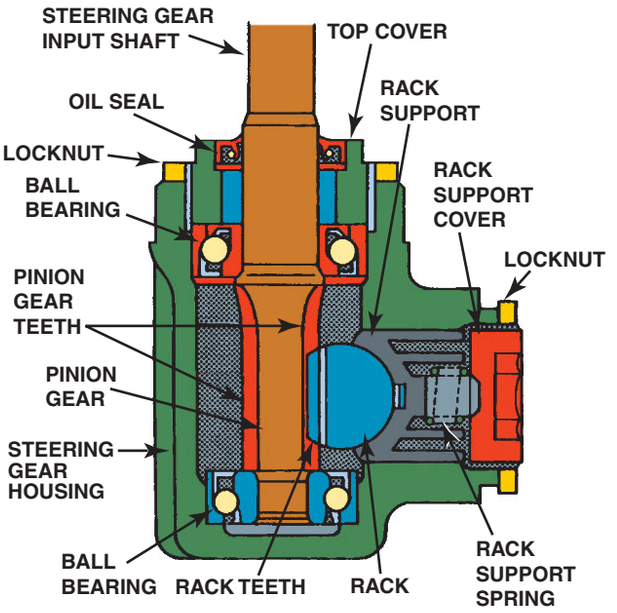


FIGURE 116–31 The spring-loaded rack support positions the rack to keep it from rubbing against the housing and establishes the pinion torque.

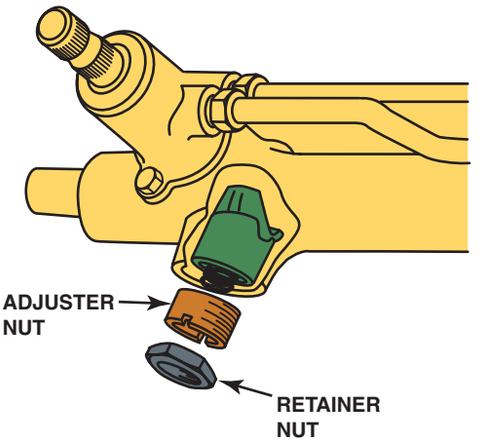


FIGURE 116–32 To adjust the rack-and-pinion gear preload, loosen the retaining nut and tighten the adjuster nut until it bottoms. Then loosen 60 degrees (one "flat" of the six-sided retainer). Tighten retaining nut.

A spring-loaded **rack support** and related hardware install through a hole at the back of the steering gear housing to position the rack. ● **SEE FIGURE 116–31.** The face of the rack support curves to match the back of the rack, which rests on it and slides back and forth across it. A spring behind the rack support cushions the rack from vibration and shocks. While the rack support provides a sliding surface to reduce friction at the pinion end of the rack, the rack rides in a bushing pressed into the steering gear housing at the opposite end to reduce friction.

To adjust the rack-and-pinion gear preload, always check service information for the exact procedure to follow. The specified procedure usually includes these steps. ● **SEE FIGURE 116–32:**

1. Loosen the adjuster plug lock nut.
2. Turn the adjuster plug clockwise until the adjuster plug bottoms in the gear assembly.
3. Turn the adjuster plug back 50 degrees to 70 degrees (approximately one flat).

Most rack-and-pinion units use a small metal tube running along the outside of the housing to connect the two boots and transfer air from one to the other. ● **SEE FIGURE 116–33.** If there were no means for air displacement between the boots, they might collapse as they expanded or explode as they compressed.

Internal threads on each end of the rack allow attachment of the externally threaded tie rods.

A rubber boot at each side of the steering gear housing covers the end of the rack and the inner tie rod end to prevent dirt, water, and other contaminants from entering the assembly. Band clamps fasten the ends of the boots to the housing and tie rods. The tie rods move back and forth with the rack and connect it to the wheels through the steering linkage.

The housing generally bolts to either a flange on the firewall or to the subframe or engine cradle. ● **SEE FIGURE 116–34.** The mounting points have rubber cushions to isolate the steering gear from shock and vibration. If the driver can feel vibration and road shocks through the steering wheel, the condition is called **kickback.** Kickback is most noticeable when driving into a curbed driveway.

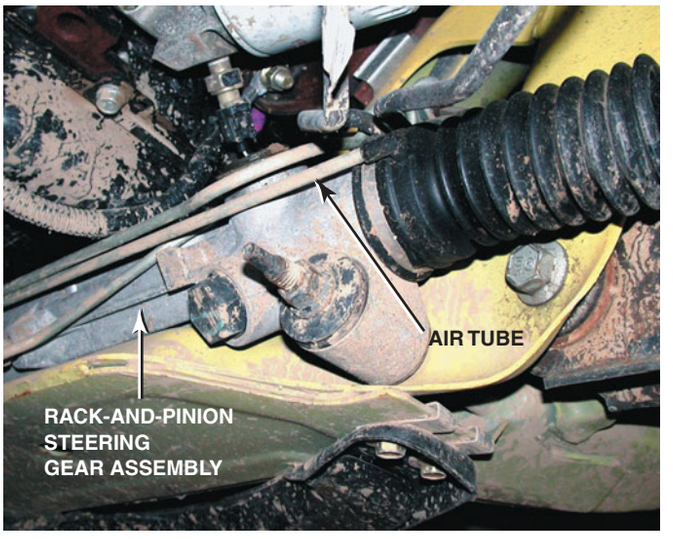


FIGURE 116–33 A small air tube is used to transfer air between the boots as they extend and compress during turns.

RACK-AND-PINION ADJUSTMENTS

PURPOSE Some rack-and-pinion steering gears can be adjusted. **Pinion torque** is a measurement of how much turning force is needed at the input shaft for the pinion to overcome the resistance of the rack and move it. ● **SEE FIGURE 116–35.** The measurement gives an indication of how closely meshed the pinion teeth and the rack teeth are. Like gear mesh preload in a standard steering gear, pinion torque indicates steering system responsiveness. The adjustment method is to thread the rack support cover farther into the steering gear housing to reduce gear lash, or thread it out to increase gear lash. Manufacturers specify an acceptable range of pinion torque in inch-pounds or Newton-meters. Because the middle teeth on the rack wear before the teeth at either end, pinion torque should be checked

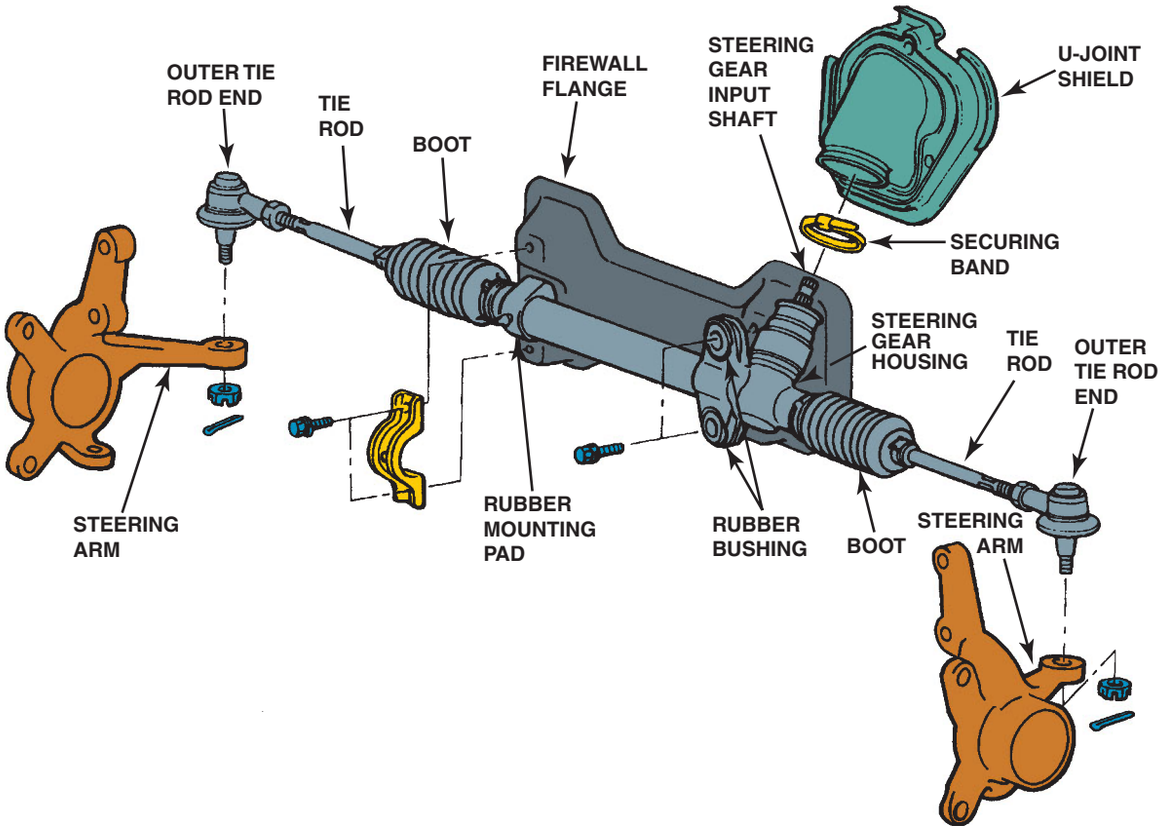


FIGURE 116–34 This manual rack-and-pinion steering gear mounts to the bulkhead (firewall), whereas others mount to the engine cradle or frame of the vehicle.

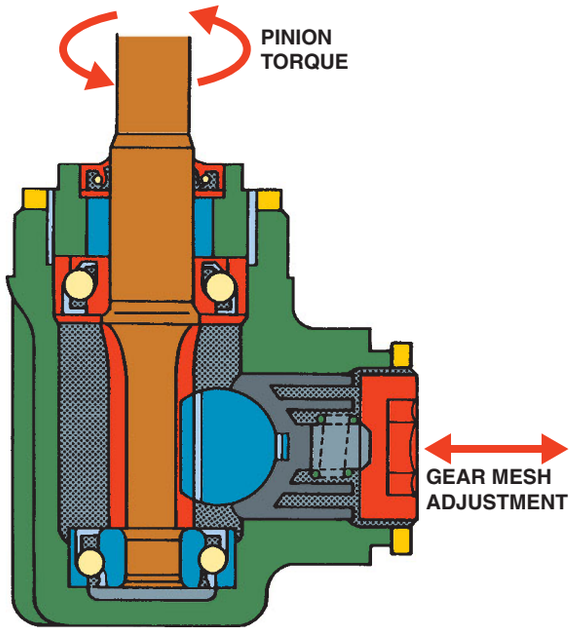


FIGURE 116–35 Pinion torque is a turning torque force measured in inch-pounds or Newton-meters. Tightening the rack support against the rack increases the pinion torque.

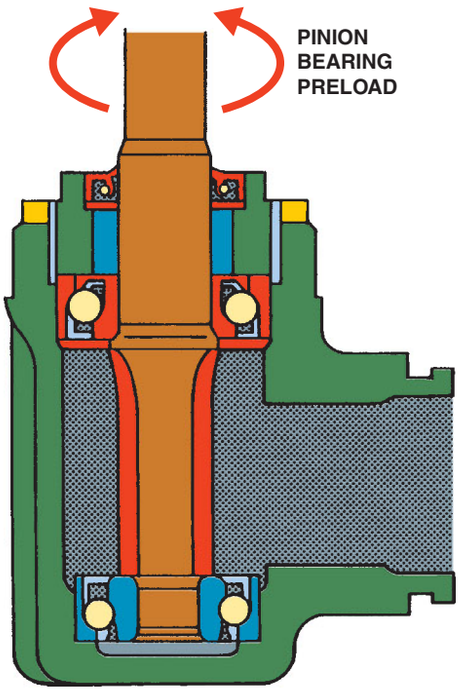


FIGURE 116–36 Pinion bearing preload is a measurement of the turning force required to overcome the resistance of the pinion shaft bearings.

across the whole stroke of the rack. Otherwise, reducing gear lash to a very close tolerance in the middle may cause binding as the pinion travels toward the end of the rack.

BEARING PRELOAD PROCEDURE Pinion bearing preload in a rack-and-pinion steering gear is the same concept as worm bearing preload in a standard steering gear. That is, it is a measurement of how much force is required to turn the steering gear input shaft against the force, or preload, that the bearings apply to the pinion gear and shaft. ● **SEE FIGURE 116–36.** To provide adjustable pinion bearing preload, there may be a threaded adjustment mechanism or selectively sized shims that install behind a shim cover.

? FREQUENTLY ASKED QUESTION

What Is a Center-Take-off Rack?

A center-take-off rack is a rack and pinion steering gear that uses long tie rods and which connect to the center of the rack rather than at the ends of the rack. Instead of using a ball and socket type of connection at the end of the rack, a center take-off rack assembly simply bolts the inner ends of the tie rods to the rack. Check service information for the exact procedures to follow when working with a center-take-off rack and pinion gear assembly.

REVIEW QUESTIONS

1. What components are included in a typical steering column assembly?
2. When the driver turns the steering wheel, how is the motion transferred to the front wheels through a conventional steering gear?
3. Why are recirculating balls used in the recirculating ball steering gear?
4. What steering gear adjustments are possible on a conventional recirculating-ball-type steering gear?
5. What steering gear adjustments are possible on a typical rack-and-pinion steering gear?

CHAPTER QUIZ

1. The circuit to the airbag inflation module is connected from the steering column to the steering wheel through what component?
   a. Slip ring and carbon brushes
   b. Clockspring (coil)
   c. Magnetic field sensor
   d. Hall-effect switch
2. Which part in the steering column allows for changes in the angle between the upper and lower shafts?
   a. Flexible coupling **c.** Universal joint
   b. Column cover **d.** Collapsible section
3. The rotation of the steering wheel causes which part to move the actual steering linkage in a conventional steering gear?
   a. Sector shaft **c.** Worm gear
   b. Pitman arm **d.** Gear nut
4. The pitman shaft is also called the _____.
   a. Sector **c.** Worm
   b. Input **d.** Spline
5. The driver rotates the steering wheel one-half of one revolution (180 degrees) on a vehicle equipped with a steering gear with a 20:1 gear ratio. How many degrees will the front wheels be rotated?
   a. 9 degrees **c.** 90 degrees
   b. 0.1 degree **d.** 11.1 degrees
6. What causes a variable-ratio steering gear to be able to change the ratio as the steering wheel is turned?
   a. Using two or three different sector gears depending on design
   b. Using a variable-length pitman arm
   c. Changing the number of teeth on the worm gear
   d. Changing the length of the teeth on the sector gear
7. Recirculating steel balls are used in most conventional steering gears because they _____.
   a. Provide for a variable ratio
   b. Keep the steering wheel centered
   c. Reduce friction
   d. Help provide feedback to the driver regarding the road surface
8. Which conventional steering gear adjustment should be the first performed?
   a. Worm bearing preload
   b. Tolerance adjustment
   c. Gear mesh preload
   d. Sector shaft endplay
9. The two rack-and-pinion steering gear adjustments include _____.
   a. Worm bearing preload and tolerance adjustment
   b. Pinion bearing preload and rack support
   c. Sector shaft and stub shaft preload
   d. Stub shaft endplay and sector shaft preload
10. A driver of a vehicle equipped with a rack-and-pinion steering gear complains that the steering wheel jerks whenever the vehicle is being driven into a curbed driveway approach at an angle. Technician A says that the rack-and-pinion gears may have too little clearance between the teeth of the gears. Technician B says that a lack of lubrication of the rack-and-pinion is the most likely cause. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

chapter 117

STEERING LINKAGE AND SERVICE

OBJECTIVES: After studying Chapter 117, the reader will be able to: • Prepare for ASE Suspension and Steering (A4) certification test content area "A" (Steering System Diagnosis and Service). • Identify steering linkage components. • Describe how the movement of the steering wheel causes the front wheels to turn. • Describe how to perform a dry park test to determine the condition of steering system components. • Perform an under-the-vehicle inspection of the steering system components. • List the service procedures for under-the-vehicle steering system service. • Explain how to replace steering linkage parts.

KEY TERMS: Articulation test 1384 • Ball socket assembly 1373 • Center link 1372 • Center take-off rack 1374 • Cross-steer linkage 1372 • Dry park test 1379 • Front steer 1375 • Grease fitting 1373 • Opposite-phase steering 1375 • Parallelogram linkage 1372 • Pitman arm 1372 • RBS 1373 • Rear steer 1375 • Same-phase steering 1375 • Steering dampener 1372 • Steering stops 1378 • SWPS 1377 • Tie rods 1372 • Zerk fitting 1373

STEERING LINKAGE

PARTS AND OPERATION

The steering linkage relays steering forces from the steering gear to the front wheels. Most conventional steering gear linkages use the **parallelogram**-type design. A parallelogram is a geometric box shape where opposite sides are parallel and equal distance. A parallelogram-type linkage uses four **tie rods,** two inner and two outer (left and right), a **center link** (between the tie rods), and an idler arm on the passenger side and a **pitman arm** attached to the steering gear output shaft (pitman shaft). ● **SEE FIGURE 117–1.**

As the steering wheel is rotated, the pitman arm is moved. The pitman arm attaches to a center link. At either end of the center link are inboard (inner) tie rods, adjusting sleeves, and outboard (outer) tie rods connected to the steering arms which moves the front wheels. The passenger side of all these parts is supported and held horizontal by an idler arm that is bolted to the frame. The center link may be known by several names, including the following:

- Center link
- Connecting link
- Connecting rod
- Relay rod
- Intermediate rod
- Drag link (usually a truck term only)

Other types of steering linkages often used on light trucks and vans include the **cross-steer linkage.** ● **SEE FIGURE 117–2** for a comparison of parallelogram and cross-steer-type steering linkage arrangements.

NOTE: Many light trucks, vans, and some luxury cars use a steering dampener attached to the linkage. A steering dampener is similar to a shock absorber, and it absorbs and dampens sudden motions in the steering linkage. ● **SEE FIGURE 117–3.**

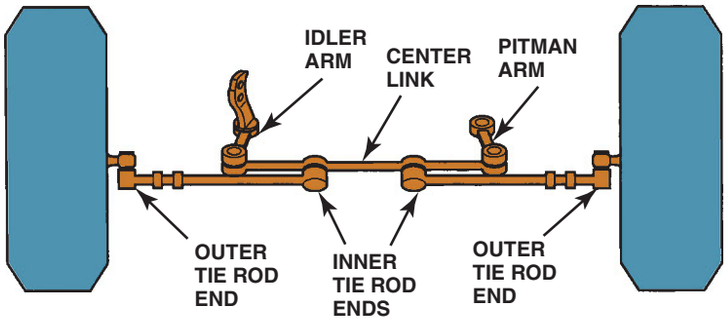


FIGURE 117–1 Steering movement is transferred from the pitman arm that is splined to the sector shaft (pitman shaft), through the center link and tie rods, to the steering knuckle at each front wheel. The idler arm supports the passenger side of the center link and keeps the steering linkage level with the road. This type of linkage is called a parallelogram-type design.

FREQUENTLY ASKED QUESTION

Why Is a Grease Fitting Sometimes Called a Zerk Fitting?

In 1922 the *zerk* fitting was developed by Oscar U. Zerk, an employee of the Alemite Corporation, a manufacturer of pressure lubrication equipment. A zerk or grease fitting is also known as an *Alemite fitting.*

Connections between all steering component parts are constructed of small ball-and-socket joints. These joints allow side-to-side movement to provide steering of both front wheels, and allow the joints to move up and down, which is required for normal suspension travel.

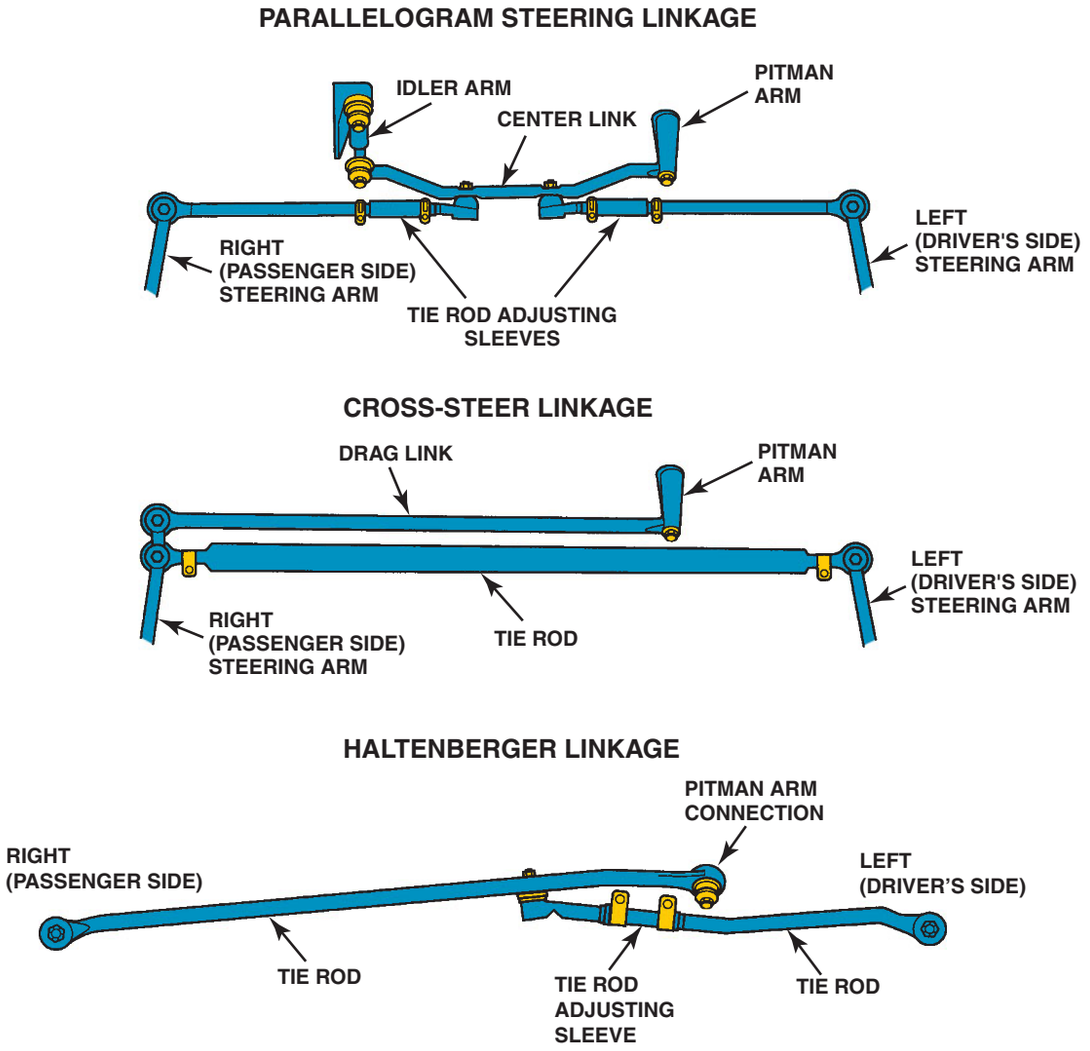


FIGURE 117–2 The most common type of steering is the parallelogram. The cross-steer and Haltenberger linkage designs are used on some trucks and vans.



FIGURE 117–3 Typical steering dampener used on a Hummer H2.

It is important that all of these joints be lubricated with chassis grease through a **grease fitting,** also called a **zerk fitting,** at least every six months or per the vehicle manufacturer's specifications.

Most vehicles come equipped with sealed joints and do not require periodic servicing. Some vehicles come from the factory with plugs that need to be removed and replaced with grease fittings and then lubricated.

TIE ROD ENDS Tie rod ends connect the steering linkage to the steering knuckles and to other steering linkage components. Conventional tie rod ends use a hardened steel ball stud assembled into a hardened steel and thermoplastic bearing. An internal preload spring limits the ball stud endplay and helps compensate for ball-and-socket wear. ● **SEE FIGURE 117–4** for two designs of tie rod ends.

For many years, Ford Motor Company used tie rod ends that included a rubber-bonded steel ball stud. Because there is no sliding friction inside the tie rod end, no lubrication was needed. This type of tie rod end is called **RBS (rubber-bonded socket).** ● **SEE FIGURE 117–5.**

RACK-AND-PINION INNER TIE ROD ENDS

TERMINOLOGY Inner tie rod end assemblies used on rack-and-pinion steering units require special consideration and often special tools. The inner tie rod end is also called a **ball socket assembly.**

The inner tie rod assemblies are attached to the end of the steering rack by one of several methods. ● **SEE FIGURE 117–6.**

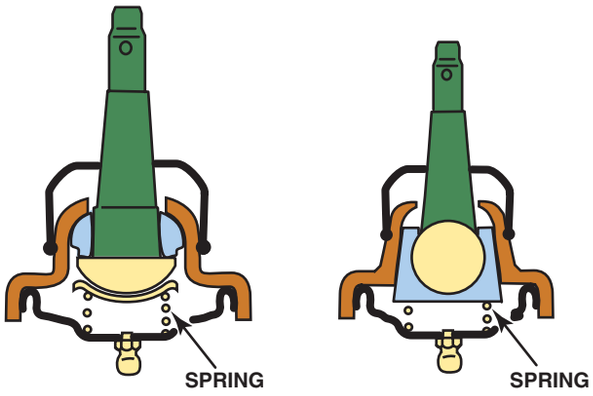


FIGURE 117–4 (a) A dual bearing design with a preload spring. The use of two bearing surfaces allows for one surface for rotation (for steering) and another surface for pivoting (to allow for suspension up-and-down movement). (b) The nylon wedge bearing type allows for extended lube intervals. Wear is automatically compensated for by the tapered design and spring-loaded bearing.

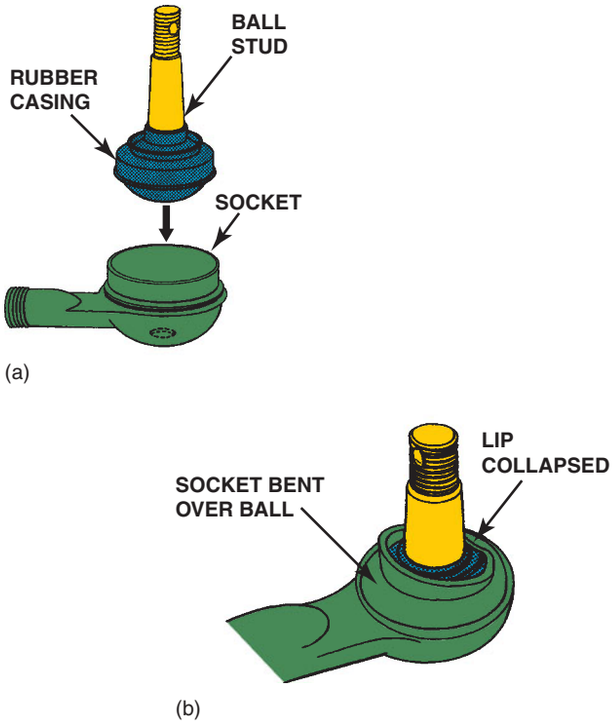


FIGURE 117–5 (a) A rubber-bonded socket is constructed of a rubber casing surrounding the ball stud, which is then inserted into the socket of the tie rod end. The hole in the socket allows air to escape as the ball stud is installed and there is not a place for a grease fitting. (b) The socket is crimped over the ball so that part of the socket lip retains the stud.

STAKED This method is common on Saginaw-style rack-and-pinion steering units found on General Motors vehicles.

The flange around the outer tie rod must be restaked to the flat on the end of the rack.

RIVETED OR PINNED This method is commonly found on Ford vehicles. Some roll pins require a special puller, or the pin can be drilled out. Many styles use an aluminum rivet. A special, very deep socket or a large open-end wrench can usually be used to shear the aluminum rivet by unscrewing the socket assembly from the end of the rack while the rack-and-pinion unit is still in the vehicle. ● **SEE FIGURE 117–7.**

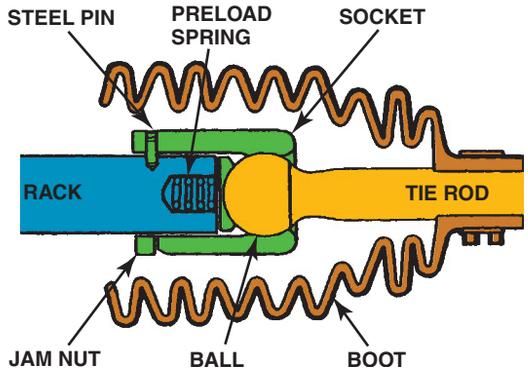


FIGURE 117–6 Rack-and-pinion steering systems use a ball-and-socket-type inner tie rod end.

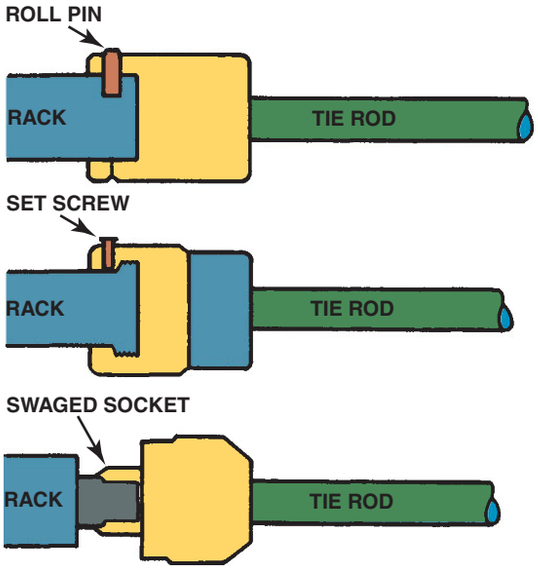


FIGURE 117–7 A variety of methods are used to secure the inner tie rod end socket assembly to the end of the rack.

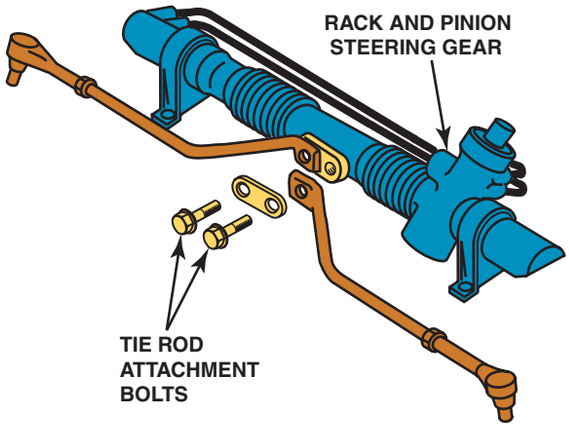
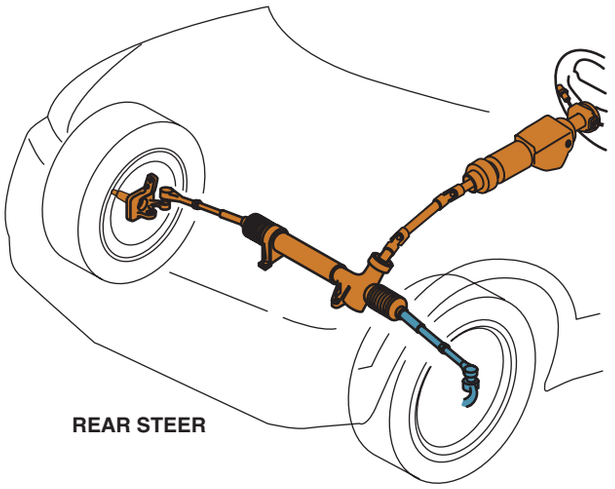


FIGURE 117–8 Exploded view of a center-take-off-style rack-and-pinion steering gear assembly.

CENTER TAKE-OFF RACKS For the **center take-off racks,** use bolts to secure the inner tie rods to the rack, as shown in ● **FIGURE 117–8.**



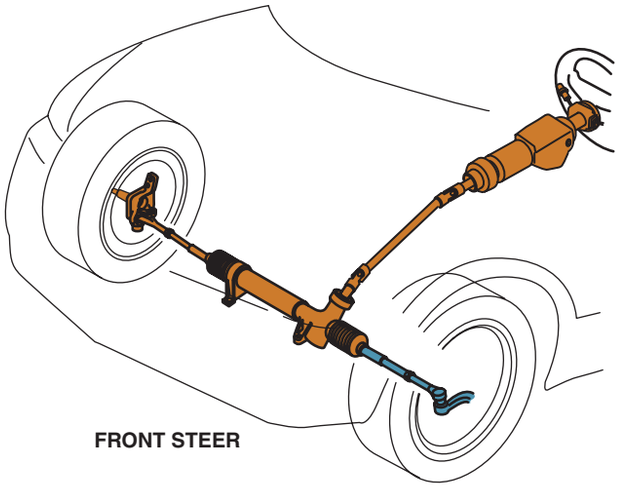


FIGURE 117–9 In a rear-steer vehicle, the steering linkage is behind the centerline of the front wheels, whereas the linkage is in front on a front-steer vehicle.

FRONT STEER VERSUS REAR STEER

Front steer, also called *forward steer,* is the term used to describe a vehicle that has the steering gear in front of the front wheel centerline. Having the steering gear located in this position improves handling and directional stability, especially when the vehicle is heavily loaded.

Front-steer vehicles usually produce an understeer effect that makes the vehicle feel very stable while cornering. If the steering gear linkage is located behind the wheels, it is called **rear steer** and the cornering forces are imposed on the steering in the direction of the turn. This is an oversteer effect. It tends to make the steering easier and makes the vehicle feel less stable.

Most front-wheel-drive vehicles are rear steering, with the rack-and-pinion steering unit attached to the bulkhead or subframe behind the engine. ● **SEE FIGURE 117–9.**

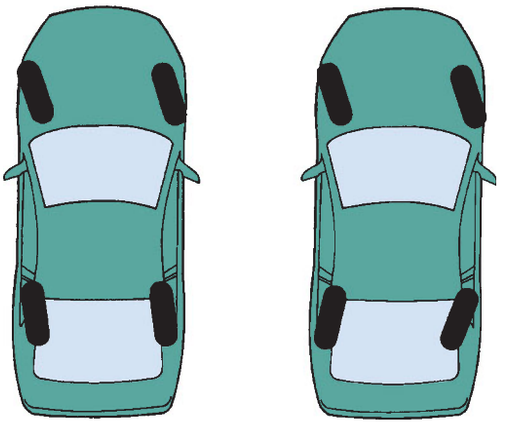


FIGURE 117–10 Opposite-phase four-wheel steer is usually used only at low vehicle speed to help in parking maneuvers. Same-phase steering helps at higher speeds and may not be noticeable by the average driver.

FOUR-WHEEL STEERING SYSTEMS

Some vehicles were equipped with a system that steers all four wheels. Two terms are commonly used when discussing four-wheel steering:

1. **Same-phase steering.** Same-phase steering means that the front and rear wheels are steered in the same direction. Same-phase steering improves steering response, especially during rapid-lane-change-type maneuvers.
2. **Opposite-phase steering.** Also called *negative-phase mode,* opposite-phase steering is when the front wheels and rear wheels are steered in the opposite direction. ● **SEE FIGURE 117–10.** Opposite-phase steering will quickly change the vehicle's direction, but may cause a feeling of oversteering.

Opposite-phase steering is best at low speeds; same-phase steering is best for higher-speed handling and lane-change maneuvers.

QUADRASTEER Quadrasteer™ is a four-wheel steering system that dramatically enhances low-speed maneuverability, high-speed stability, and towing capability. ● **SEE FIGURE 117–11.**

The system is an electrically powered rear wheel steering system comprised of the following components:

- A steerable, solid rear axle
- A heavy-duty wiring harness and fuse
- A programmable control module
- A power relay in the control module
- A rack-and-pinion-style steering actuator mounted on the rear differential cover
- An electric motor assembly on top of the rear steering actuator
- Three Hall-effect switches in the motor assembly
- A shorting relay in the motor assembly
- A rear wheel position sensor located under a cover on the bottom of the actuator, below the motor assembly

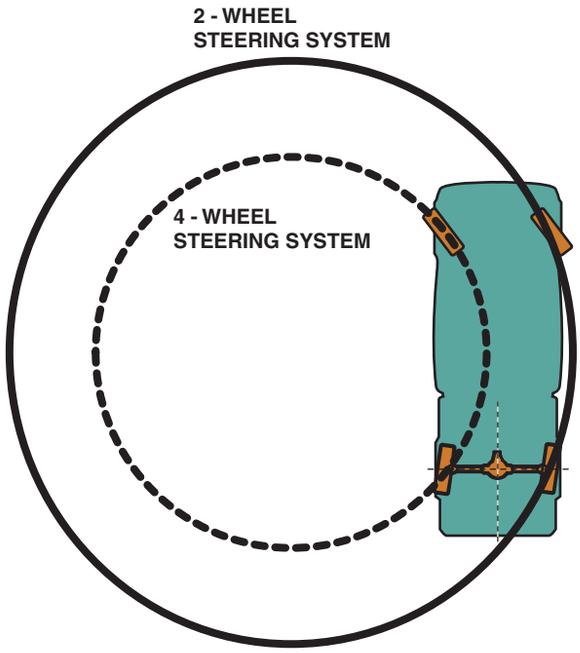


FIGURE 117–11 Being equipped with four-wheel steer allows a truck to make shorter turns than would otherwise be possible.

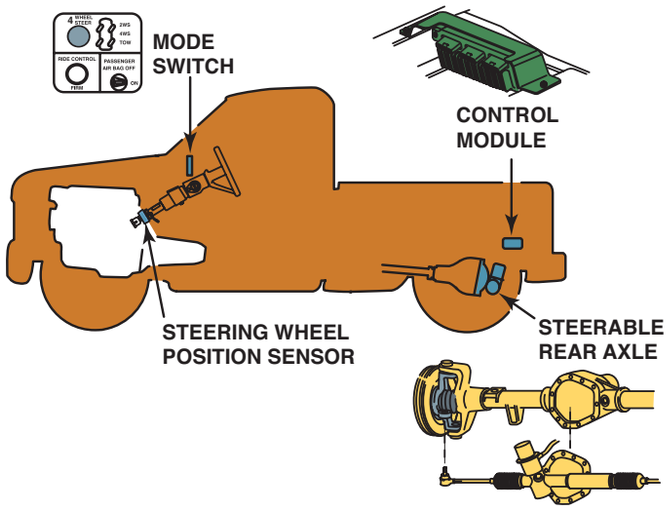


FIGURE 117–12 The Quadrasteer system includes many components that all work together.

- A steering wheel position sensor located at the base of the steering column
- A mode select switch on the dash

● **SEE FIGURE 117–12** for an overall view of the components of the Quadrasteer system.

The rear wheel steering control module has the following inputs:

- Battery voltage
- Switched battery voltage
- Class 2 serial data
- Steering wheel position sensor analog signal, via class 2 message from the body control module (BCM)
- Steering wheel position sensor phase A
- Steering wheel position sensor phase B

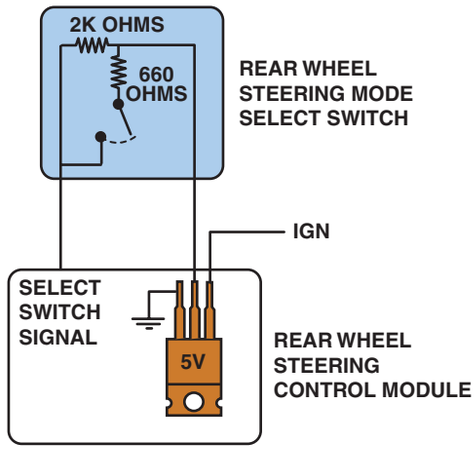


FIGURE 117–13 Rear steer select switch schematic.

- Steering wheel position sensor marker pulse
- Rear wheel position sensor position 1
- Rear wheel position sensor position 2
- Rear wheel steering motor Hall sensor A
- Rear wheel steering motor Hall sensor B
- Rear wheel steering motor Hall sensor C
- Vehicle speed signal from the instrument panel cluster (IPC)
- Rear wheel steering mode switch signal

● **SEE FIGURE 117–13.**

The system operates in three principal modes, as follows:

- **Two-wheel steer mode.** Normal steering operation—the rear wheels are held in a centered position and rear wheel steering is disabled while in this mode.
- **Four-wheel steer mode.** The four-wheel steering mode provides three principal phases of steering: negative phase, neutral phase, and positive phase. Negative phase occurs at low speeds and the rear wheels turn opposite of the front wheels. In the neutral phase, the rear wheels are centered and do not turn. Positive phase occurs at higher speeds and the rear wheels turn in the same direction as the front wheels.
- **Four-wheel steer tow mode.** The four-wheel steer tow mode provides more positive-phase steering than the normal four-wheel steering at high speed. During low-speed driving, the four-wheel steer tow mode provides similar negative-phase steering as it does in the normal four-wheel steering mode.

REAR WHEEL STEERING CONTROL MODULE

The rear wheel steering control module controls all functions of the rear wheel steering system. The module has a dedicated power feed line from an underhood fuse holder, via a 125-amp mega fuse. The module is located in the rear of the vehicle on the underbody. The module uses the inputs listed earlier to determine when and how far to turn the rear wheels. The module uses the Hall switches in the motor assembly, a shorting relay, and a motor control relay to monitor and control the direction and speed of the motor. The module also controls the duty cycle of the phase leads to the motor. The motor control relay is part of the rear wheel steering control module and is not serviceable.

The control module allows the vehicle rear wheels to turn a maximum of 12 degrees left or right. When the vehicle is operated in reverse, the maximum rear wheel steering angle is 5 degrees left or right. When the vehicle is sitting still in the test mode, the system will move a maximum of 5 degrees left or right.

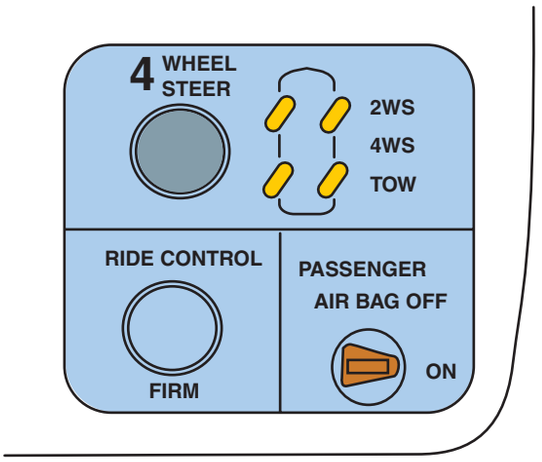


FIGURE 117–14 The dash-mounted select switch showing the three positions for the four-wheel steer system.

REAR WHEEL STEERING MODE SWITCH

The mode switch located in the instrument panel allows the driver the option of selecting two-wheel steering, four-wheel steering, or four-wheel steering tow modes of operation. The mode switch has indicators that show which mode the rear wheel steering system is in. When all indicators are lit the rear wheel steering control module has lost its memory settings and the scan tool must be used to recalibrate the rear wheel steering control module. During a mode change, the indicator for the selected mode will flash until the mode change is complete. The rear wheel steering control module will wait for the steering wheel to pass the center position before entering the selected mode. The indicators on the mode switch are LEDs; the switch is also back lit. ● **SEE FIGURE 117–14.**

REAR WHEEL STEERING MOTOR ASSEMBLY. The rear wheel steering motor assembly is a three-phase, six-pole, brushless DC motor. The motor assembly is located on the top of the rear steering actuator, and transmits its power through a planetary gearset inside the actuator. There are three Hall switches inside the assembly: Hall A, Hall B, and Hall C. The rear wheel steering control modules uses the Hall switch inputs to monitor the position, speed, and direction of the motor.

STEERING WHEEL POSITION SENSOR. The **steering wheel position sensor (SWPS)** provides one analog signal and three digital signals. The digital signals—Phase A, Phase B, and marker pulse—are direct inputs to the rear wheel steering control module. The analog signal is input to the body control module (BCM) and is sent via a class 2 message to the rear wheel steering control module. Battery voltage is supplied to the sensor from the cruise fuse to operate the digital portion of the sensor. A 12-volt reference is provided by the rear wheel steering control module to the Phase A, Phase B, and marker pulse circuits of the SWPS. The module monitors each circuit as it remains high or is pulled low by the SWPS. The scan tool displays the Phase A and Phase B data parameters as either high or low when the steering wheel is being rotated. Each change from high to low, or low to high, represents 1 degree of steering wheel rotation. When observing with the scan tool, the parameters for Phase A and Phase B will not always display the same value at the same time. The marker pulse is a digital pulse signal that is displayed as high by the scan tool with the steering wheel angle between +10 degrees and −10 degrees. At greater than 10 degrees steering wheel angle in either direction, the marker pulse data will be displayed as low. The BCM provides the 5-volt reference and low reference for the analog portion of the SWPS. The BCM reads the SWPS analog signal in voltage, which is typically 2.5 volts with the steering wheel on center.

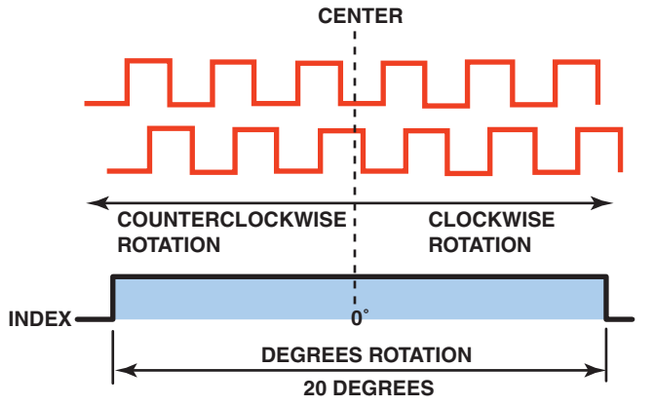


FIGURE 117–15 The output of the handwheel sensor digital signal.

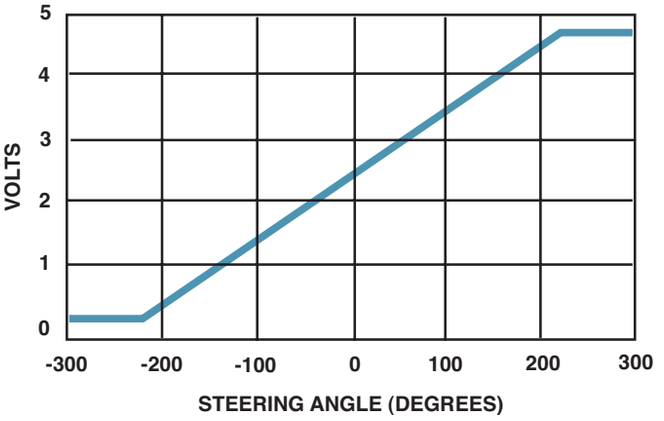


FIGURE 117–16 Handwheel analog signal.

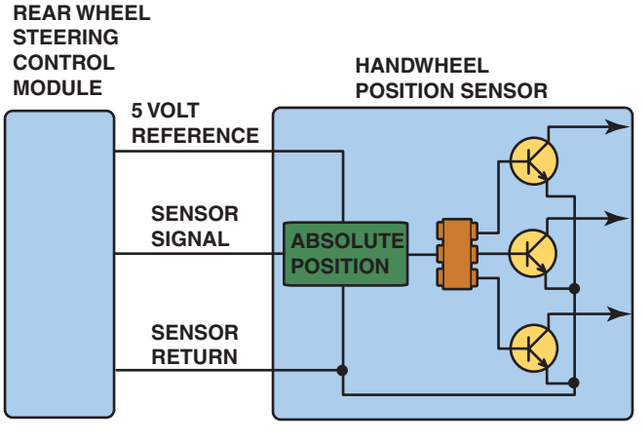


FIGURE 117–17 Handwheel position sensor analog signal to control module.

The voltage ranges from 0.25 volts at approximately one full turn left to 4.75 volts at approximately one full turn right. The voltage will then remain at that level for the remainder of steering wheel travel. This voltage can be monitored in BCM data display on a scan tool. The sensor may also be utilized by other optional systems. ● **SEE FIGURES 117–15 THROUGH 117–18.**

REAR WHEEL POSITION SENSOR. The rear wheel position sensor has two signal circuits: position 1 and position 2. Position 1 is a linear measurement of voltage per degree. The voltage range for position 1 is from 0.25 to 4.75 volts, and the angular measurement range is from −620 degrees to +620 degrees. At 0.25 volts the steering wheel has been rotated −600 degrees past center. At 4.75 volts

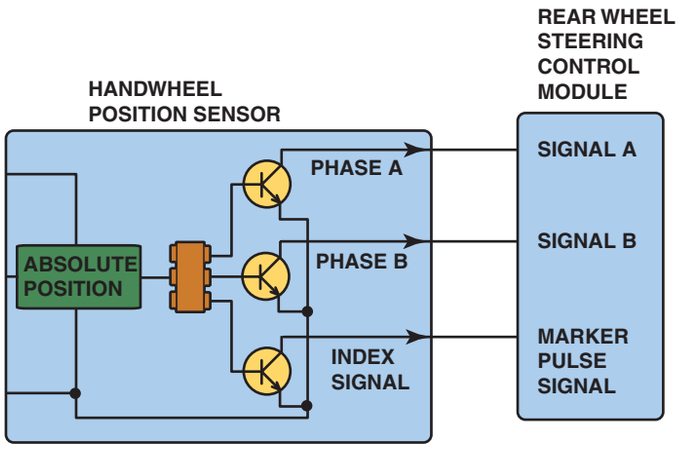


FIGURE 117–18 Handwheel position sensor digital signal to control module.



FIGURE 117–19 A Quadrasteer system showing all of the components. The motor used to power the rear steering rack can draw close to 60 amperes during a hard turn and can be monitored using a Tech 2.

the steering wheel has been rotated +600 degrees past center. The position 2 circuit is a linear measurement of voltage per degree. The voltage for position 2 increases or decreases from 0.25 to 4.75 volts every 180 degrees. When the steering wheel is 0 degrees center, the position 1 and position 2 output signals each measure 2.5 volts.

STEERABLE REAR AXLE. The steerable rear axle has a rack-and-pinion-style actuator mounted to the differential cover, specially designed axle shafts, and movable hub and bearing assemblies mounted by upper and lower ball joints. The actuator housing is part of the differential cover. In the event of a system malfunction, the actuator returns the rear wheels to the center position through internal springs. The actuator has specially designed inner and outer tie rod ends. There are inner tie rod boots to prevent contaminants from entering the actuator. The actuator has the rear wheel steering motor assembly attached to the upper housing. There are shields and a skid plate on the rear axle to protect the actuator. There are no internal adjustments to the actuator. ● **SEE FIGURE 117–19.**

STEERING LINKAGE LUBRICATION

Keeping all joints equipped with a grease fitting properly greased is necessary for long life and ease of steering. ● **SEE FIGURE 117–20.**



FIGURE 117–20 Greasing a tie rod end. Some joints do not have a hole for excessive grease to escape, and excessive grease can destroy the seal.



FIGURE 117–21 Part of steering linkage lubrication is applying grease to the steering stops. If these stops are not lubricated, a grinding sound may be heard when the vehicle hits a bump when the wheels are turned all the way one direction or the other. This often occurs when driving into or out of a driveway that has a curb.

During a chassis lubrication, do not forget to put grease on the *steering stop,* if so equipped. **Steering stops** are the projections or built-up areas on the control arms of the front suspension designed to limit the steering movement at full lock. ● **SEE FIGURE 117–21.**

When the steering wheel is turned as far as it can go, the steering should *not* stop inside the steering gear! Forces exerted by the power steering system can do serious damage to the steering gear if absorbed by the steering gear rather than the steering stop.

NOTE: Many rack-and-pinion steering units are designed with a rack-travel-limit internal stop and do not use an external stop on the steering knuckle or control arm.

Most steering stops are designed so that the lower control arm hits a small section of the body or frame when the steering wheel is turned to the full "lock" position. Steering stops should be lubricated to prevent a loud grinding noise when turning while the vehicle is going over a bump. This noise is usually noticeable when turning into or out of a driveway.

FREQUENTLY ASKED QUESTION

What Is "Goofy Mode"?

Trucks that are equipped with the Quadrasteer system have a three-position switch on the dash:

1. 2WS
2. 4WS
3. Tow

The Quadrasteer module then determines the right amount of rear steer and in which direction based on vehicle speed and steering wheel angle. If trailer towing mode is selected and the truck is *not* towing a trailer, the computer will adjust the steering as if there is a trailer and will slightly delay the rear steering action when changing lanes and other maneuvers. As a result, when the steering wheel is turned the front wheels will of course turn in direct proportion to the input from the steering wheel; however, the rear wheels will be delayed in their action to allow the trailer to track properly. If, however, a trailer is not being towed, this delay feels "goofy" and could result in customer concerns about the proper operation of the Quadrasteer system. Be sure that the control switch is placed in the off or normal modes unless a trailer is in fact being towed.

DRY PARK TEST

PURPOSE Since many steering (and suspension) components do *not* have exact specifications for replacement purposes, it is extremely important that the beginning service technician work closely with an experienced veteran technician. While most technicians can determine when a steering component such as a tie rod end is definitely in need of replacement, marginally worn parts are often hard to spot and can lead to handling problems. One of the most effective, yet easy to perform, steering component inspection methods is called the **dry park test.**

Excessive play in the steering wheel can be caused by worn or damaged steering components. Looseness in the steering components usually causes freeplay in the steering wheel. Freeplay refers to the amount of movement of the steering wheel required to cause movement of the front wheels. The exact cause of freeplay in the steering should be determined if the freeplay exceeds 2 in. (5 cm) for parallelogram-type steering linkages, or 3/8 in. (1 cm) for rack-and-pinion steering. ● **SEE FIGURE 117–22.**

PROCEDURE This simple test is performed with the vehicle on the ground or on a drive-on ramp-type hoist, moving the steering wheel back and forth *slightly* while an assistant feels for movement at each section of the steering system. The technician can start checking for any looseness in the steering linkage starting either at the outer tie rod ends and working toward the steering column, or from the steering column toward the outer tie rod ends. It is important to check each and every joint and component of the steering system, including the following:

1. The intermediate shaft and flexible coupling.
2. All steering linkage joints, including the inner tie rod end ball socket. ● **SEE FIGURE 117–23**.
3. Steering gear mounting and rack-and-pinion mounting bushings.

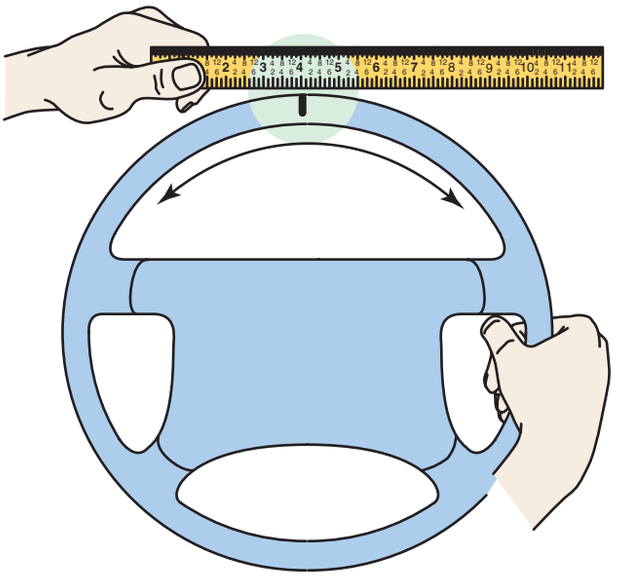


FIGURE 117–22 Checking for freeplay in the steering.

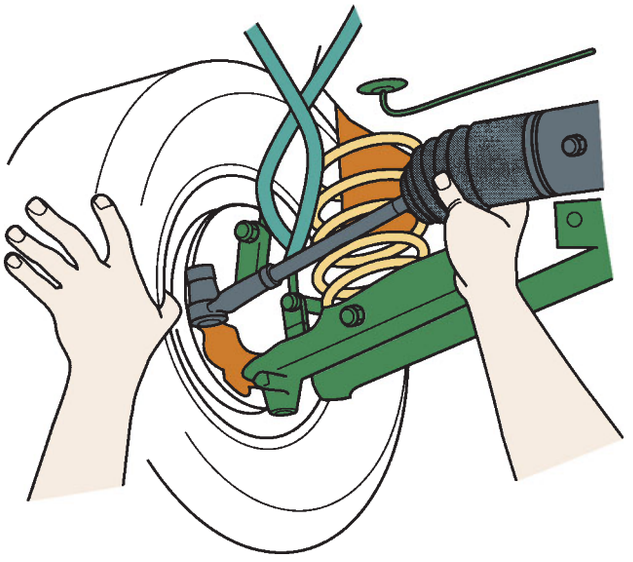


FIGURE 117–23 All joints should be felt during a dry park test. Even inner tie rod ends (ball socket assemblies) can be felt through the rubber bellows on many rack-and-pinion steering units.

FREQUENTLY ASKED QUESTION

Why Do Only a Few Vehicles Use Grease Fittings?

Many years ago, all vehicles were equipped with grease fittings, while today very few vehicles are so equipped. The reasons for this, as given by engineers, include the following:

- It has been determined that the use of the wrong type of grease can cause more harm than good.
- If a grease fitting is used to allow grease to enter the suspension or steering joint, then water can also get inside the joint.
- Grease fittings are often ignored or the greasing of the joint is not performed by the service technician.
- Low-friction joints do not require routine service like the older metal-to-metal joints required.

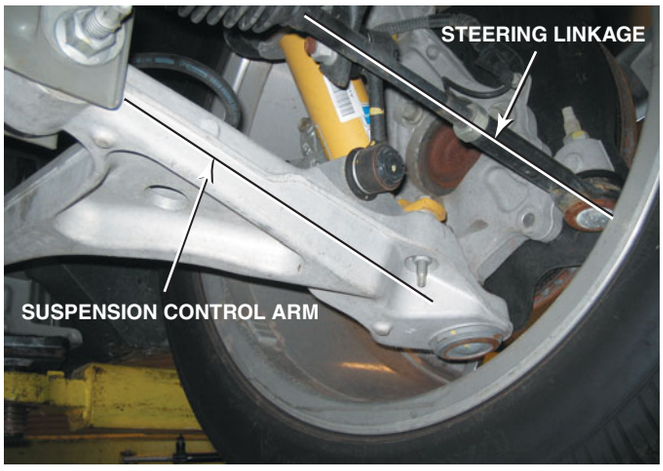


FIGURE 117–24 The steering and suspension control arms must remain parallel to prevent the up-and-down motion of the suspension from causing the front wheels to turn inward or outward.

TECH TIP

Jounce/Rebound Test

All steering linkage should be level and "work" at the same angle as the suspension arms, as shown in ● **FIGURE 117–24.** A simple test to check these items is performed as follows:

1. Park on a hard, level surface with the wheels straight ahead and the steering wheel in the *unlocked* position.
2. Bounce (jounce) the vehicle up and down at the front bumper while watching the steering wheel.

The steering wheel should *not* move during this test. If the steering wheel moves while the vehicle is being bounced, look for a possible bent steering linkage, suspension arm, or steering rack. ● **SEE FIGURE 117–25.**

COMMON WEAR ITEMS

On a vehicle equipped with a conventional steering gear and parallelogram linkage, as shown in ● **FIGURE 117–26,** typical items that wear first, second, and so on include the following:

Steering Component	Estimated Mileage to Wear Out*
1. Idler arm	40,000–60,000 miles (60,000–100,000 km)
2. Outer tie rod ends (replaced in pairs only)	60,000–100,000 miles (100,000–160,000 km)
3. Inner tie rod ends	80,000–120,000 miles (130,000–190,000 km)
4. Center link	90,000–130,000 miles (140,000–180,000 km)
5. Pitman arm	100,000–150,000 miles (160,000–240,000 km)

*Mileage varies greatly due to different road conditions and levels of vehicle maintenance. This chart should be used as a guide only.

Note that there are overlapping mileage intervals for several components. Also note that the mileage interval for an idler arm is such that by the time other components are worn, the idler arm may need to be replaced a second time.

For vehicles that use rack-and-pinion-type steering systems, the list is shorter because there are fewer steering components and the forces exerted on a rack-and-pinion system are in a straight line. The first to wear is usually the outer tie rod ends (one or both) followed by the inner tie rod ball-and-socket joints, usually after 60,000 miles (100,000 km) or more. Intermediate shaft U-joints usually become worn and can cause steering looseness after 80,000 miles (130,000 km) or more.

NOTE: Experienced front-end technicians can often guess the mileage of a vehicle simply by careful inspection of the steering linkage. For example, if the idler arm is a replacement part and again needs to be replaced, and the outer tie rods also need replacement, then the vehicle probably has at least 60,000 miles and usually more! When inspecting a used vehicle for possible purchase, perform a careful steering system inspection. This is one area of the vehicle where it is difficult to hide long or hard service.

PARALLELISM

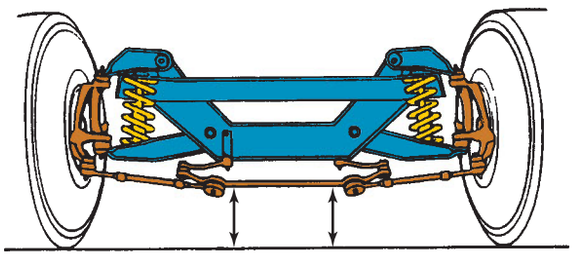


FIGURE 117–25 The center link should be parallel to the ground.

TECH TIP

Wear and Nonwear Center Links

Some center links are equipped with ball-and-socket joints, which can wear. Other center links are manufactured with holes for ball joint studs only. ● **SEE FIGURE 117–27.** Generally, the center links that do not use joints are unlikely to need replacement unless a joint becomes loose and wears the tapered stud hole. Knowing which style of center link is used will help determine the most likely location to check for excessive steering linkage play.

UNDER-VEHICLE INSPECTION

After checking the steering system components as part of a dry park test, hoist the vehicle and perform a thorough part-by-part inspection:

1. Inspect each part for damage due to an accident or bent parts due to the vehicle's hitting an object in the roadway.

CAUTION: Never straighten a bent steering linkage; always replace with new parts.

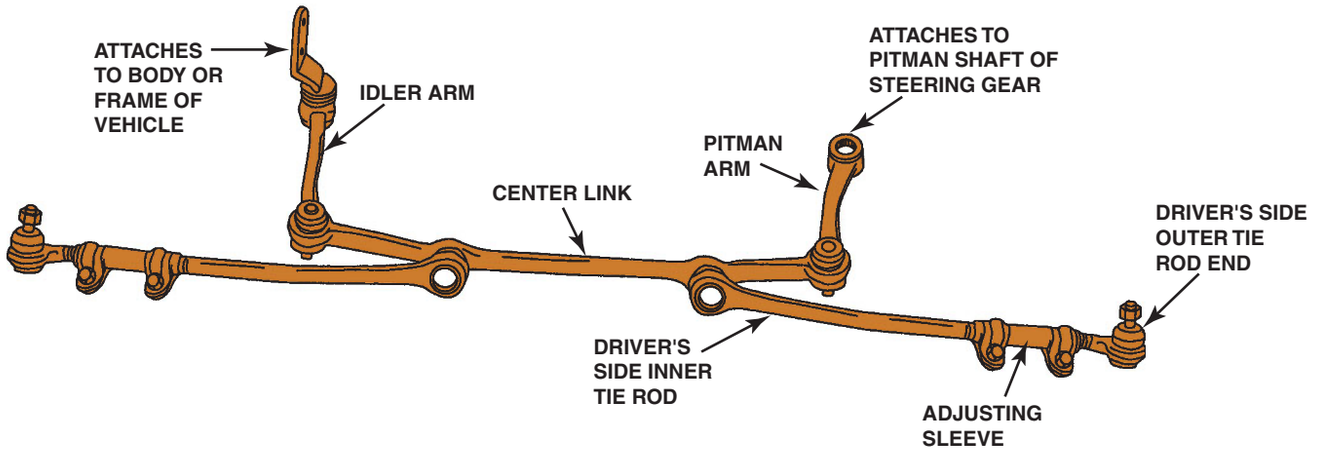


FIGURE 117–26 Typical parallelogram steering linkage. The center link can also be named the relay rod, drag link, or connecting link.

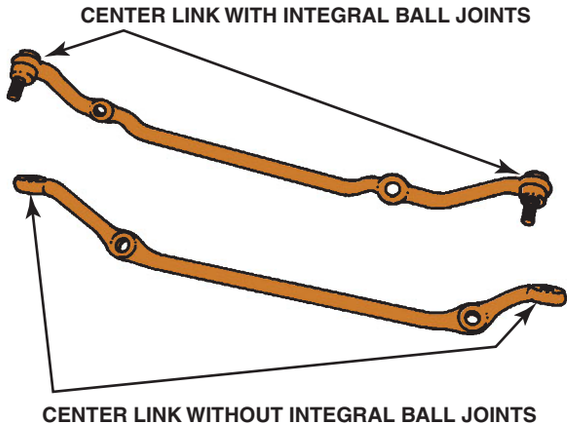


FIGURE 117–27 Some center links have ball joints while others have tapered socket holes to accept ball joints on the pitman arm, idler arm, and inner tie rod ends.

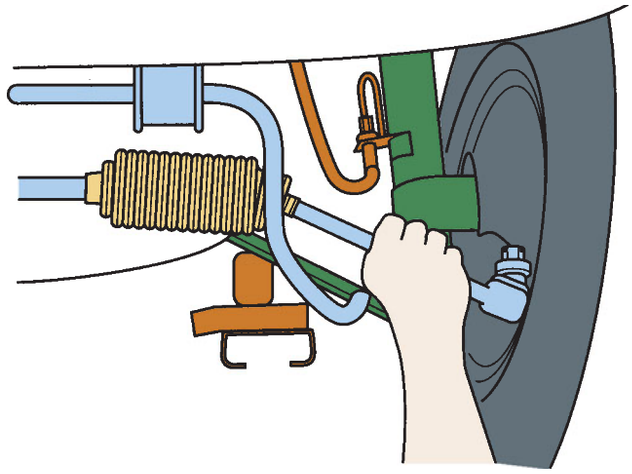


FIGURE 117–29 Steering system component(s) should be replaced if any noticeable looseness is detected when moved by hand.

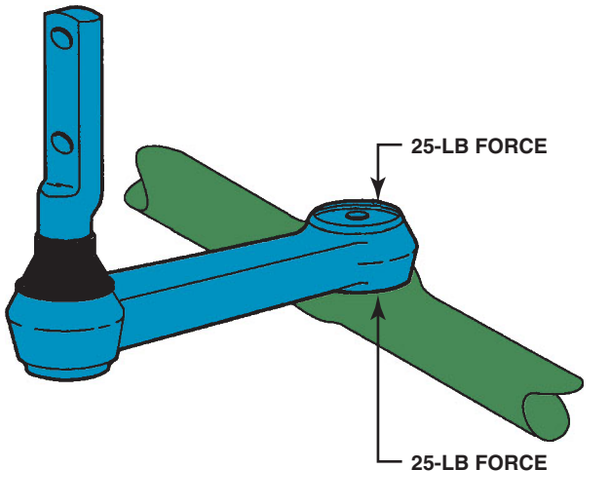


FIGURE 117–28 To check an idler arm, most vehicle manufacturers specify that 25 pounds of force be applied by hand up and down to the idler arm. The idler arm should be replaced if the total movement (up and down) exceeds 1/4 in. (6 mm).

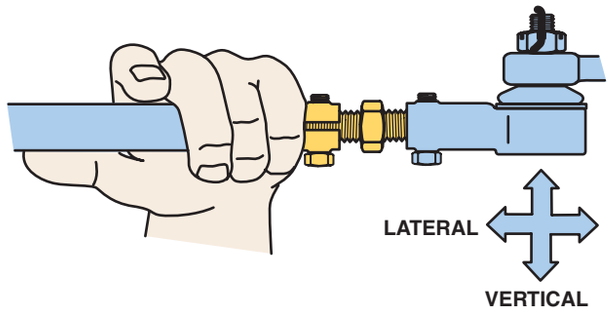


FIGURE 117–30 All joints should be checked by hand for any lateral or vertical play.

2. Idler arm inspection is performed by using *hand* force of 25 lb (110 N-m) up and down on the arm. If the *total* movement exceeds 1/4 in. (6 mm), the idler arm should be replaced. ● **SEE FIGURE 117–28.**
3. All other steering linkage should be tested *by hand* for any vertical or side-to-side looseness. Tie rod ends use ball-and-socket joints to allow for freedom of movement for suspension travel and to transmit steering forces to the front wheels. It is therefore normal for tie rods to rotate in their sockets when the tie rod sleeve is rocked. **Endplay in any tie rod should be zero.** Many tie rods are spring loaded to help keep the ball-and-socket joint free of play as the joint wears. Eventually, the preloaded spring cannot compensate for the wear, and endplay occurs in the joint. ● **SEE FIGURES 117–29 AND 117–30.**
4. All steering components should be tested with the wheels in the straight-ahead position. If the wheels are turned, some apparent looseness may be noticed due to the angle of the steering linkage.

REAL WORLD FIX

Bump Steer

Bump steer, or *orbital steer,* is used to describe what happens when the steering linkage is not level: The front tires turn inward or outward as the wheels and suspension move up and down. (Automotive chassis engineers call it *roll steer.*) The vehicle's direction is changed *without moving the steering wheel* whenever the tires move up and down over bumps, dips in the pavement, or even over gentle rises!

This author experienced bump steer once and will never forget the horrible feeling of not having control of the vehicle. After replacing an idler arm and aligning the front wheels, everything was OK until about 40 mph (65 km/h); then the vehicle started darting from one lane of the freeway to another. Because there were no "bumps" as such, bump steer was not considered as a cause. Even when holding the steering wheel perfectly still and straight ahead, the vehicle would go left, then right. Did a tie rod break? It certainly felt exactly like that's what happened. I slowed down to below 30 mph and returned to the shop.

After several hours of checking everything, including the alignment, I discovered that the idler arm was not level with the pitman arm. This caused a pull on the steering linkage whenever the suspension moved up and down. As the suspension compressed, the steering linkage pulled inward on the tie rod on that side of the vehicle. As the wheel moved inward (toed in), it created a pull just as if the wheel were turned by the driver.

This is why all steering linkages must be parallel with the lower control. The reason for the bump steer was that the idler arm was bolted to the frame, which was slotted vertically. I didn't pay any attention to the location of the original idler arm and simply bolted the replacement to the frame. After raising the idler arm back up where it belonged (about 1/2 in. [13 mm]), the steering problem was corrected.

Other common causes of bump steer are worn or deteriorated rack mounting bushings, a noncentered steering linkage, or a bent steering linkage. If the steering components are not level, any bump or dip in the road will cause the vehicle to steer one direction or the other. ● **SEE FIGURE 117–31.**

Always check the steering system carefully whenever a customer complains about any "weird" handling problem.

TECH TIP

The Killer Bs

The "three Bs" that can cause steering and suspension problems are bent, broken, or binding components. Always inspect each part under the vehicle for each of the killer Bs.

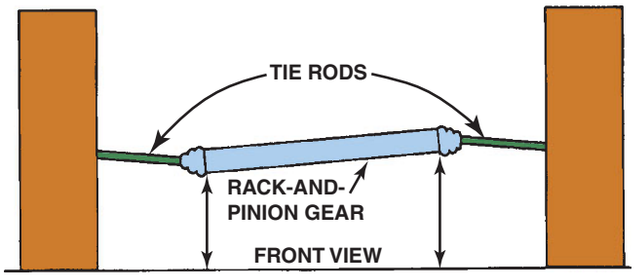


FIGURE 117–31 If a rack-and-pinion or any other steering linkage system is not level, the front tires will be moved inward and/or outward whenever the wheels of the vehicle move up or down.

CAUTION: Do not turn the front wheels of the vehicle while suspended on a lift to check for looseness in the steering linkage. The extra leverage of the wheel and tire assembly can cause a much greater force to be applied to the steering components than can be exerted by hand alone. This extra force may cause some apparent movement in good components that may not need replacement.

STEERING LINKAGE REPLACEMENT

PARALLELOGRAM TYPE

When replacing any steering system component, it is best to replace all defective and marginally good components at the same time. Use the following guidelines.

Parts that can be replaced *individually* include the following:

Idler arm

Center link

Pitman arm

Intermediate shaft

Intermediate shaft U-joint

Parts that should be replaced in *pairs only* include the following:

Outer tie rod ends

Inner tie rod ends

Idler arm (if there are two on the same vehicle, such as GM's Astro van)

Replacing steering system components involves these steps:

STEP 1 Hoist the vehicle safely with the wheels in the straight-ahead position. Remove the front wheels, if necessary, to gain access to the components.

STEP 2 Loosen the retainer nut on tapered components, such as tie rod ends. Use a tie rod removal puller (also called a *taper breaker),* as shown in ● **FIGURE 117–32**, or use hammers to slightly deform the taper, as shown in ● **FIGURE 117–33**.

CAUTION: Vehicle manufacturers often warn not to use a tapered pickle-fork tool to separate tapered parts. The wedge tool can tear the grease seal and damage both the part being removed and the adjoining part.

Pitman arms require a larger puller to remove the pitman arm from the splines of the pitman shaft. ● **SEE FIGURES 117–34 AND 117–35**.

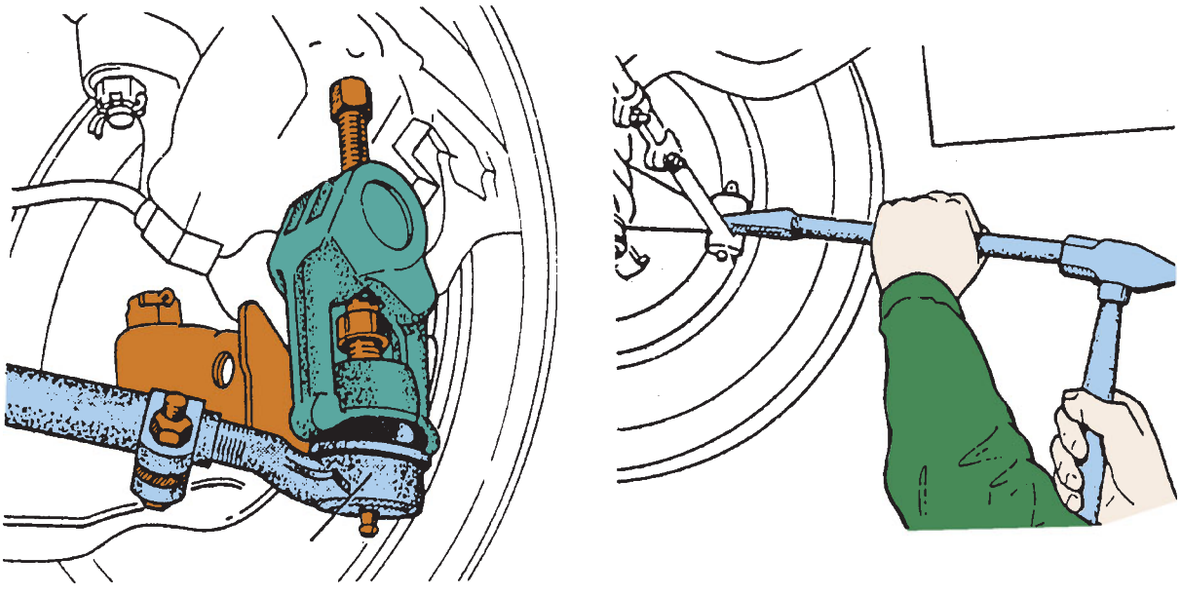


FIGURE 117–32 The preferred method for separating the tie rod end from the steering knuckle is to use a puller such as the one shown. A pickle-fork-type tool should only be used if the tie rod end is going to be replaced. A pickle-fork-type tool can damage or tear the rubber grease boot.

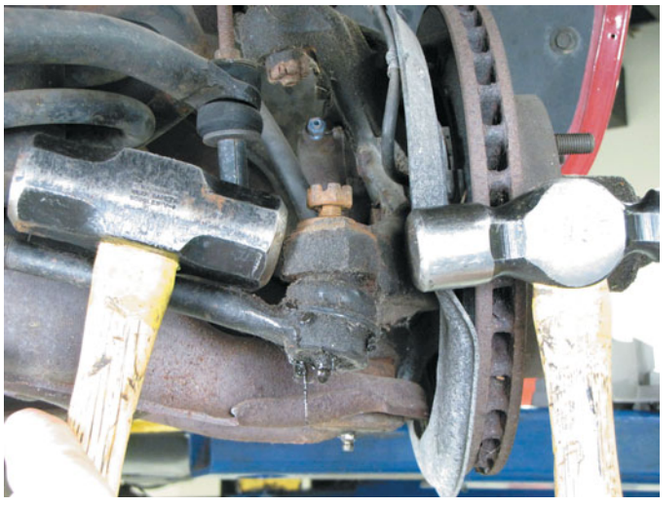


FIGURE 117–33 Two hammers being used to disconnect a tie rod end from the steering knuckle. One hammer is used as a backing for the second hammer. Notice that the attaching nut has been loosened, but not removed. This prevents the tie rod end from falling when the tapered connection is knocked loose.

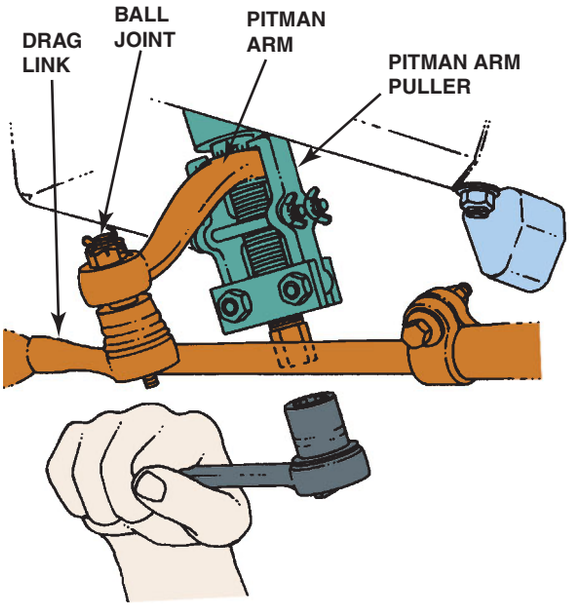


FIGURE 117–34 A pitman arm puller is used to remove the pitman arm from the pitman shaft.

STEP 3 Replace the part using the hardware and fasteners supplied with the replacement part. *Do not reuse the precrimped torque prevailing nuts used at the factory as original equipment on many tie rod ends.*

CAUTION: Whenever tightening the nuts of tapered parts such as tie rods, *DO NOT* loosen after reaching the proper assembly torque to align the cotter key hole. If the cotter key does not fit, *tighten* the nut farther until the hole lines up for the cotter key. ● SEE FIGURE 117–36. Always use a new cotter key.

When replacing tie rod ends, use the adjusting sleeve to adjust the total length of the tie rod to the same position and length as the original. Measure the original length of the tie rods and assemble the replacement tie rod(s) to the same overall length. ● **SEE FIGURE 117–37.**

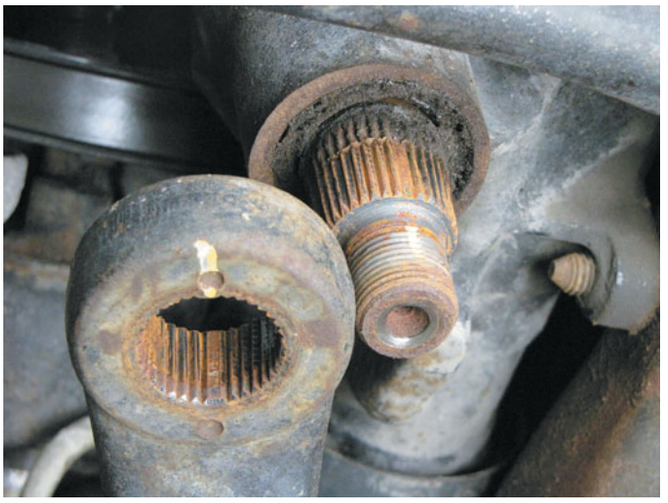


FIGURE 117–35 Pitman arm and pitman shaft indexing splines.

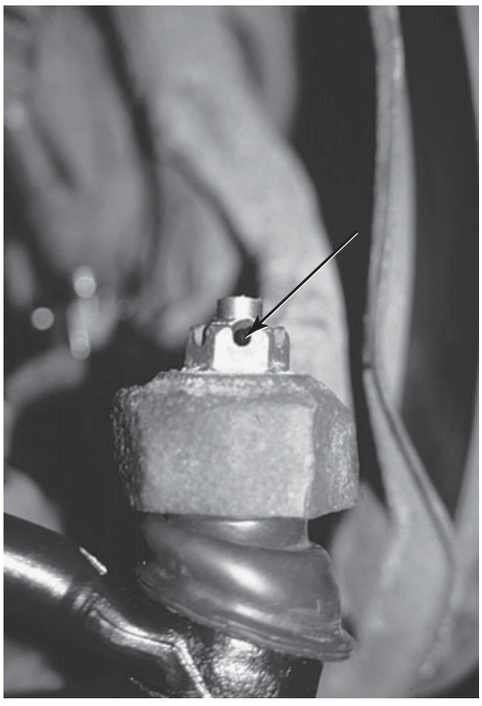


FIGURE 117–36 Align the hole in the tie rod end with the slot in the retaining nut. If the holes do not line up, always tighten the nut farther (never loosen) until the hole lines up.

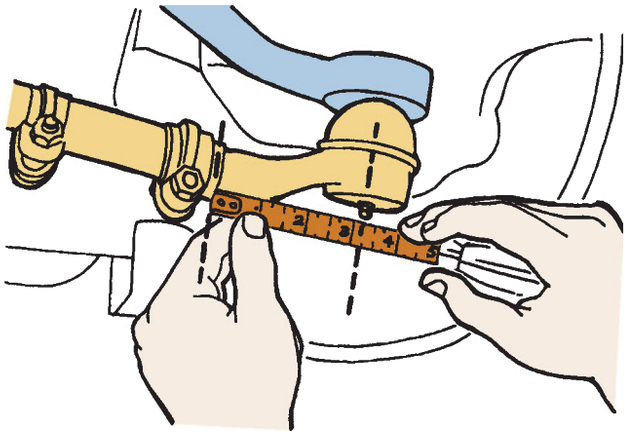


FIGURE 117–37 Replacement tie rods should be of the same overall length as the originals. Measure from the edge of the tie rod sleeve to the center of the grease fitting. When the new tie rod is threaded to this dimension, the toe setting will be close to the original.

When positioning the tie rod end(s), check that the stud is centered in the socket, as shown in ● **FIGURE 117–38.** This permits maximum steering linkage movement without getting into a bind if the steering linkage is pivoted beyond the angle the tie rod end can move in the socket.

NOTE: To ensure proper wheel alignment, install the adjusting sleeve with an equal number of threads showing at each end of the sleeve. Some manufacturers also specify a *minimum* of three threads showing at each end. If the sleeve itself is corroded or bent, it should be replaced along with either or both of the tie rod ends (inner and outer). ● **SEE FIGURE 117–39.**

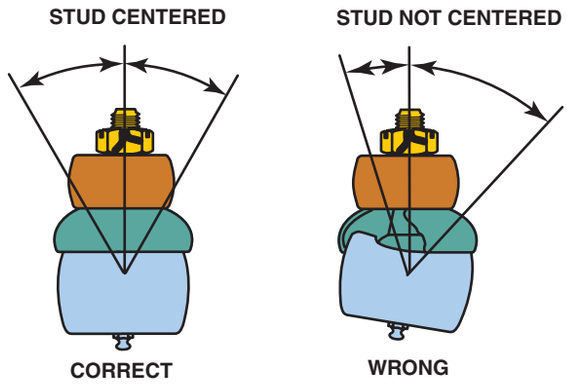


FIGURE 117–38 All tie rod ends should be installed so that the stud is in the center of its operating range, as shown.

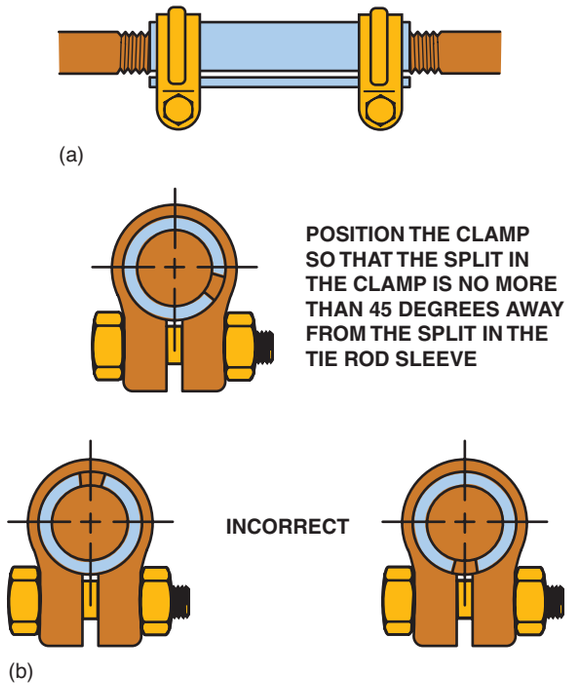


FIGURE 117–39 (a) Tie rod adjusting sleeve. (b) Be sure to position the clamp correctly on the sleeve.

SERVICE OF BALL SOCKET ASSEMBLIES

Inner tie rod end assemblies used on rack-and-pinion steering units require special consideration and often special tools. The inner tie rod end, also called a ball socket assembly, should be replaced whenever there is any noticeable freeplay in the ball-and-socket joint. Another test of this joint is performed by disconnecting the outer tie rod end and measuring the effort required to move the tie rod in the socket, as shown in ● **FIGURE 117–40.** This is called the **articulation test.**

NOTE: The articulation test is to be used on metal-to-metal ball socket assemblies. Low-friction joints (polished ball and plastic liner-type joints) may require less effort to move and still be serviceable.

The inner tie rod assemblies are attached to the end of the steering rack by one of several methods.

Removing a ball socket assembly usually requires the use of two wrenches or a special tool. ● **SEE FIGURE 117–41.**

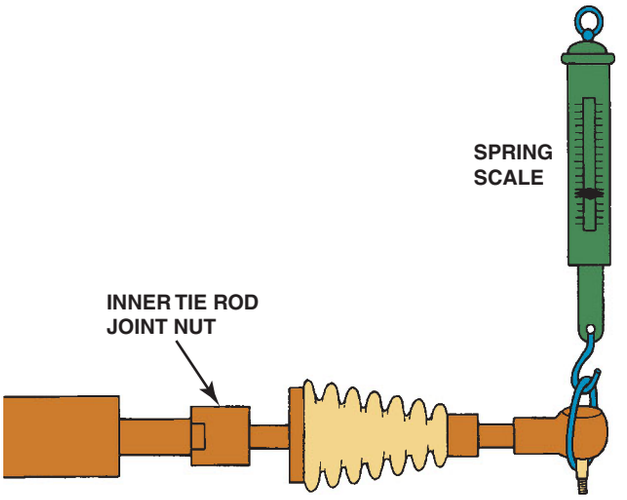


FIGURE 117–40 An articulation test uses a spring scale to measure the amount of force needed to move the tie rod in the ball socket assembly. Most manufacturers specify a minimum of 1 lb (4.4 N) of force and a maximum of 6 lb (26 N).

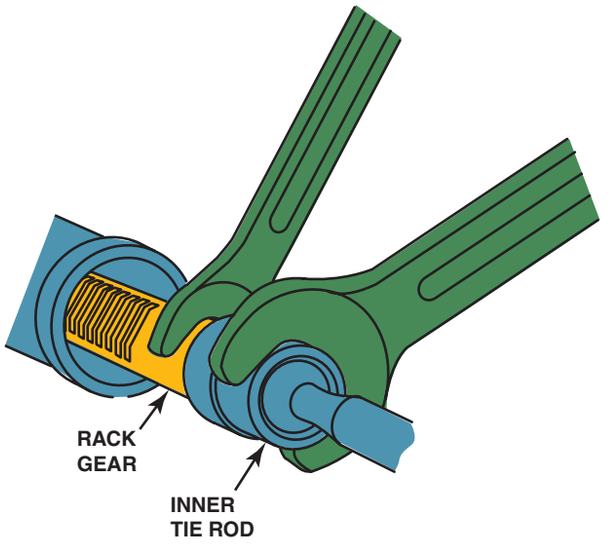


FIGURE 117–41 Removing a staked inner tie rod assembly requires two wrenches—one to hold the rack and the other to unscrew the joint from the end of the steering rack.

The flange around the outer tie rod must be restaked to the flat shoulder on the end of the rack, as shown in ● **FIGURE 117–42.**

Always follow the instructions that come with the replacement part(s). ● **SEE FIGURE 117–43.**

NOTE: When replacing a rack-and-pinion assembly, specify an entire replacement rack and pinion assembly if possible. A short rack does not include the bellows (boots) or inner tie rod ends (ball socket assemblies). The labor and cost required to exchange or replace these parts usually make it easier and less expensive to replace the entire steering unit.

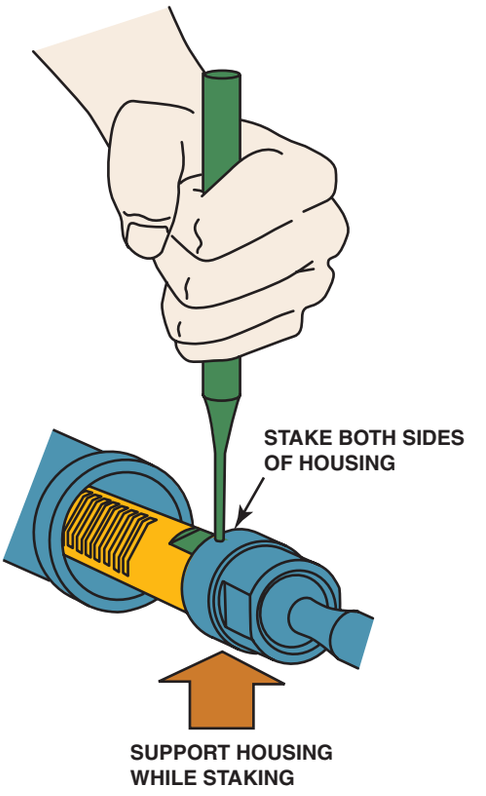


FIGURE 117–42 When the inner tie rod end is reassembled, both sides of the housing must be staked down onto the flat shoulder of the rack.

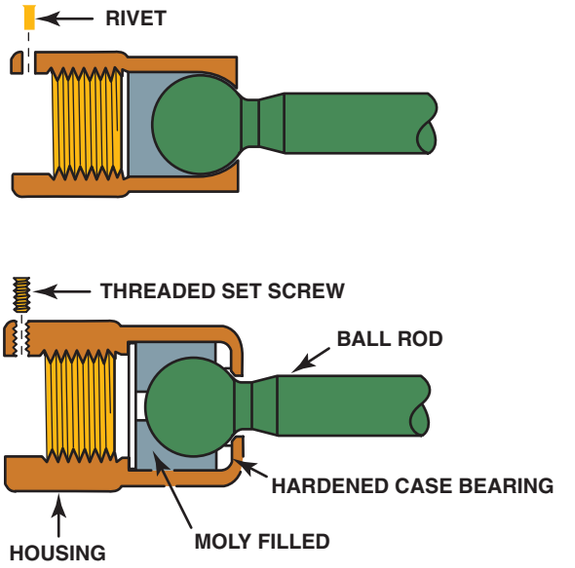


FIGURE 117–43 After replacing an inner tie rod end, the socket assembly should be secured with a rivet or set screw depending on the style of the replacement part.

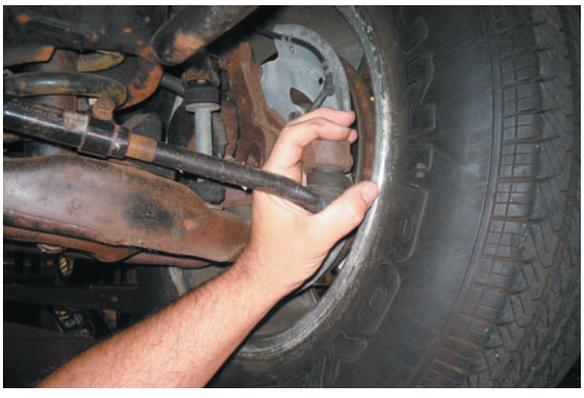
DRY PARK TEST



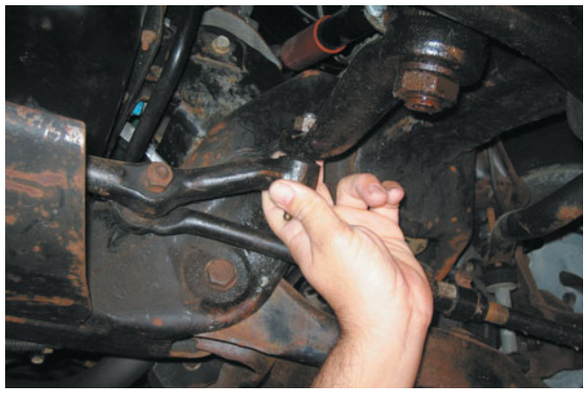
1 Drive the vehicle onto a drive-on-type hoist and have an assistant gently rotate the steering wheel back and forth about 2 inches (50 mm).



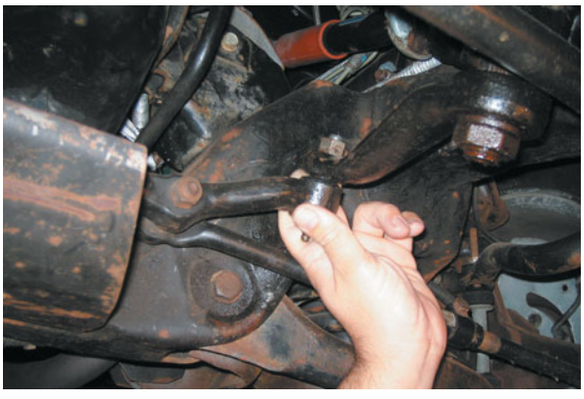
2 Perform a visual inspection of the steering and suspension system, looking for damage from road debris or other faults.



3 As the assistant wiggles the steering wheel, grasp the joint at the outer tie rod end on the driver's side to check for any movement.



4 Next, check for any freeplay at the pitman arm.



5 Check the joint between the left inner tie rod end and the center link for play.



6 Move to the passenger side and check for any looseness at the joint between the center link and the right-side inner tie rod end.



7 Check for looseness at the idler arm connector to the center link and the idler arm at the frame mount.



8 Check for looseness at the passenger-side outer tie rod end. After the inspection, record the results on the work order.

REVIEW QUESTIONS

1. Describe how to perform a dry park test.
2. List the steering parts that should be replaced in pairs.
3. What test procedure can be used to check that the steering linkage is straight and level?
4. What is the difference between a wear and nonwear center link?

CHAPTER QUIZ

1. A "dry park" test to determine the condition of the steering components and joints should be performed with the vehicle _____.
   a. On level ground or on a drive-on lift
   b. On turn plates that allow the front wheels to move
   c. On a frame contact lift with the wheels off the ground
   d. Lifted off the ground about 2 in. (5 cm)
2. Two technicians are discussing bump steer. Technician A says that an unlevel steering linkage can be its cause. Technician B says that if the steering wheel moves when the vehicle is bounced up and down, the steering linkage may be bent. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
3. A vehicle has an excessive amount of freeplay in the steering wheel and it is difficult to keep it traveling straight on a straight and level road. Which is the *least likely* cause?
   a. Worn tie rod ends
   b. Excessive play in the ball socket assemblies
   c. Worn idler arms
   d. Loose pitman arm retaining nut
4. How are the inner tie rods attached to the rack on a center-take-off-type rack-and-pinion steering gear?
   a. Staked **c.** Riveted
   b. Bolted **d.** Pinned
5. What is the *most likely* cause of bump steer?
   a. Worn outer tie rod ends
   b. A worn center link
   c. Worn or oil-soaked rack bushings
   d. A lack of proper lubrication of all ball-and-socket joints
6. How much endplay is usually acceptable in tie rod ends?
   a. Zero **c.** 0.030 to 0.050 in.
   b. 0.0010 to 0.030 in. **d.** 0.050 to 0.100 in.
7. Technician A says that outer tie rod ends should be replaced in pairs, even if only one is worn. Technician B says that inner tie rod ends should be replaced in pairs, even if only one is worn. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
8. Which tool is *not* recommended to be used to separate tapered steering components because it can do harm?
   a. Taper breaker **c.** Tie rod removal puller
   b. Pickle fork **d.** Two hammers
9. Technician A says that torque prevailing nuts can be reused unless damaged. Technician B says that a new cotter key should always be used. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
10. New tie rods are being installed. Technician A says to tighten the retaining nuts to specification and then loosen, if needed, to align the cotter pin hole. Technician B says to tighten farther to align the cotter key hole. Which technician is correct?
    a. Technician A only **c.** Both Technicians A and B
    b. Technician B only **d.** Neither Technician A nor B

chapter 118

POWER-ASSISTED STEERING OPERATION AND SERVICE

OBJECTIVES: **After studying Chapter 118, the reader will be able to:** • Prepare for ASE Suspension and Steering (A4) certification test content area "A" (Steering Systems Diagnosis and Repairs). • Discuss the components and operation of power steering pumps. • List the components of a typical power-recirculating-ball-nut steering gear system. • Describe the operation of a power rack-and-pinion steering system. • Discuss how electric power steering works • Describe how to perform a power steering pressure and volume test. • Explain how to flush power steering fluid.

KEY TERMS: BPP 1402 • EHPS 1402 • EPS 1399 • EVO 1397 • Flow control valve 1390 • Force 1388 • Integral reservoir 1389 • Magnasteer 1397 • Pascal's law 1388 • Pressure 1388 • Pressure-relief valve 1391 • PSCM 1400 • PSP 1391 • Remote reservoir 1389 • Rotary control valve 1392 • Self-park 1401 • SPS 1401 • SSS 1397 • TFE 1397 • VES 1396

POWER STEERING HYDRAULIC SYSTEMS

PURPOSE AND FUNCTION Power-assisted steering hydraulically boosts the mechanical steering gear operation so the driver can turn the steering wheel with less effort for the same response. Hydraulic power steering has been available since the 1950s, and many late-model systems are enhanced by electronic controls.

PRINCIPLES INVOLVED Hydraulics is the study of liquids and their use to transmit force and motion. Hydraulic systems transmit force and motion through the use of fluid pressure. **Force** is a push or pull acting on an object and is usually measured in pounds or Newtons. **Pressure** is force applied to a specific area. Pressure is usually measured in force per unit of area, such as pounds per square inch (PSI), or kilopascals (kPa). One PSI is equal to 6.895 kPa.

The Pascal is a unit of measure named after the French scientist Blaise Pascal (1623–1662), who studied the behavior of fluids in closed systems. One of his discoveries, known as **Pascal's law,** was that pressure on a confined fluid is transmitted equally in all directions and acts with equal force on equal areas.

Hydraulic systems can transmit force and motion through liquids because, for all practical purposes, a liquid cannot be compressed. No matter how much pressure is placed on a liquid, its volume remains the same. This allows a liquid to transmit force much like a mechanical lever. ● **SEE FIGURE 118–1.**

The advantage of a liquid over a mechanical lever is that a liquid has volume but does not have a fixed shape. Because it assumes the shape of its container, a liquid can transfer force around obstacles or through pipes and passages of any shape. As explained by Pascal's law, a liquid can also decrease or increase the force it transmits depending on the area of the output surface to which the force is applied. ● **SEE FIGURE 118–2.**

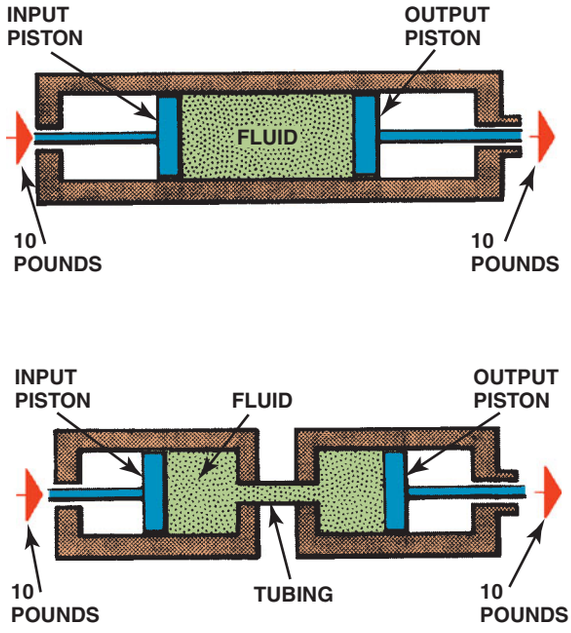


FIGURE 118–1 Hydraulic fluid transmits the same force whether it passes through a single chamber or two chambers connected by a narrow passage.

POWER STEERING PUMP AND RESERVOIR

PURPOSE AND FUNCTION The power steering pump draws fluid from the reservoir, pressurizes it, and delivers it to the power steering system. A power steering pump produces a high-pressure stream of fluid, typically in the 1,500-PSI (10,500 kPa) range. The fluid reservoir may be either integral to (built into) the pump or remotely mounted and connected to the pump by a hose. The power

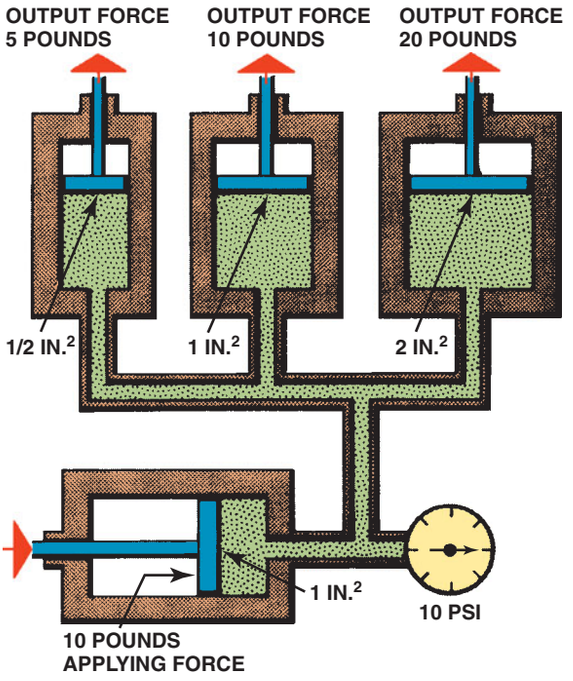


FIGURE 118–2 A fluid applies a force equal to the applied force on a surface that is equal in size to the applying surface. If the surface is half the size, then the fluid exerts half the force: if the surface is twice as large, the fluid exerts twice the force.

steering fluid reservoir is usually made of either plastic or stamped metal, and it includes the fluid filler neck, cap, and dipstick. An **integral reservoir** is part of the pump, and the pump itself operates submerged in power steering fluid. ● **SEE FIGURE 118–3.** Although once common, steering pumps with an integral reservoir have given way to those with a remote reservoir on many current-production vehicles. This is because the remote reservoir allows for a smaller, more compact pump assembly that is better suited to the cramped engine compartment of a modern vehicle.

A **remote reservoir** is a separate assembly from the pump and provides fluid to it through a suction hose. ● **SEE FIGURE 118–4.**

OPERATION

A typical power steering system requires only 2 to 3.5 lb (0.9 to 1.6 kg) of effort to turn the steering wheel.

Most power steering systems use an engine-driven hydraulic pump. Power steering hydraulic pumps are usually belt driven from the front crankshaft pulley of the engine. Pumps come in many sizes and styles. ● **SEE FIGURE 118–5.**

The power steering pump delivers a constant flow of hydraulic fluid to the power steering gear or rack. A typical power steering pump requires less than 1/2 horsepower, which is less than 1% of engine power while driving straight ahead. Even while parking at low speed, the power steering requires only about 3 horsepower while providing high hydraulic pressures. Typical pressures generated by a power steering system include the following.

Straight ahead	less than 150 PSI (1,400 kPa)
Cornering	about 450 PSI (3,100 kPa)
Parking (maximum)	750–1,400 PSI (5,200–10,0000 kPa)

The power steering pump drive pulley is usually fitted to a chrome-plated shaft with a press fit. The shaft is applied to a rotor with vanes that rotate between a thrust plate and a pressure plate. ● **SEE FIGURE 118–6.**

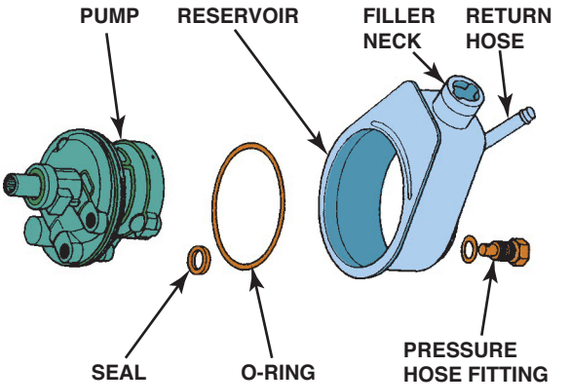


FIGURE 118–3 A typical integral power steering pump when the pump is mounted inside the reservoir.



FIGURE 118–4 Typical remote reservoir.

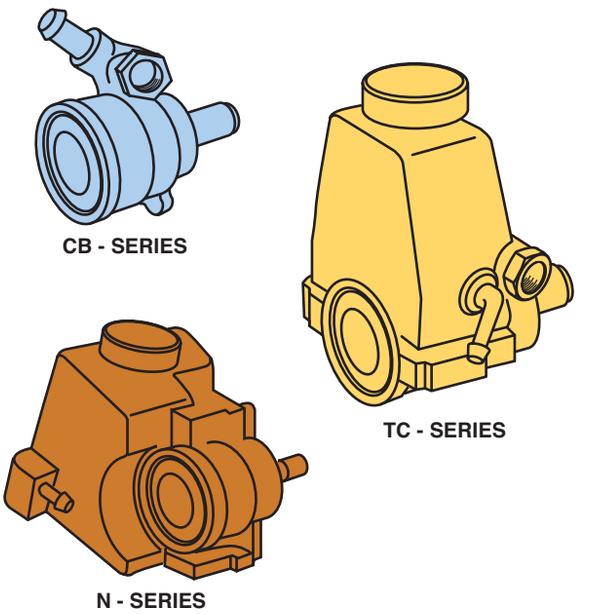


FIGURE 118–5 Typical power steering pump assemblies.

TYPES OF PUMPS

Some power steering pumps are of the slipper or roller design instead of the vane type. When the engine starts, the drive belt rotates the power steering pump pulley and the rotor assembly inside the power steering pump.

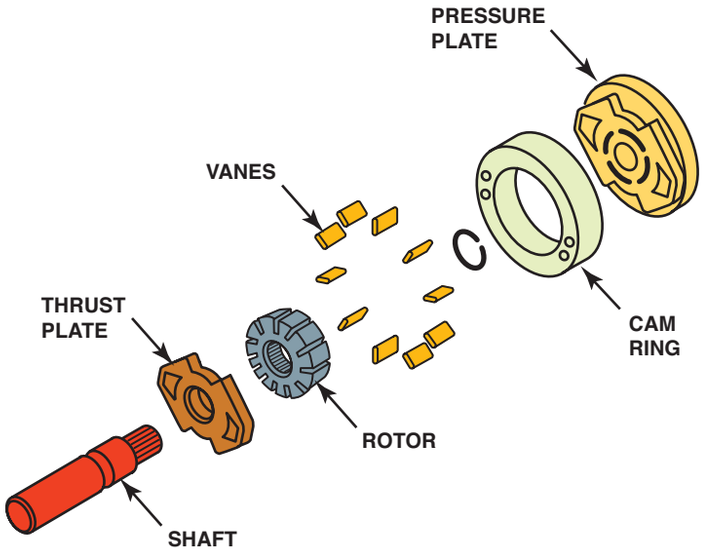


FIGURE 118–6 General Motors vane-type pump.

With a vane-type pump, centrifugal force and hydraulic pressure push the vanes of the rotor outward into contact with the pump ring. The shape of the pump ring causes a change in the volume of fluid between the vanes. As the volume increases, the pressure is decreased in the space between the vanes and draws in fluid from the pump reservoir. When the volume between the vanes decreases, the pressure is increased and flows out the pump discharge port. ● **SEE FIGURES 118–7, 118–8, AND 118–9.**

PRESSURE AND VOLUME CONTROL The pressure outlet hose connects to a fitting that threads into the outlet port of the pump body. A modulator valve, commonly called a **flow control valve,** installs in the same bore as the hose fitting. ● **SEE FIGURE 118–10.**

The modulator valve is a spring-loaded pressure-relief device that bleeds off excess pressure to prevent system damage. When pump output is more than the power steering system requires, the excess pressure overcomes spring force and moves the valve down in its bore. This uncovers an orifice through which the fluid can flow back into the inlet passages. An orifice is a small opening

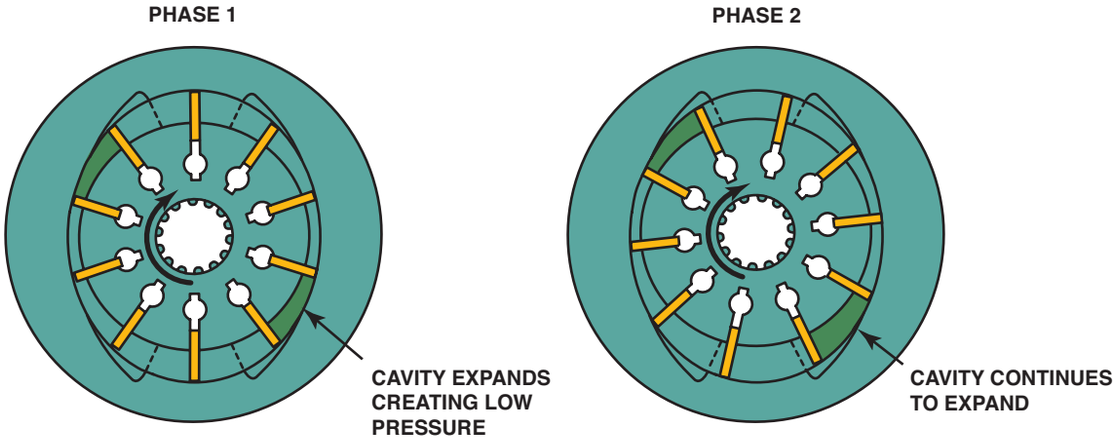


FIGURE 118–7 Vane pump operation. In phase 1, the rotor moves past the opposed suction ports, and the vanes move out to maintain contact with the ring. This creates a low-pressure area, drawing fluid into the cavities formed by the vanes. As the rotor continues to move during phase 2, the vanes follow the contour of the ring. The contour of the ring forms a larger cavity between the vanes. This increases the suction and draws more fluid into the pump.

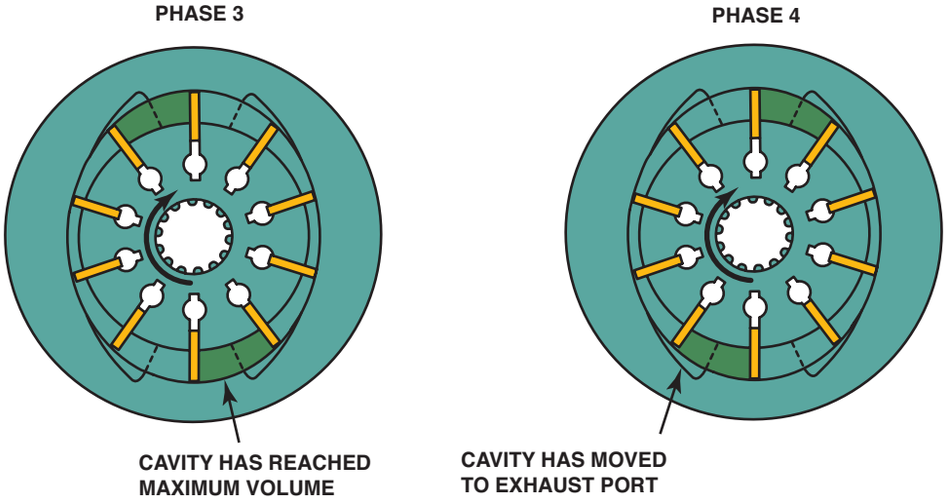


FIGURE 118–8 Vane pump operation—continued. At phase 3, the vanes are at the end of the intake port of the pump and the cavity has reached its maximum volume. In phase 4, the rotor moves into alignment with the opposed discharge ports.

that regulates fluid pressure and flow. It can be a restriction in a fluid line or a hole between two fluid chambers. This particular opening is called a *variable orifice* because the size of the opening varies with the amount of pressure applied to the valve. When fluid pressure is not high, spring force keeps the valve seated so that all of the pressurized fluid flows through the outlet port and into the pressure hose.

Because the engine drives the pump, the power steering pump places a load on the engine whenever the engine is running. Under certain conditions, such as when the steering wheel is turned to or near full stop for more than a few seconds, pressure builds in the system and the pump must work harder to keep up with the demand. As a result, the pump draws more power from the engine. If the engine is running at idle, the extra load can cause it to stall. A pressure switch, known as the **power steering pressure (PSP)** switch, transmits an electronic signal to the powertrain control module (PCM) when the pressure in the system is high enough to increase the load on the engine. In response to the PSP switch signal, the PCM increases the engine idle speed to prevent stalling.

The pressure increases when the steering wheel is turned to its full stop in either direction. To handle the excess pressure, a pressure-relief passage runs from a point near the pressure hose fitting to the spring end of the modulator valve. Inside the passage is a **pressure-relief valve.** The spring end of the modulator valve forms a seat for the pressure-relief check ball. Under normal circumstances, the check ball remains seated.

The parts of the pressure-relief valve are the following:

- Spring
- Valve piston
- Check ball
- Seat

A shim installs on the check ball seat to adjust the pressure at which the check ball unseats to open the pressure-relief valve. Normally, the spring force holds the piston against the check ball to keep it in its seat. When pressure becomes excessive in the pressure-relief passage, the check ball raises off its seat to allow fluid to flow through the relief passage and out through an orifice in the modulator valve. ● **SEE FIGURE 118–11.** The pressure when this occurs varies from 750 to 1,400 PSI (5,200 to 10,0000 kPa) depending on the calibration of the pressure-relief valve. When power steering systems are pushed to the limit, most will make a chattering or squealing noise until the pressure is reduced.

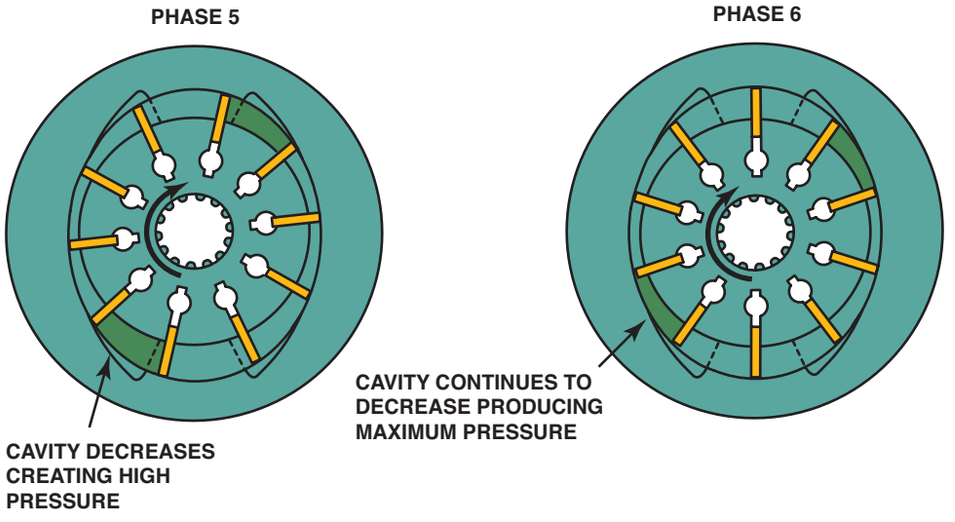


FIGURE 118–9 Vane pump operation—continued. As the rotor continues to move during phase 5, the volume of the cavity decreases, which increases the discharge pressure. At phase 6, the last phase, the contour of the ring results in the minimum cavity volume, and the discharge of fluid is completed.

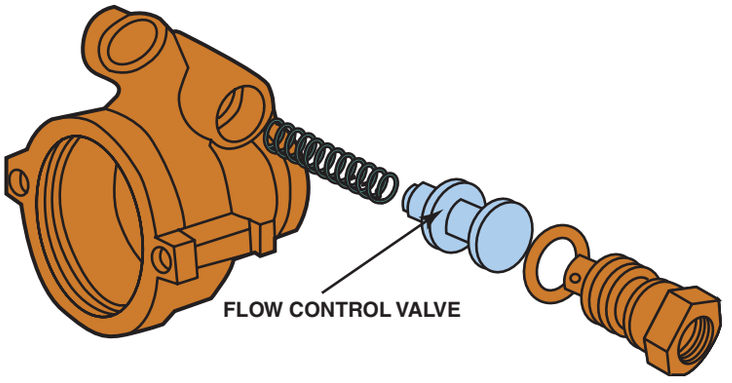


FIGURE 118–10 Flow control valve.

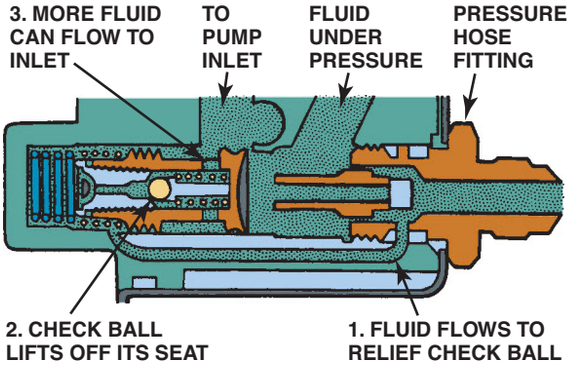


FIGURE 118–11 The pressure-relief check ball unseats, allowing fluid to flow back into the pump inlet if the pressure rises above a certain limit.

POWER STEERING HOSES

Because the power steering pump and the steering gear are not part of the same assembly, the system requires two hoses to connect the power steering pump and gear assembly. The pressure hose is connected to the flow control/relief valve. This hose supplies pressurized fluid to the steering gear. The second hose is called the return hose and it returns the fluid from the steering gear back to the pump. Some vehicles will use a cooler in the return path to the pump. The cooler is used to reduce the temperature of the fluid before it enters the pump. ● **SEE FIGURE 118–12.**

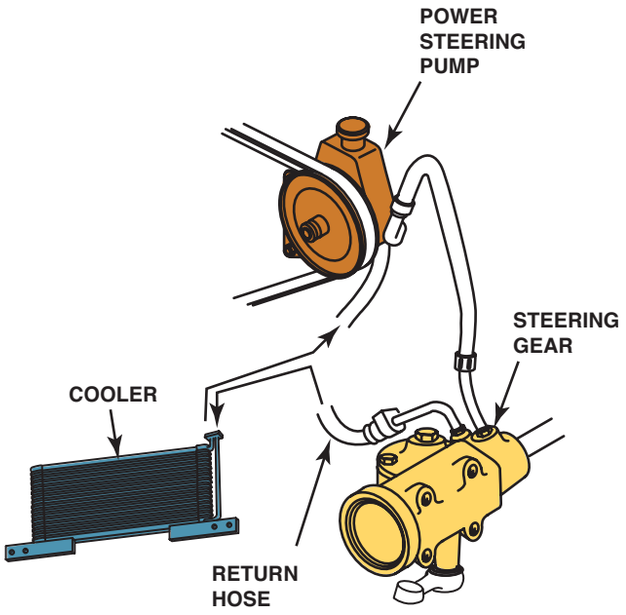


FIGURE 118–12 The power steering fluid cooler, if used, is located in the return hose. Often the "cooler" is simply a length of return metal line that is arranged in a loop and routed near the front of the vehicle. The airflow past the return line helps reduce the temperature of the fluid.

INTEGRAL POWER STEERING

In an integral power steering system, the control valve and the power piston are incorporated into the steering gear construction. The control valve regulates the application of pressurized fluid against the power piston, and the power piston helps move the output member of the steering gear when pressure is applied to one side of it.

INTEGRAL STANDARD STEERING GEAR

Most standard steering gears with power assist are the recirculating-ball type, and the ball nut functions as the power piston. Hydraulic pressure from the steering gear control valve is applied directly against the ball nut to help move it through the housing. The ball nut in this type of power steering gear is called the *power piston* because hydraulic pressure moves it as if it were a piston traveling in a cylinder. ● **SEE FIGURE 118–13.**

ROTARY CONTROL VALVE

A **rotary control valve** is a two-piece assembly that operates by rotating an inner valve within an outer valve. A steering gear with a rotary control valve is also a *torsion bar steering* gear, because a small torsion bar is used to control valve movement.

The rotary control valve consists of two cylindrical elements: the inner valve element and outer valve element. The inner valve element is secured to the steering gear input shaft and the torsion bar. In the valve, the inner element and the input shaft are one piece, and the torsion bar attaches to them. ● **SEE FIGURE 118–14.** The inner element assembly fits inside the outer valve element, and is also secured to the torsion bar by a pin. The outer valve element is also the steering worm gear. The torsion bar acts as a spring between the two elements to allow movement between them when the steering shaft turns. The spring force of the torsion bar tends to pull the elements back to their neutral positions when the steering wheel is released or returned to center. The strength of the torsion bar determines steering feel. A weak torsion bar moves easily and provides soft steering, while a strong bar resists movement and makes steering feel firm. Many high performance vehicles use a steering gear that has a thicker torsion bar to increase the firmness of the steering.

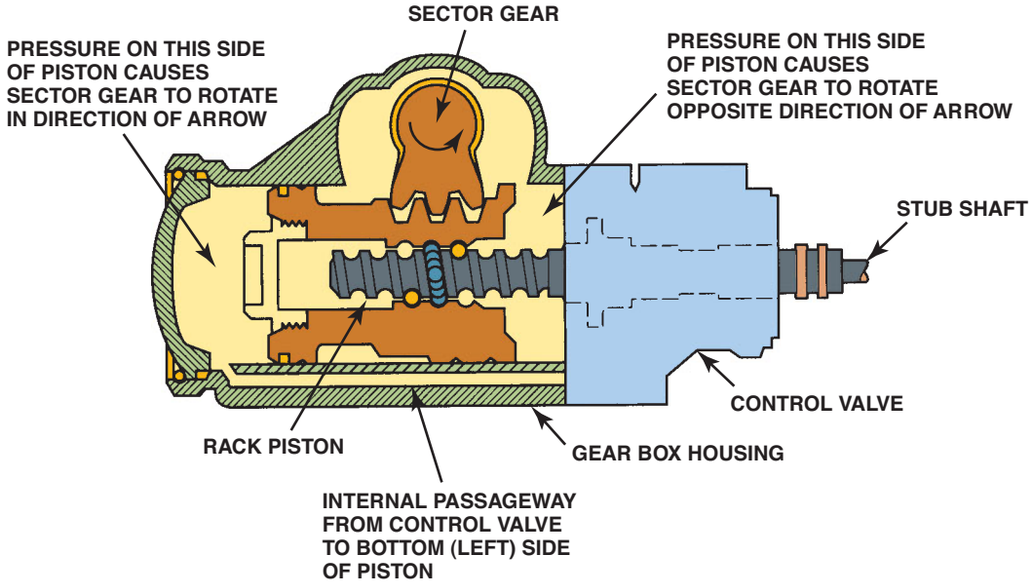


FIGURE 118–13 Forces acting on the rack piston of an integral power steering gear.

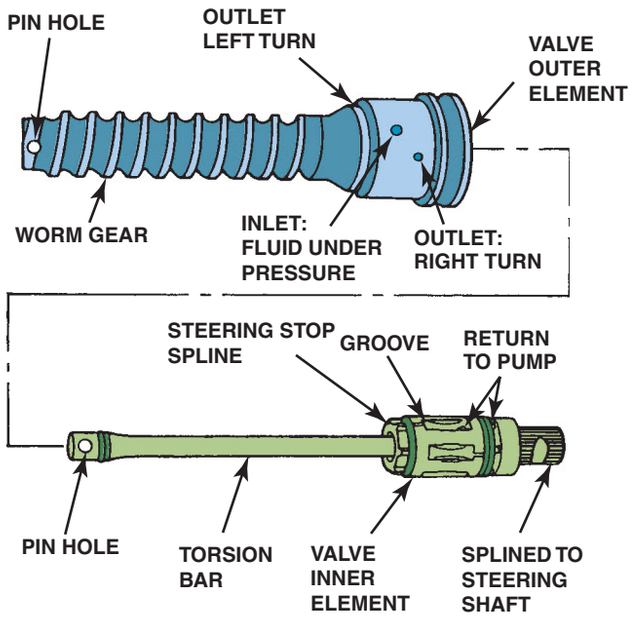


FIGURE 118–14 The rotary valve consists of inner and outer elements. The worm gear is part of the outer element and the torsion bar is part of the inner element. A pin attaches the worm gear to the bottom of the torsion bar to join the two elements together.

The facing surfaces of the inner and outer elements have grooves machined into them through which fluid can flow. Passages carry fluid from some of the inner-element grooves to the center of the element, where it travels through the return line to the pump reservoir. The outer element has three sets of fluid passages that connect the outside of the element to a groove at the inside. One set of passages carries fluid into the element from the pressure hose fitting, the second set carries fluid to and from the left-turn side of the power piston, and the third carries it to and from the right-turn side.

When the steering wheel is aimed straight ahead, the valve is in its neutral position. Fluid enters the valve and flows equally to both sides of the steering gear piston and to the return line. ● **SEE FIGURE 118–15.**

When the steering wheel and steering shaft turn to the left, the inner element twists on the torsion bar and repositions the valve ports. In this left-turn position, pressurized fluid flowing into the valve can only exit through the left-turn ports. ● **SEE FIGURE 118–16.** Meanwhile, the right-turn ports align with the return ports to bleed off residual pressure from the opposite side of the power piston. Pressurized fluid flowing through the left-turn ports is directed into the steering gear, where it applies force to the power piston and reduces the effort needed to turn the steering linkage to the left. ● **SEE FIGURE 118–17.** As the piston moves, it forces fluid out of the right-turn side, and that fluid returns through the control valve to the pump reservoir. Exactly the opposite flow occurs during a right-hand turn: The right-turn ports are opened and the left-turn ports exhaust to the return line. ● **SEE FIGURE 118–18.** Hydraulic pressure moves the piston up the housing bore during a right-hand turn. ● **SEE FIGURE 118–19.**

When the steering wheel is released, the spring force of the torsion bar returns the two elements to their natural positions. Fluid pressure equalizes throughout the steering gear and recenters the piston in the middle of the steering gear.

POWER RACK-AND-PINION STEERING The rotary control valve on a power rack-and-pinion steering gear is located between the steering gear input shaft and the pinion gear. ● **SEE FIGURE 118–20.**

STRAIGHT-AHEAD

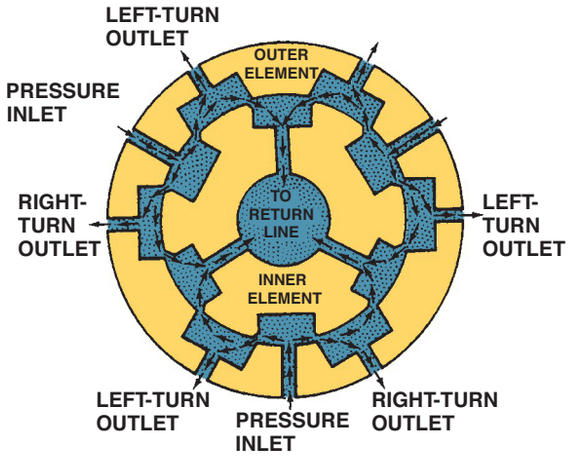


FIGURE 118–15 When the steering wheel is in the straight-ahead position, all of the ports in a rotary valve are open equally to the pressure and return circuits.

LEFT TURN

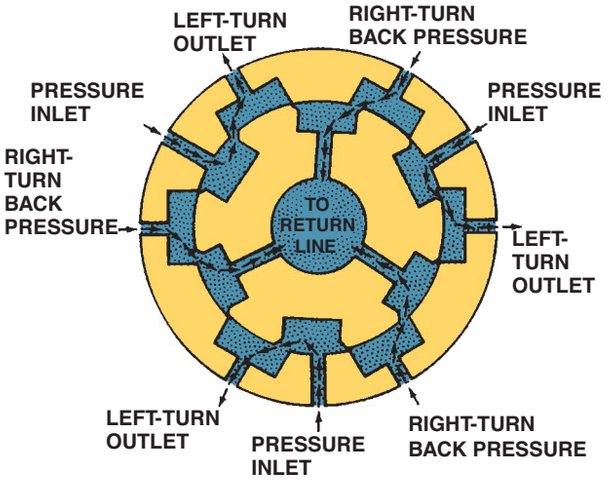


FIGURE 118–16 During a left turn, the inner element turns so that the left-turn circuits are open to pressure and the right-turn circuits are open to the return circuit.

Fluid discharged by the valve travels through external steel lines to either side of the power piston. A steel air-transfer tube allows air displacement between the boots as they compress and expand, since the power piston prevents air from passing through the rack housing. The rotary valve in a rack-and-pinion steering unit operates in the same manner as the one previously described for a standard steering gear. During a left-hand turn, the control valve directs fluid flow into the left-turn steel line, which routes it to the right-hand side of the power piston in order to move the rack to the left. As this happens, fluid on the opposite side of the power piston is forced out through the right-turn steel line and back to the control valve, where it is exhausted to the return circuit. When the steering wheel is turned to the right, fluid flow is reversed so the power piston moves to the right and fluid in the left-turn chamber is exhausted to the return circuit. ● **SEE FIGURE 118–21.**

FLOW CONTROL VALVE OPERATION When the power steering pump begins operation, the fluid from the output of the pump flows into the control valve. The fluid then flows through the orifice, where

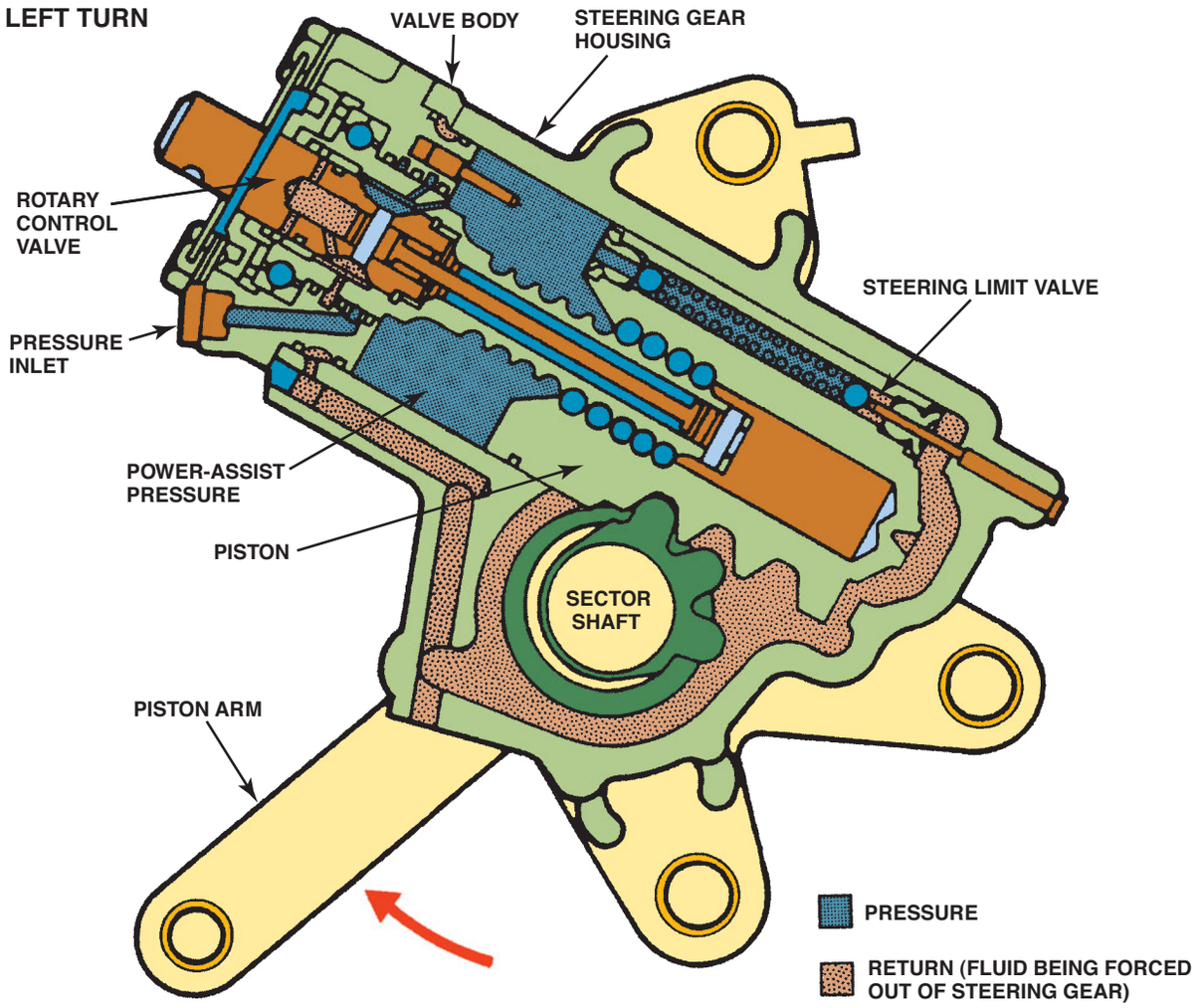


FIGURE 118–17 During a left turn, the high-pressure fluid helps push the piston along the worm gear, thereby reducing the steering effort from the driver.

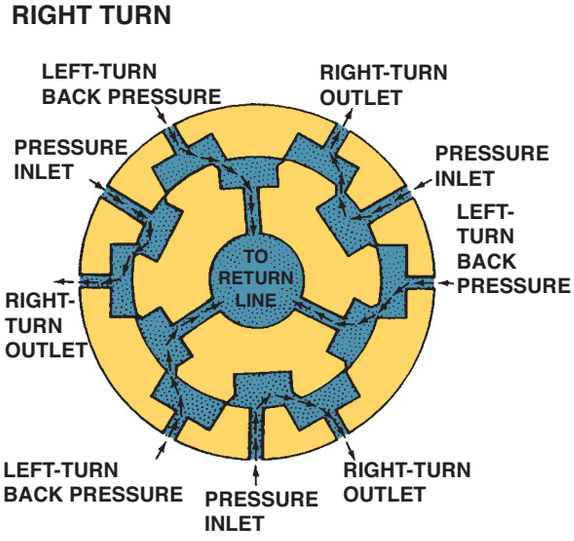


FIGURE 118–18 During a right turn, the inner element turns so that the right-turn outlets are open to pressure and the left-turn outlets are open to the return circuit.

a pressure differential is formed. The pressure differential results in a higher pressure on the pump side than on the system side. The fluid from the orifice flows into the power steering system and through a passage on the backside of the control valve. ● **SEE FIGURE 118–22.**

The fluid on the backside of the control valve is used to assist the spring force acting on the valve. At this point, the combination of the spring force and hydraulic pressure is higher than the output pressure of the pump. This causes the control valve to block the passage to the pump intake. When the output pressure is higher than the spring force, the pressure behind the valve forces the control valve to move. The movement of the valve opens the passage to the intake side of the pump. This allows some of the fluid to flow into the passage. As the pump speed continues to increase, the valve moves more to compensate for the higher pressure and flow. The pressure and flow in the power steering system must remain in the correct range or the steering system components can be damaged. Failure of the control valve to regulate the pressure in the power steering system can result in excessive pressure and temperature. As long as fluid can flow through the system, the control valve can regulate the pressure. ● **SEE FIGURE 118–23.**

However, there are times during normal operation when the flow in the system will stop. Fluid flow can stop during parking maneuvers and when the steering wheel is turned to the extreme right and left positions.

When the fluid flow through the system stops, the pressure equalizes on both sides of the orifice. This creates equal pressure on both sides of the control valve. Because the backside of the valve has a spring, the combination of the hydraulic pressure and spring force positions the control valve to prevent flow into the pump intake passage. As the pump continues to operate, the pressure in

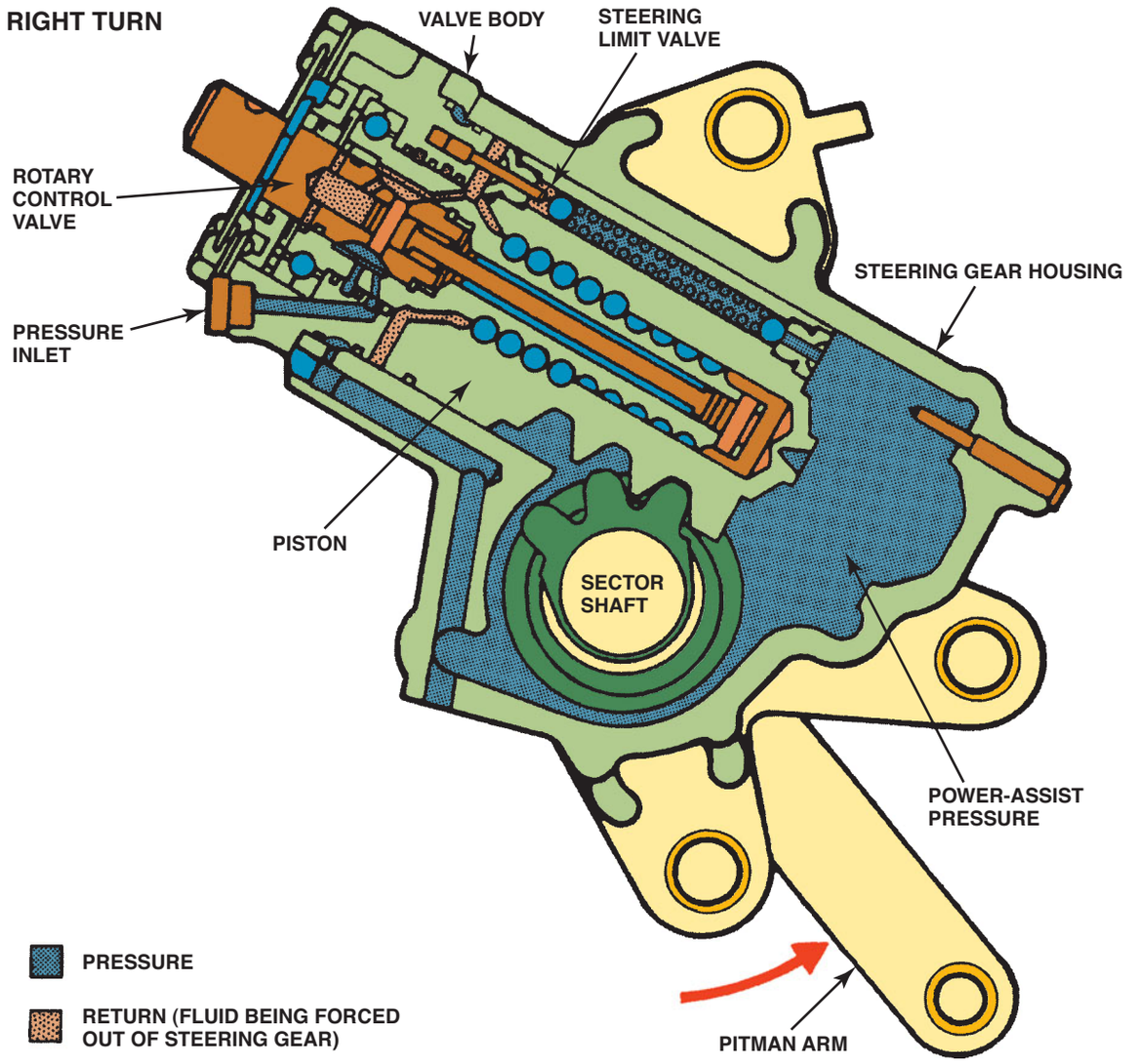


FIGURE 118–19 During a right turn, high-pressure fluid pushes the piston up the worm gear, moving the sector shaft and pitman arm to provide assist during a right turn.

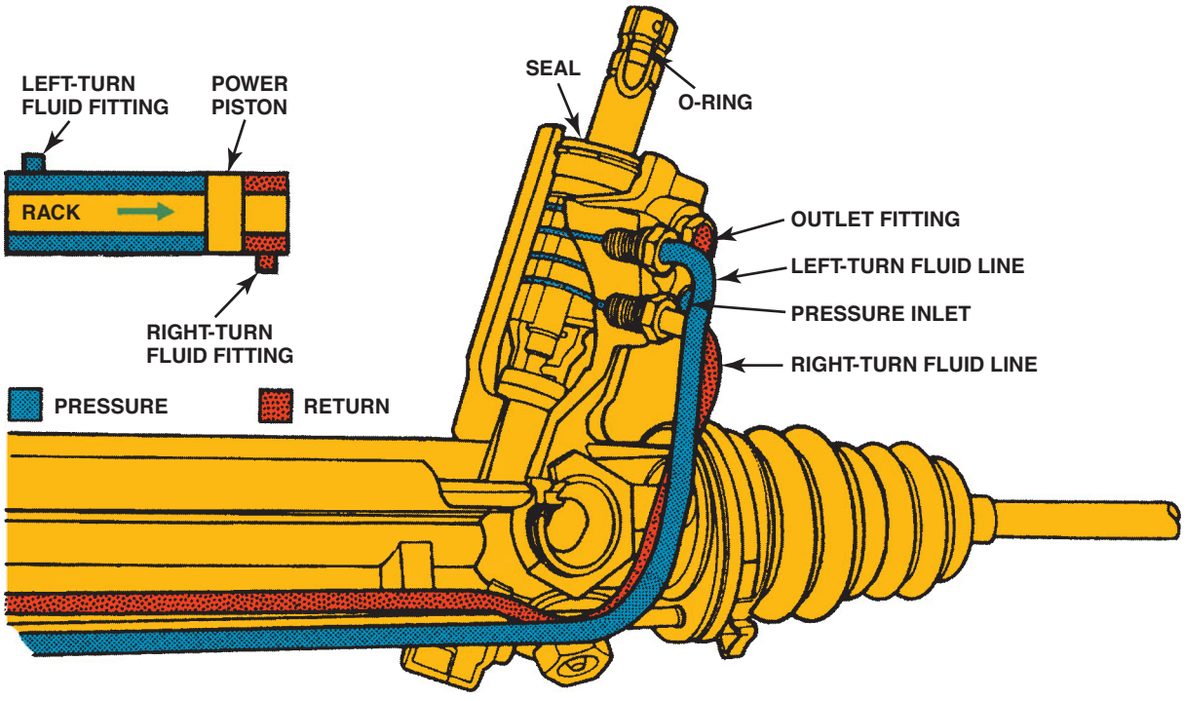


FIGURE 118–20 During a left turn, the control valve directs pressure into the left-turn fluid line and the rack moves left. (See inset.) Fluid pushed out of the right-turn fluid chamber travels back through the right-turn fluid line and control valve to the return circuit.

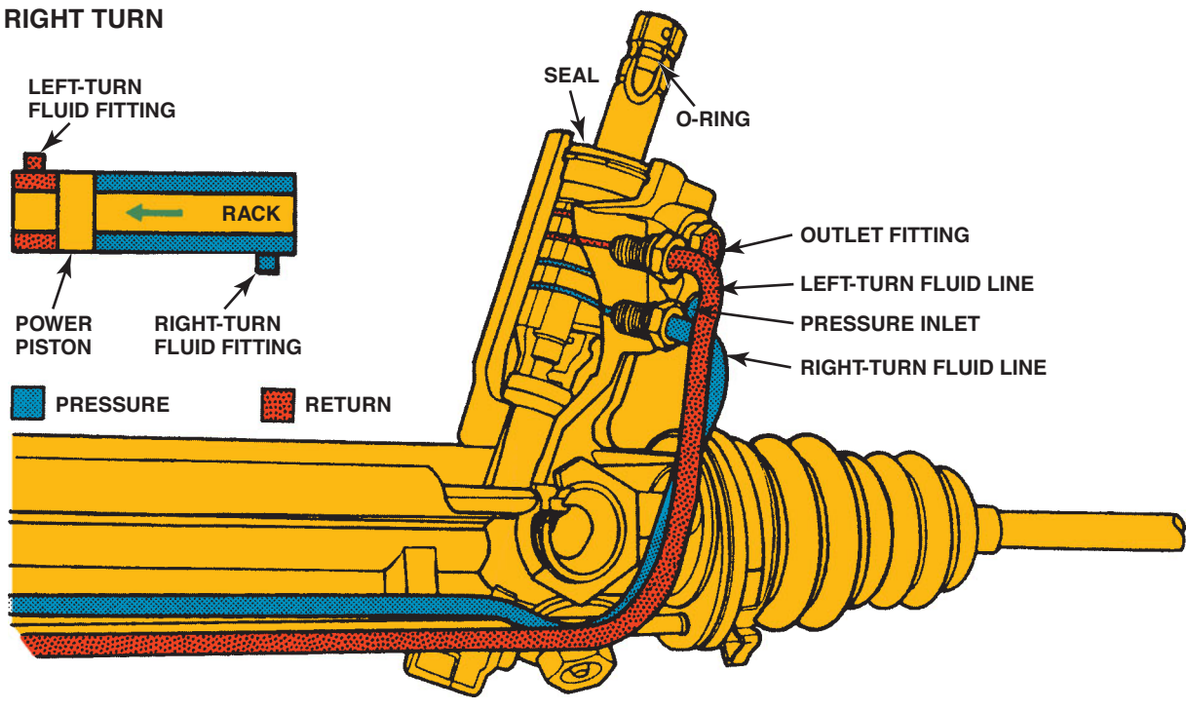


FIGURE 118–21 The control valve routes high-pressure fluid to the left-hand side of the power piston, which pushes the piston and assists in moving the rack toward the right when the steering wheel is turned right.

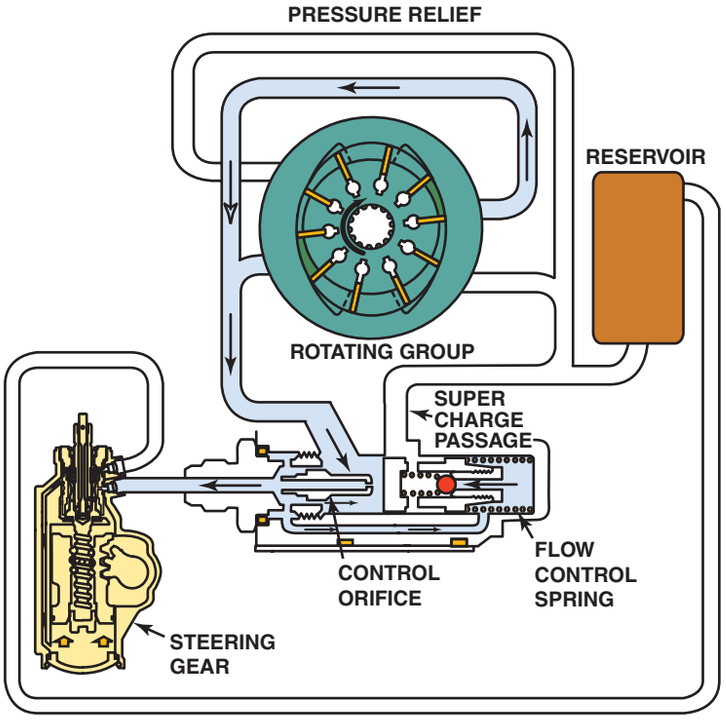


FIGURE 118–22 Low-speed flow control.

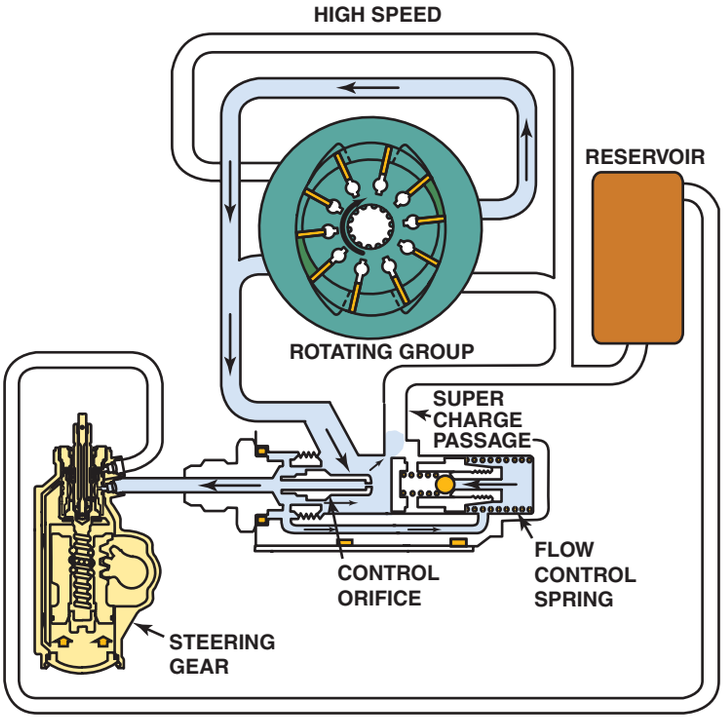


FIGURE 118–23 High-speed flow control operation.

the system builds. If the pressure is not relieved, the system can be damaged. To prevent this, the control valve has a check valve inside of it. At a specific pressure, the check valve opens to relieve the pressure on the backside of the control valve. This creates a pressure differential and allows the control valve to move. With the control valve moved, the high pressure is allowed into the pump intake passage. At this point, the check valve and control valve seat. ● **SEE FIGURE 118–24.**

VARIABLE-EFFORT STEERING

Variable-effort steering (VES) systems are designed to provide variable power-assisted steering. The amount of power assist increases at lower vehicle speeds to aid parking maneuvers and decreases at higher speeds for greater road feel.

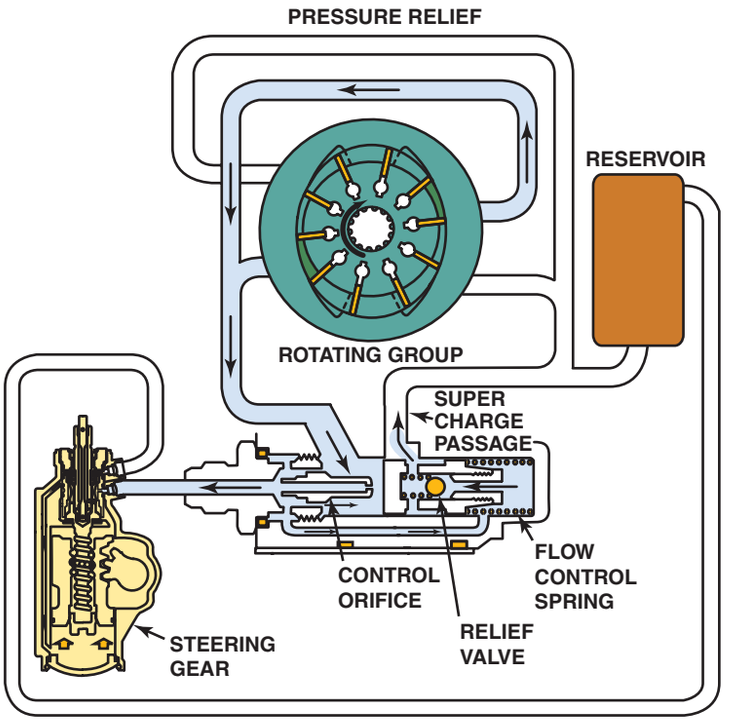


FIGURE 118–24 Pressure-relief mode. In this mode the steering gear has blocked the flow of fluid from the pump and the pressure rises, which unseats the pressure-relief valve. Now fluid flows back to the inlet through the pressure-relief orifice and passage.

As examples, General Motors uses four different variable-effort steering systems:

- **Electronic Variable Orifice (EVO)**
- **Two-Flow Electronic (TFE)**
- **Speed Sensitive Steering (SSS)**
- **Magnasteer**

The Electronic Variable Orifice (EVO) system provides a wide range of power-assisted steering based on the vehicle's operating conditions. ● **SEE FIGURE 118–25.**

The system uses vehicle speed and steering wheel speed to regulate the current to a solenoid that changes the orifice size of the flow control valve.

The size of the orifice controls the flow rate through the valve and the pressure in the hydraulic system. The desired amount is then directed to the steering gear for the power assist. The second type of power assist is the TFE system, which provides two rates of power assist:

- At low speeds, the TFE solenoid provides maximum power assist.
- At high speeds, the solenoid provides minimum power assist.

Another type of power assist is the Speed Sensitive Steering (SSS) system, which uses hydraulic pressure to resist movement in the steering gear as speed increases. This provides a firmer sense of control and stability in the steering gear at higher speeds.

ELECTRONIC VARIABLE ORIFICE (EVO) SYSTEM COMPONENTS

The main components of the EVO system are:

- Vehicle speed sensor
- Power steering control module
- Steering wheel speed sensor
- Power steering gear
- Power steering pump and solenoid actuator

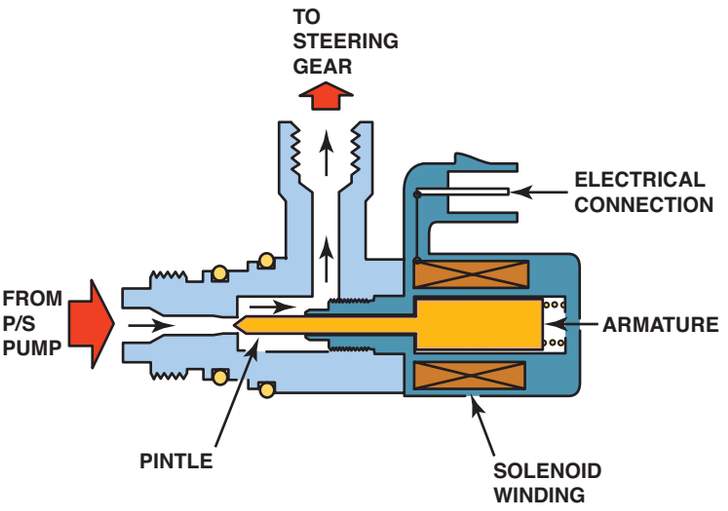


FIGURE 118–25 EVO actuator assembly.

The actuator is a solenoid-operated pintle valve. Electrical current flow through the solenoid controls the position of the pintle in relation to the orifice.

As the vehicle speed increases, the control module provides a higher current flow and the solenoid positions the pintle to change the size of the orifice.

This increased speed results in a reduced amount of hydraulic flow and provides less hydraulic pressure to the steering gear.

The control module uses the signal from the vehicle speed sensor to calculate the required amperage for the solenoid.

The amperage has a direct effect on steering effort and the flow rate to the gear. As the vehicle speed increases, the solenoid extends the pintle and reduces the size of the orifice. Hydraulic pressure is being reduced as the vehicle speed increases and less power assist is available.

The other sensor for the EVO system is the steering wheel speed sensor. This sensor is used to determine if the vehicle operator is performing an evasive steering maneuver.

In this situation, the controller increases the hydraulic pressure to assist the operator. The faster the driver turns the steering wheel, the stronger the signal generated by the sensor. The faster the steering wheel is rotated, the more the solenoid retracts the pintle and enlarges the size of the orifice. This increases hydraulic pressure to the steering gear and provides more power assist for the operator.

TWO-FLOW ELECTRONIC (TFE) SYSTEM

The main components of the TFE system are:

- Power steering pump and solenoid actuator
- Steering rack-and-pinion gear
- Powertrain Control Module (PCM)

The TFE actuator is a solenoid-operated pintle valve. The pintle valve only has two positions—maximum assist and reduced assist. When the solenoid is provided a ground from the chime module, the pintle extends out from the orifice and provides maximum assist. When the chime module opens the ground path, the pintle moves in to restrict the orifice and thus reduces steering assist.

The PCM provides the chime module with a vehicle speed signal. The logic circuits in the chime module determine when to energize the solenoid. The solenoid is energized whenever the vehicle speed is approximately 20 mph (32 km/h) or lower and the pintle is extended, causing the power steering pressure to increase.

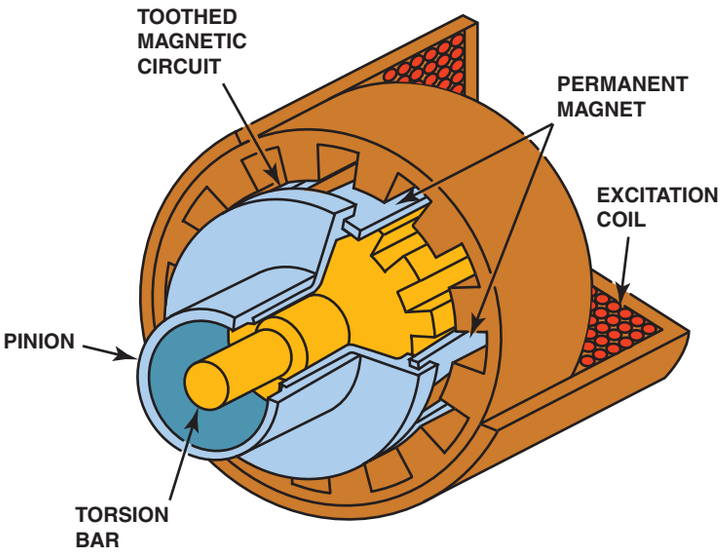


FIGURE 118–26 Integrated with the pinion shaft is a spool valve that senses the level of torque in the shaft and applies hydraulic pressure to the steering rack whenever assistance is needed. The electromagnet acts in parallel with the input shaft from the steering wheel to open or close the spool valve. The electromagnet generates variable torque, which can either increase or decrease the amount of steering torque that is needed to open the spool valve.

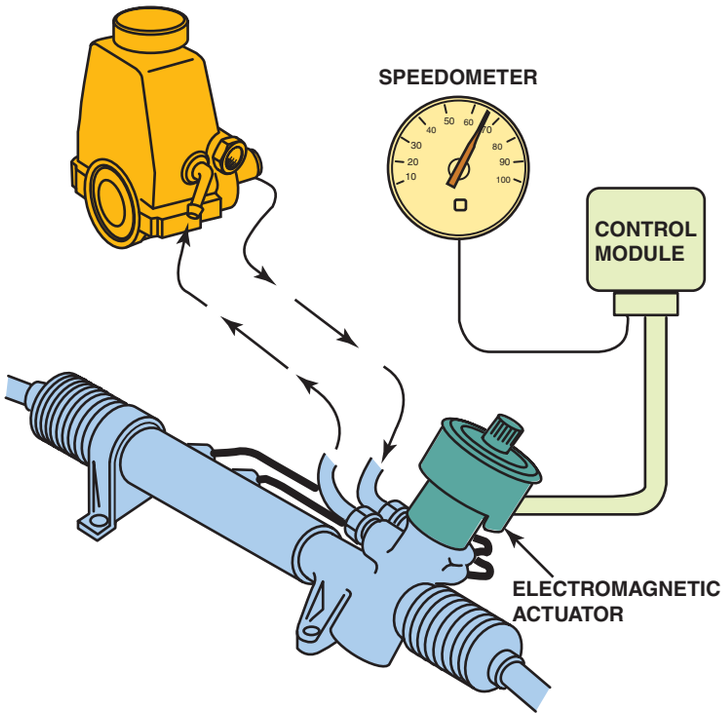


FIGURE 118–27 Magnasteer system.

This provides maximum assist and the steering effort is low. When the vehicle speed is higher than 20 mph (32 km/h), the pintle is moved in and the steering pressure is low. This provides reduced assist and higher steering effort.

SSS SYSTEM

The major components of the SSS system are:

- Power steering pump
- SSS actuator
- Steering gear
- Road sensing suspension control module

The actuator is a solenoid-operated valve that controls the flow of fluid into the chambers of the steering gear valve. As more fluid flows into the chamber, pressure is built against the four pistons that are located around the spool shaft. As the pistons are loaded and pushed against the spool shaft, steering effort is increased.

Unlike the EVO and TFE systems, the SSS system uses hydraulic pressure to resist movement in the steering gear. The amount of fluid allowed into the chambers is based on the electrical current flow through the solenoid.

The Road Sensing Suspension (RSS) control module, using the signal from the vehicle speed sensor, calculates the required amperage for the solenoid.

The amperage has a direct effect on steering effort and the hydraulic flow rate into the chambers of the spool shaft. As the vehicle's speed increases, more hydraulic pressure is built against the pistons and the steering effort is increased. The steering effort adjustment begins at a vehicle speed of 20 mph (32 km/h).

MAGNASTEER

The fourth type of VES steering system used by General Motors is the Magnasteer system. This system uses a variable bi-directional magnetic rotary actuator built into the steering rack. The bi-directional magnetic rotary actuator has no effect on the hydraulic operation of the steering rack.

The main components in the system include:

- Power steering pump
- Magnasteer actuator assembly
- Steering gear
- Electronic brake control module (EBCM)

The Magnasteer system uses a conventional rack-and-pinion steering gear and an engine-driven hydraulic pump to provide power assist. The Magnasteer actuator consists of the following:

- A permanent magnet attached to the rotary input shaft
- A pole-piece assembly attached to the pinion
- An electromagnetic coil mounted in the steering gear housing

Integrated with the pinion shaft is a spool valve that senses the level of torque in the shaft and applies hydraulic pressure to the steering rack whenever assistance is needed. The electromagnet acts in parallel with the input shaft from the steering wheel to open or close the spool valve.

The electromagnet generates variable torque, which can either increase or diminish the amount of steering torque that is needed to open the spool valve. ● **SEE FIGURES 118–26 AND 118–27.**

To vary the amount of steering assist, the EBCM uses the signal from the wheel speed sensor to calculate the required amperage and direction of current flow to the Magnasteer actuator.

The amperage and direction of current flow have a direct effect on steering effort and the flow rate to the rack piston. When the vehicle is stationary, approximately 1.6 amps of current flow through the electromagnetic coil.

As the vehicle speed increases to approximately 45 mph, the current decreases to 0 amps. The EBCM then switches the direction of current flow. Current flow through the electromagnetic coil causes either a magnetic attraction or repelling in the Magnasteer actuator.

At low vehicle speeds below 45 mph, the direction of current flow creates a magnetic field that opposes the permanent magnet.

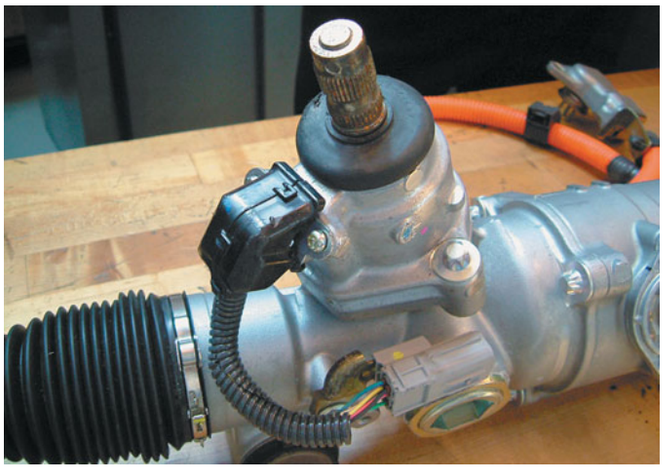


FIGURE 118–28 A Toyota Prius EPS assembly. (*Courtesy of Tony Martin*)

The repelling force of the magnetic field assists the spool valve in moving out of alignment with the valve body, and this increases the power assist.

With vehicle speeds below 45 mph, increased current provides increased steering assist. At vehicle speeds above 45 mph, the direction of current through the electromagnetic coil creates a magnetic field that attracts the permanent magnet.

- The magnet helps keep the spool valve aligned with the valve body, and this reduces the power assist and provides a greater road feel.
- As the vehicle speed increases, the amount of effort required to overcome the attracting force of the magnetic field increases.

With vehicle speeds above 45 mph, increased current flow provides decreased steering assist.

ELECTRIC POWER STEERING SYSTEM

PURPOSE AND FUNCTION Many of today's vehicles use electric power steering systems. Electric power steering takes the place of hydraulic components by using an electric motor to provide power assist effort.

PARTS AND OPERATION Most electric power steering units use a DC electric motor. Some operate from 42 volts while others operate from 12 volts. The **electric power steering (EPS)** is also called electric power-assisted steering (EPAS).

The Toyota system on a Prius uses a DC motor, reduction gear, and torque sensor all mounted to the steering column. ● **SEE FIGURE 118–28.**

The electric power steering (EPS) is controlled by the EPS electronic control unit (ECU), which calculates the amount of needed assist based on the input from the steering torque sensor. The steering torque sensor is a noncontact sensor that detects the movement and torque applied to the torsion bar. The torsion bar twists when the drive exerts torque to the steering wheel, and the more torque

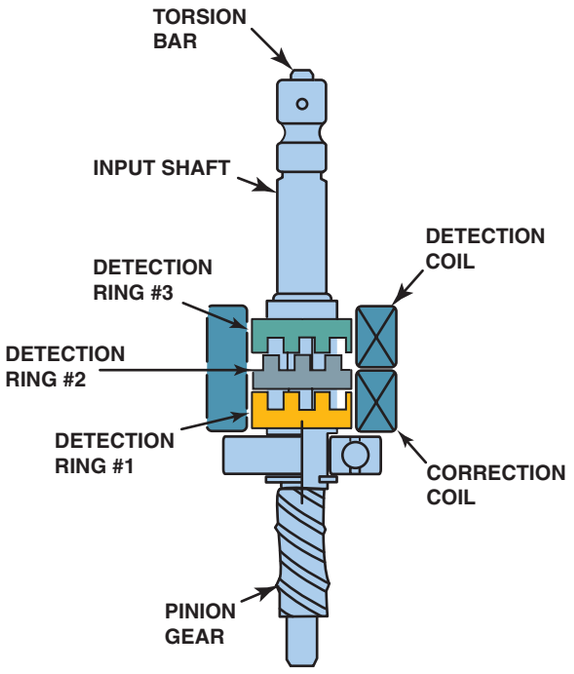


FIGURE 118–29 The torque sensor converts the torque the driver is applying to the steering wheel into a voltage signal.

applied the farther the bar will twist. This generates a higher-voltage signal to the EPS ECU. ● **SEE FIGURE 118–29.**

The steering shaft torque sensor and the steering wheel position sensor are not serviced separately from each other or from the steering column assembly. The steering column assembly does not include the power steering motor and module assembly. The detection ring 1 and detection ring 2 are mounted on the input shaft and detection ring 3 is mounted on the output shaft. The input shaft and the output shaft are connected by a torsion bar. When the steering wheel is turned, the difference in relative motion between detection rings 2 and 3 is sensed by the detection coil and it sends two signals to the EPS ECU. These two signals are called Torque Sensor Signal 1 and Torque Signal 2. The EPS ECU uses these signals to control the amount of assist, and also uses the signals for diagnosis.

NOTE: If the steering wheel, steering column, or steering gear is removed or replaced, the zero point of the torque sensors must be reset.

The Toyota Highlander and Lexus RX 400h use a different electric power steering unit due to the larger size of the vehicles. This unit uses a brushless DC motor on the steering rack. ● **SEE FIGURES 118–30 AND 118–31.**

The Honda electric power steering uses an electric motor to provide steering assist and torque sensor is used to measure road resistance and the direction that the driver is turning the steering wheel. The torque sensor input and the vehicle speed are used by the EPS controller to supply the EPS motor with the specified current to help assist the steering effort. ● **SEE FIGURE 118–32.**

The motor turns the pinion shaft using a worm gear. The worm gear is engaged with the worm wheel so that the motor turns the pinion shaft directly when providing steering assist. The steering rack is unique because the tie rods are mounted to the center of the rack rather than at the ends of the rack as in a conventional Honda power steering arrangement. ● **SEE FIGURE 118–33.**

If a major fault were to occur, the control module would first try to maintain power-assisted steering even if some sensors had failed. If the problem is serious, then the vehicle can be driven and

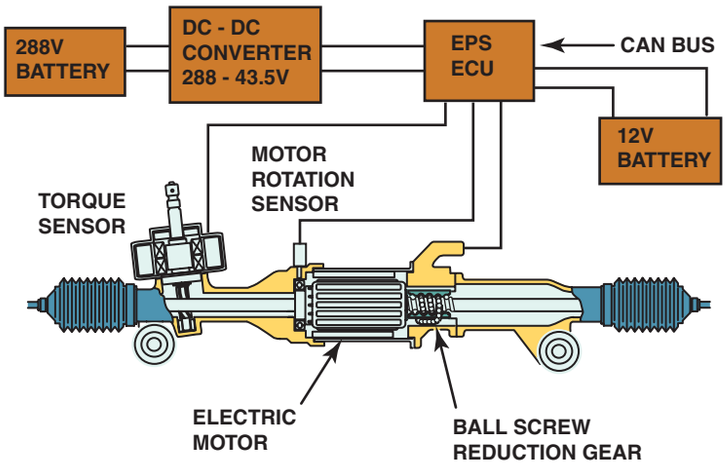


FIGURE 118–30 The electric power steering in Toyota/Lexus SUVs uses a brushless DC motor around the rack of the unit and operates on 42 volts.



FIGURE 118–33 Honda electric power steering unit cutaway.



FIGURE 118–31 Photo of the electric power steering gear on a Lexus RX 400h taken from underneath the vehicle.

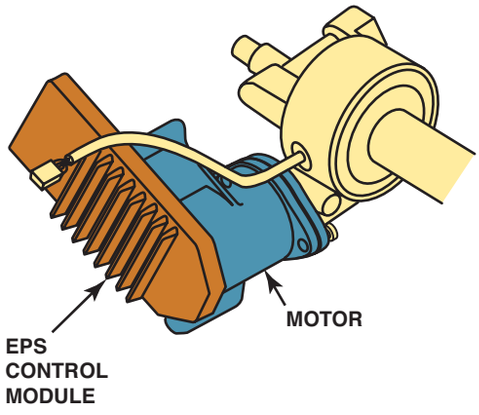


FIGURE 118–34 The Power Steering Control Module (PSCM) is attached to the motor of the electric power steering assembly.

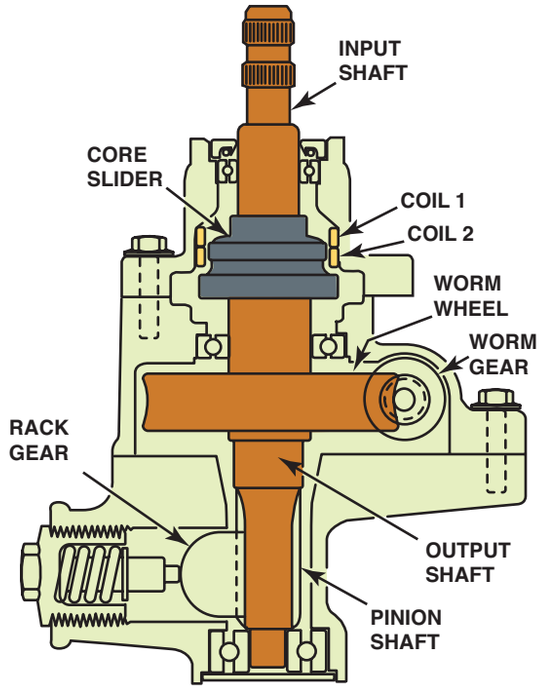


FIGURE 118–32 A cross-sectional view of a Honda electric power steering (EPS) gear.

steered manually. The EPS control unit will turn on the EPS dash warning light if a fault has been detected. A fault in the system will not cause the malfunction indicator light to come on because that light is reserved for emission-related faults only. Fault codes can be retrieved by using a scan tool. Check service information for the exact procedures to follow when diagnosing electric power steering faults.

EPS INPUTS AND OUTPUTS

The EPS system includes the following components and inputs/outputs:

- Powertrain Control Module (PCM)
- Body control module (BCM)
- Power steering control module (PSCM)
- Battery voltage
- Steering shaft torque sensor
- Steering wheel position sensor
- Power steering motor
- Driver information center (DIC)
- Serial data circuit to perform the system functions

The **power steering control module (PSCM)** and the power steering motor are serviced as an assembly and are serviced separately from the steering column assembly. ● **SEE FIGURE 118–34.**

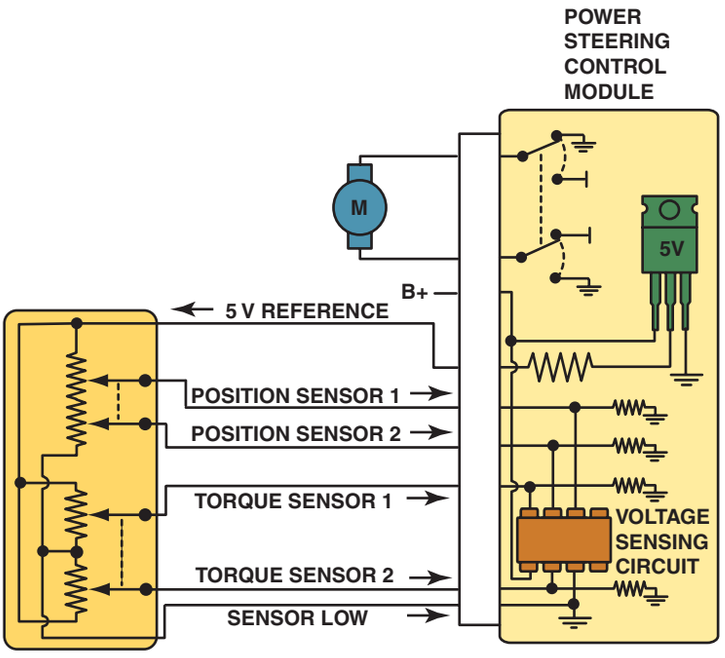


FIGURE 118–35 Schematic showing the electric power steering and the torque/position sensor.

The steering shaft torque sensor and the steering wheel position sensor are not serviced separately from each other or from the steering column assembly. The steering column assembly does not include the power steering motor and module assembly.

STEERING SHAFT TORQUE SENSOR The PSCM uses the steering shaft torque sensor as a main input for determining steering direction and the amount of assist needed. The steering column has an input shaft, from the steering wheel to the torque sensor, and an output shaft, from the torque sensor to the steering shaft coupler. The input and output shafts are separated by a section of torsion bar, where the torque sensor is located. The sensor is a 5-volt dual-analog inverse signal device with a signal voltage range of 0.25 to 4.75 volts. The sensors are used to detect the direction the steering wheel is being rotated.

- When torque is applied to the steering column shaft during a right turn, the sensor signal 1 voltage increases, while the signal 2 voltage decreases.
- When torque is applied to the steering column shaft during a left turn, the sensor signal 1 voltage decreases, while the signal 2 voltage increases.

The PSCM recognizes this change in signal voltage as steering direction and steering column shaft torque.

STEERING WHEEL POSITION SENSOR The PSCM uses the **steering position sensor (SPS)** to determine the steering system on-center position. Because the power steering motor provides a slight amount of return-to-center assist, the PSCM will command the power steering motor to the steering system center position and not beyond. The sensor is a 5-volt dual-analog signal device with a signal voltage range of 0 to 5 volts. The sensor's signal 1 and signal 2 voltage values will increase and decrease within 2.5 to 2.8 volts of each other as the steering wheel is turned. ● **SEE FIGURE 118–35.**

POWER STEERING MOTOR The power steering motor is a 12-volt brushless DC reversible motor with a 65-amp rating. The motor assists steering through a worm gear and reduction gear located in the steering column housing.

POWER STEERING CONTROL MODULE (PSCM) The PSCM uses a combination of steering shaft torque sensor input, vehicle speed, calculated system temperature, and steering tuning to determine the amount of steering assist. When the steering wheel is turned, the PSCM uses signal voltage from the steering shaft torque sensor to detect the amount of torque and steering direction being applied to the steering column shaft and then commands the proper amount of current to the power steering motor. The PSCM receives a vehicle speed message from the PCM by way of the serial data circuit. At low speeds more assist is provided for easy turning during parking maneuvers, and at higher speeds, less assist is provided for improved road feel and directional stability.

NOTE: The PSCM and the power steering motor are not designed to handle 65 amps continuously. If the power steering system is exposed to excessive amounts of static steering conditions, the PSCM will go into a protection mode to avoid thermal damage to the power steering components. In this mode the PSCM will limit the amount of current commanded to the power steering motor, which reduces system temperature and steering assist levels. The PSCM has the ability to detect malfunctions within the power steering system. Any malfunction detected will cause the driver information center to display the *power steering* warning message and/or the *service vehicle soon* indicator.

The PSCM must also be set up with the correct steering tunings, which are different in relation to the vehicle's powertrain configuration, model type, tire and wheel size.

SELF-PARKING SYSTEM

Several vehicle manufacturers offer a **self-parking** feature that uses the electric power steering to steer the vehicle. The driver has control of the brakes. Most systems use the following sensors:

- Wheel speed sensor (WSS)
- Steering-angle sensor
- Ultrasonic sensors, which are used to plot a course into a parking space

Some systems, such as those manufactured by Valeo for Volkswagen, allow the driver to control the accelerator as well as the brakes, making it possible to add power to park uphill. The Toyota/Lexus system stops working if the accelerator is depressed during a self-parking event. The Toyota/Lexus system is camera based and uses the navigation system to display the parking spot with touchscreen controls. The system displays a green video box to indicate that the spot is large enough and a red box to indicate that the spot is too small. The driver positions a yellow flag on the video screen to mark the front corner of the parking spot and then the vehicle backs into the space at idle speed. The driver has to complete the parking event by straightening the vehicle and pulling forward in the spot.

DIAGNOSIS AND TESTING Self-parking systems use many sensors to achieve the parking event, and a fault in any one sensor will disable self-parking. Before trying to diagnose a self-parking fault, be sure that the driver is operating the system as designed. For example, the self-parking event is cancelled if the accelerator pedal is depressed on some units. Always follow the factory-recommended diagnostic and testing procedures.

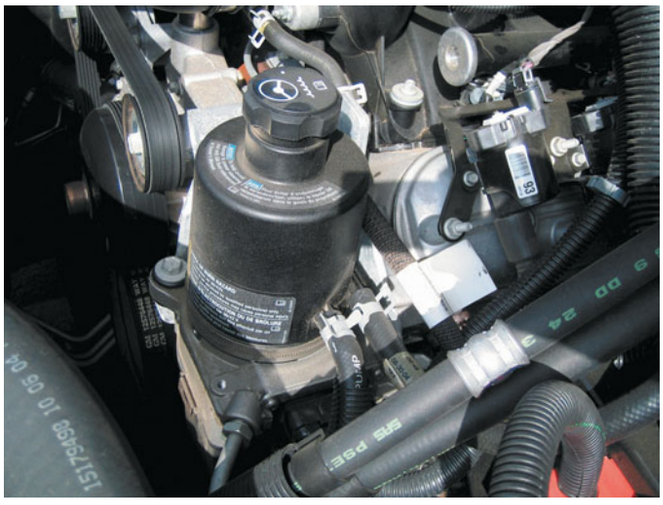


FIGURE 118–36 An electrohydraulic power steering assembly on a Chevrolet hybrid pickup truck.

ELECTROHYDRAULIC POWER STEERING

PURPOSE AND FUNCTION Electrohydraulic power steering is used on the Chevrolet Silverado hybrid truck. This system uses an electric motor to drive a hydraulic pump.

The **electrohydraulic power steering (EHPS)** module controls the power steering motor, which has the function of providing hydraulic power to the brake booster and the steering gear.

A secondary function includes the ability to improve fuel economy by operating on a demand basis and the ability to provide speed-dependent variable-effort steering.

The EHPS module controls the EHPS powerpack, which is an integrated assembly consisting of the following components:

- Electric motor
- Hydraulic pump
- Fluid reservoir
- Reservoir cap
- Fluid level sensor
- Electronic controller
- Electrical connectors

SEE FIGURE 118–36.

EHPS MODULE The electrohydraulic power steering (EHPS) module is operated from the 36-volt (nominal) power supply. The EHPS module uses class 2 for serial communications. A 125-amp, 36-volt fuse is used to protect the EHPS module. If this fuse were to blow open, the EHPS system would not operate and communication codes would be set by the modules that communicate with the EHPS module. The Powertrain Control Module (PCM) is the gateway that translates controller area network (CAN) messages into class 2 messages when required for diagnostic purposes. The EHPS module receives the following messages from the CAN bus:

- Vehicle speed
- Service disconnect status
- PRNDL (shift lever) position
- Torque converter clutch (TCC)/Cruise Dump signal (gives zero-adjust brake switch position)

The EHPS module outputs the following messages to the CAN bus:

- Brake pedal rate, position, in-range rationality, and out-of-range diagnosis
- EHPS system status
- Diagnostic messages to driver information center (DIC) via hybrid control module (HCM)
- Diagnostic information requested by service technicians via Tech 2 link (class 2 via PCM)
- Steering wheel sensor diagnostic message (in-range, out-of-range failure)

The EHPS module is not attached to class 2 data and receives several signals through wiring. The signals received and used by the EHPS module include:

- The digital steering wheel speed signals from the steering wheel sensor mounted on the steering column. The steering wheel speed sensor output contains three digital signals that indicate the steering wheel position. The signals are accurate to within 1 degree. The index output references a steering wheel position of 0 degrees plus or minus 10 degrees (steering wheel centered) and is repeated every 360 degrees of steering wheel rotation.
- An analog brake pedal position signal from the brake-pedal-mounted **brake pedal position (BPP)** sensor. The BPP sensor outputs an analog signal, referenced to 5 volts, that increases or decreases with brake pedal depression. The electrical range of the BPP sensor motion is −55 degrees to +25 degrees. The mechanical range of the BPP sensor is −70 degrees to +40 degrees.
- The EHPS module also receives ignition key position signals. These signals are the ignition signal and the accessory signal. The EHPS module receives an input from the ignition 0 circuit indicating when the key is in the ACCY position. This input is used to provide an independent wake-up signal in the event of loss of the ignition input, and to activate the EHPS module when the key remains in the ACCY position.

EHPS system performance may be reduced with power steering fluid temperature change.

POWER STEERING DIAGNOSIS AND TROUBLESHOOTING

Power steering systems are generally very reliable, yet many problems, such as hard steering, are caused by not correcting simple service items such as the following:

1. **A loose, worn, or defective power steering pump drive belt.** This can cause jerky steering and belt noise, especially when turning. It is generally recommended that all belts, including the serpentine (poly V) belt, be replaced every four years.

   If the vehicle does not use a belt tensioner, then a belt tension gauge is needed to achieve the specified belt tension. Install the belt and operate the engine with all of the accessories turned on to "run-in" the belt for at least five minutes. Adjust the tension of the accessory drive belt to factory

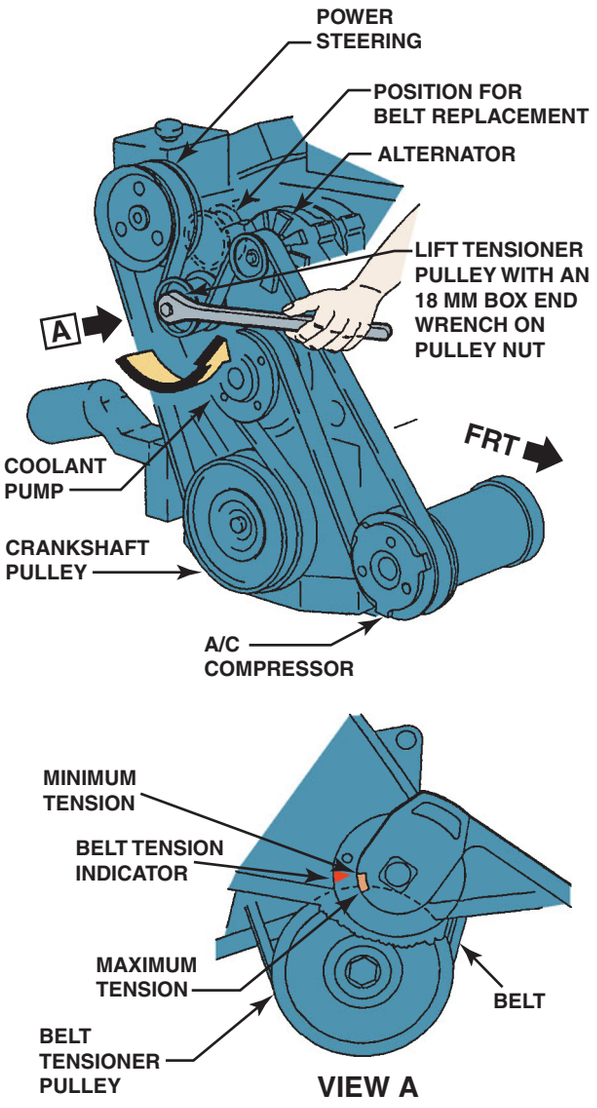


FIGURE 118–37 A typical service manual illustration showing the method to use to properly tension the accessory drive belt.

specifications or use the following table for an example of the proper tension based on the size of the belt.

Serpentine Belts

Number of Ribs Used	Tension Range (lbs.)
3	45–60
4	60–80
5	75–100
6	90–125
7	105–145

Replace any serpentine belt if more than three cracks appear in any one rib within a 3-inch span.

NOTE: Do not guess at the proper belt tension. Always use a belt tension gauge or observe the marks on the tensioner. ● **SEE FIGURE 118–37.**

2. **A bent or misaligned drive pulley** is usually caused by an accident or improper reassembly of the power steering pump after an engine repair procedure. This can cause a severe grinding noise whenever the engine is running and may sound like an engine problem.

TECH TIP

The Visual Test

Whenever diagnosing any power steering complaint, check the level *and* condition of the power steering fluid. Often this is best accomplished by putting your finger down into the power steering fluid reservoir and pulling it out to observe the texture and color of the fluid. ● **SEE FIGURE 118–38.**

A common problem with some power rack-and-pinion units is the wearing of grooves in the housing by the Teflon sealing rings of the spool (control) valve. When this wear occurs, aluminum particles become suspended in the power steering fluid, giving it a grayish color and thickening the fluid.

Normally clear power steering fluid that is found to be grayish in color and steering that is difficult when cold are clear indications as to what has occurred and why the steering is not functioning correctly.

3. **Low or contaminated power steering fluid** is usually caused by a slight leak at the high-pressure hose or defective inner rack seals on a power rack-and-pinion power steering system. This can cause a loud whine and a lack of normal power steering assist. See the Tech Tip, "The Visual Test."
4. **Broken or loose power steering pump mounting brackets.** In extreme cases, the pump mounting bolts can be broken. These problems can cause jerky steering. It is important to inspect the pump mounting brackets and hardware carefully when diagnosing a steering-related problem. The brackets tend to crack at the adjustment points and pivot areas. Tighten all the hardware to ensure the belt will remain tight and not slip, which would cause noise or a power-assist problem.
5. **Underinflated tires.**
6. **Engine idle speed below specifications.**
7. **A defective power steering pressure switch.** If this switch fails, the computer will not increase engine idle speed while turning.
8. **Internal steering gear mechanical binding.** As part of a complete steering system inspection and diagnosis, a steering wheel turning effort test should be performed. The power steering force, as measured by a spring scale during turning, should be less than 5 lb (2.3 kg).

NOTE: Some vehicles use power steering reservoir caps with *left-hand threads.* Always clean the top of the cap and observe all directions and cautions. Many power steering pump reservoirs and caps have been destroyed by technicians attempting to remove a cap in the wrong direction using large pliers.

POWER STEERING FLUID

The correct power steering fluid is *critical* to the operation and service life of the power steering system! The exact power steering fluid to use varies as to vehicle manufacturer. There are even differences within the same company because of various steering component suppliers.



FIGURE 118–38 A check of the power steering fluid should include inspecting not only the level but the condition and color of the fluid, which could indicate a possible problem with other components in the steering system.

NOTE: Remember, multiple-purpose power steering fluid does not mean *all*-purpose power steering fluid. Always consult the power steering reservoir cap, service manual, or owner's manual for the exact fluid to be used in the vehicle being serviced.

The main reason for using the specified power steering fluid is the compatibility of the fluid with the materials used in seals and hoses of the system. Using the wrong fluid (substituting ATF, for example) can lead to seal or hose deterioration and/or failure and fluid leaks.

NOTE: Always use the power steering fluid recommended by the manufacturer. The correct fluid to use is usually imprinted on or near the power steering reservoir fill cap. ● **SEE FIGURE 118–39.**

1. Check the power steering fluid level. Bleed the air from the system by turning the steering wheel lock-to-lock with the engine off and the front wheel off the ground.
2. Check the condition and tension of the drive belt. If in doubt, replace the belt.
3. Inspect the condition of all hoses, checking for any soft hose or places where the hose could touch another component.
4. Check the tightness of all mounting bolts of the pump and gear.
5. Check for leaks at pump, reservoir, hoses, steering gear and/or rack and pinion assembly.

POWER STEERING FLUID FLUSHING PROCEDURE

Whenever there is any power steering service performed, such as replacement of a defective pump or steering gear or rack-and-pinion unit, the entire system should be flushed. If all of the old fluid is not flushed from the system, small pieces of a failed bearing or rotor could be circulated through the system. These metal particles can block paths in the control valve and cause failure of the new power steering pump or gear assembly.

NOTE: Besides flushing the old power steering fluid from the system and replacing it with new fluid, many technical experts recommend installing a filter in the low-pressure return line as an added precaution against serious damage from debris in the system. Power steering filters are commonly available through vehicle dealer parts departments, as well as aftermarket sources from local auto supply stores.

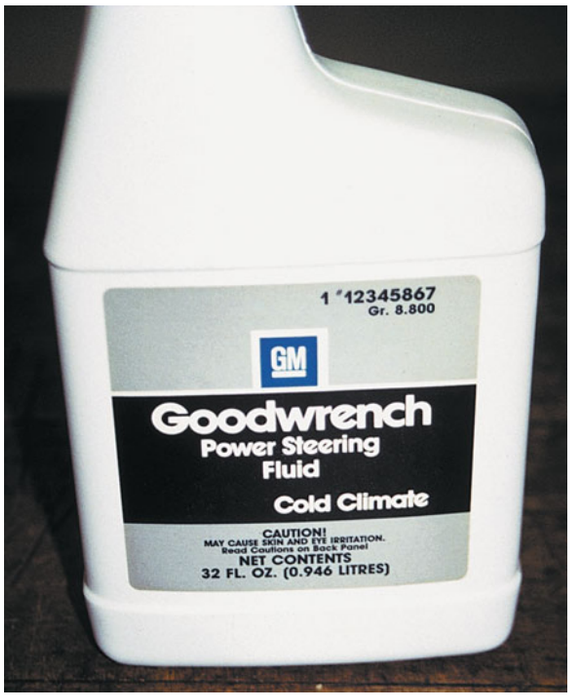


FIGURE 118–39 Some power steering fluid is unique to the climate, such as this **cold climate fluid** recommended for use in General Motors vehicles when temperatures are low.

Always follow the vehicle manufacturer's recommended flushing procedure. Two people are needed to flush the system. Use the following steps:

STEP 1 Raise the front wheels off the ground.

STEP 2 Remove the low-pressure return hose from the pump and plug the line fitting on the pump.

STEP 3 Place the low-pressure return hose into an empty container.

STEP 4 Fill the pump reservoir with fresh fluid and start the engine.

STEP 5 As the old and dirty power steering fluid is being pumped into the container, keep the reservoir full of clean fluid while the assistant turns the steering wheel full lock one way to full lock the other way.

CAUTION: Never allow the pump reservoir to run dry of power steering fluid. Severe internal pump damage can result.

STEP 6 When the fluid runs clean, stop the engine and reattach the low-pressure return hose to the pump reservoir.

STEP 7 Restart the engine and fill the reservoir to the full mark. Turn the steering wheel back and forth, avoiding the stops one or two times to bleed any trapped air in the system.

BLEEDING AIR OUT OF THE SYSTEM

If the power steering fluid is tan, there may be air bubbles trapped in the fluid. Stop the engine and allow the air to burp out to the surface for several minutes. Lift the vehicle off the ground, then rotate the steering wheel. This method prevents the breakup of large air bubbles into thousands of smaller bubbles that are more difficult to bleed out of the system.

NOTE: To help rid the power steering system of unwanted trapped air, it is recommend that the engine be cranked and that the wheels be turned from stop to stop *with the tires*

off the ground. **Check service information for the specified procedure to follow to the disable ignition or fuel injection system to keep the engine from starting. Do not crank the engine for longer than 15 seconds to prevent starter damage due to overheating. Allow the starter to cool at least 30 seconds before cranking again.**

Sometimes trapped air just cannot be bled out of the system using ordinary methods. This trapped air makes the pump extremely noisy and this noise sometimes convinces the technician that the pump itself is defective. If the power steering system has been opened for repairs and the system has been drained, trapped air may be the cause.

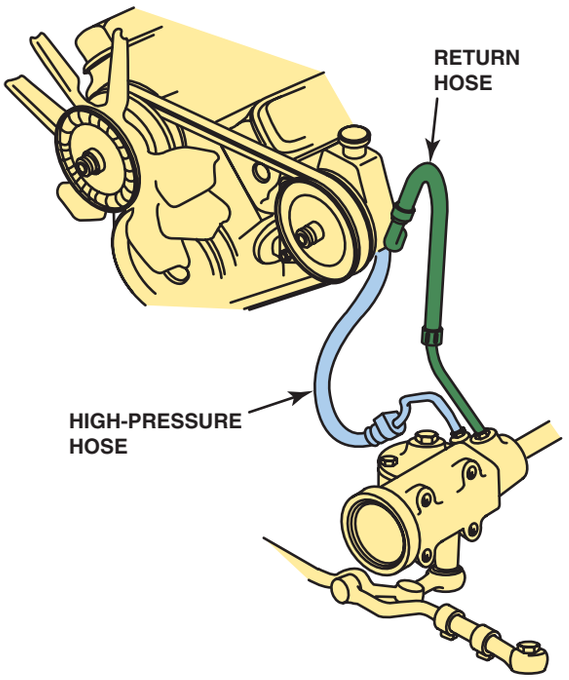


FIGURE 118–40 Inspect both high-pressure and return power steering hoses. Make sure the hoses are routed correctly and not touching sections of the body to prevent power steering noise from being transferred to the passenger compartment.

HOSE INSPECTION Both high-pressure and low-pressure return hoses should be inspected as part of any thorough vehicle inspection. While the low-pressure return hose generally feels softer than the high-pressure return hose, neither should feel *spongy.* A soft, spongy hose should always be replaced. ● **SEE FIGURE 118–40.**

When replacing any power steering hose, make certain that it is routed the same as the original and does not interfere with any accessory drive belt, pulley, or other movable component such as the intermediate steering shaft.

PRESSURE TESTING Use of a power steering pressure tester involves the following steps:

1. Disconnect the pressure hose at the pump.
2. Connect the hoses of the tester to the pump and the disconnected pressure line. ● **SEE FIGURE 118–41**.
3. Open the valve on the tester.
4. Start the engine. Allow the power steering system to reach operating temperatures.
5. The pressure gauge should register 80 to 125 PSI (550 to 860 kPa). If the pressure is greater than 150 PSI (1,400 kPa), check for restrictions in the system, including the operation of the poppet valve located in the inlet of the steering gear.
6. Fully close the valve three times. (Do not leave the valve closed for more than five seconds!) All three readings should be within 50 PSI (345 kPa) of each other and the peak pressure should be higher than 1,0000 PSI (6,900 kPa).
7. If the pressure readings are high enough *and* within 50 PSI (345 kPa) of each other, the pump is OK.
8. If the pressure readings are high enough, yet not within 50 PSI (345 kPa) of each other, the flow control valve is sticking.

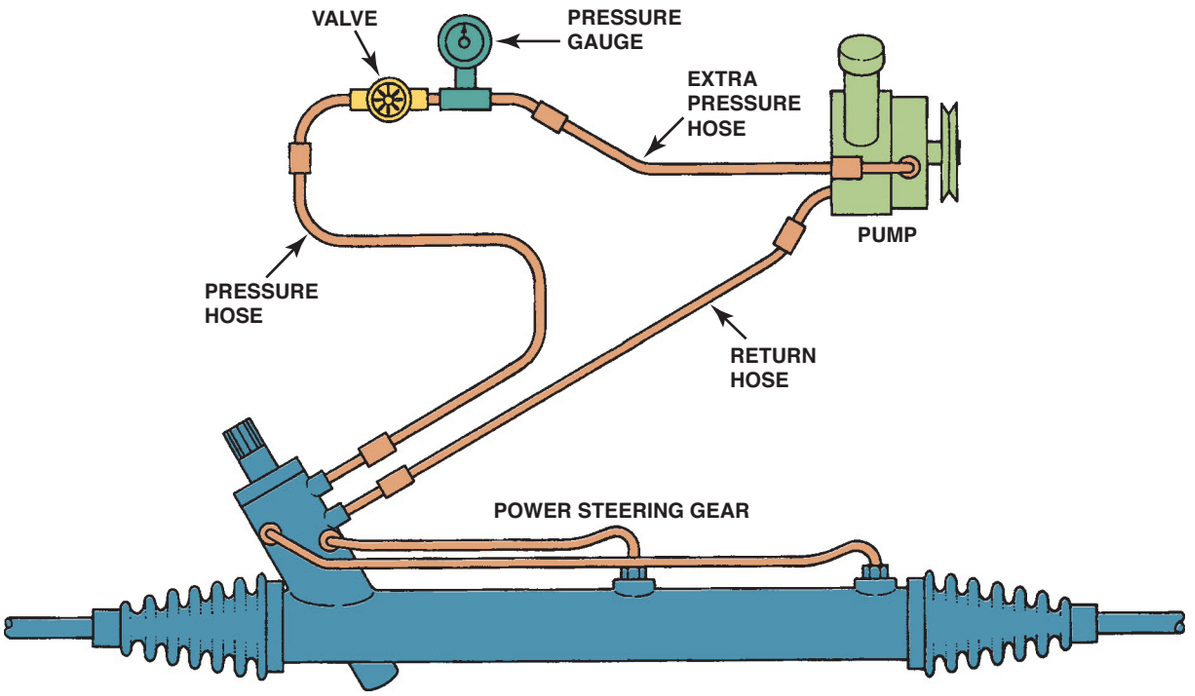


FIGURE 118–41 A drawing showing how to connect a power steering pressure gauge to the system.



FIGURE 118–42 A power steering analyzer that measures both pressure and volume. The shut-off valve is used to test the maximum pressure of the pump.

9. If the pressure readings are less than 1,0000 PSI (6,900 kPa), replace the flow control valve and recheck. If the pressures are still low, replace the rotor and vanes in the power steering pump.
10. If the pump is OK, turn the steering wheel to both stops. If the pressure at both stops is not the same as the maximum pressure, the steering gear (or rack and pinion) is leaking internally and should be repaired or replaced.

Many vehicle manufacturers recommend using a power steering analyzer that measures both pressure and volume, as shown in ● **FIGURE 118–42.**

Knowing the volume flow in the system provides information to the technician in addition to that of the pressure gauge. Many manufacturers' diagnostic procedures specify volume measurements and test results that can help pinpoint flow control or steering gear problems. Always follow the vehicle manufacturer's recommended testing procedures. Pressure and volume measurements specified by the manufacturer usually fall within the range noted in the following chart.

Typical Power Steering Pressures and Volume Specifications

Steering Action	Pressure, PSI (kPa)	Volume* (gal/min) (l/min)
Straight ahead, no steering	Less than 150 PSI (1,0000 kPa)	2.0 to 3.3 gpm (10 to 15 lpm)
Slow cornering	300–450 PSI (2,000–3,000 kPa)	Within 1 gpm (4 lpm) of straight ahead
Full turn at stops	750–1,450 PSI** (5,200–10,000 kPa)	Less than 1 gpm (4 lpm)

*Volume is determined by orifice size in the outlet of the pump and is matched to the steering gear.

**Upper-limit pressure is determined by the calibration of the pressure-relief valve.

PUMP SERVICE

Some power steering pump service can usually be performed without removing the pump, including the following:

1. Replacing the high-pressure and return hoses.
2. Removing and cleaning the flow control valve assembly. ● **SEE FIGURE 118–43.**

Most power steering pump service requires the removal of the pump from the engine mounting and/or removal of the drive pulley.

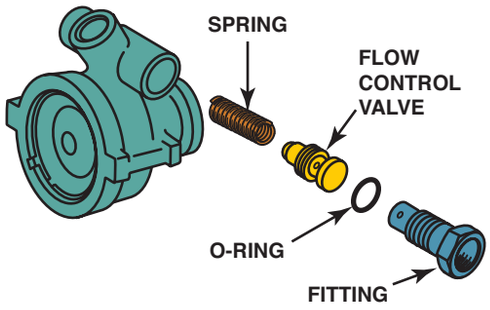
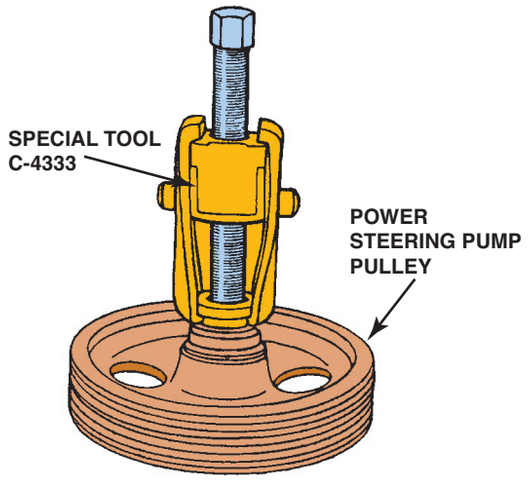
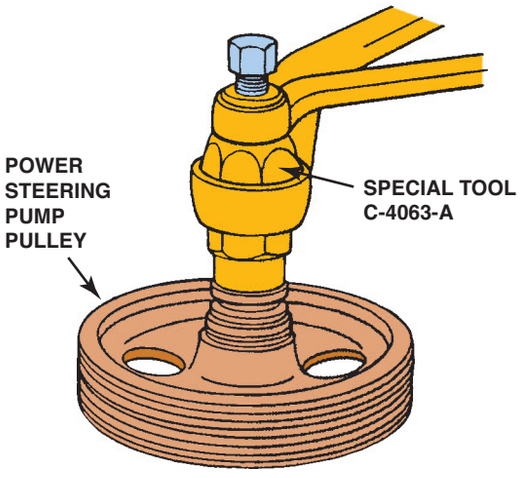


FIGURE 118–43 Typical power steering pump showing the order of assembly. The high-pressure (outlet) hose attaches to the fitting (#16). The flow control valve can be removed from the pump by removing the fitting.



REMOVE DRIVE PULLEY (TYPICAL)



INSTALL DRIVE PULLEY (TYPICAL)

FIGURE 118–44 Typical tools required to remove and install a drive pulley on a power steering pump. Often these tools can be purchased at a relatively low cost from automotive parts stores and will work on many different makes of vehicles.

NOTE: Most replacement pumps are not equipped with a pulley. The old pulley must be removed and installed on the new pump. The old pulley should be carefully inspected for dents, cracks, or warpage. If the pulley is damaged, it must be replaced.

The pulley must be removed and installed with a pulley removal and installation tool. ● **SEE FIGURE 118–44.**

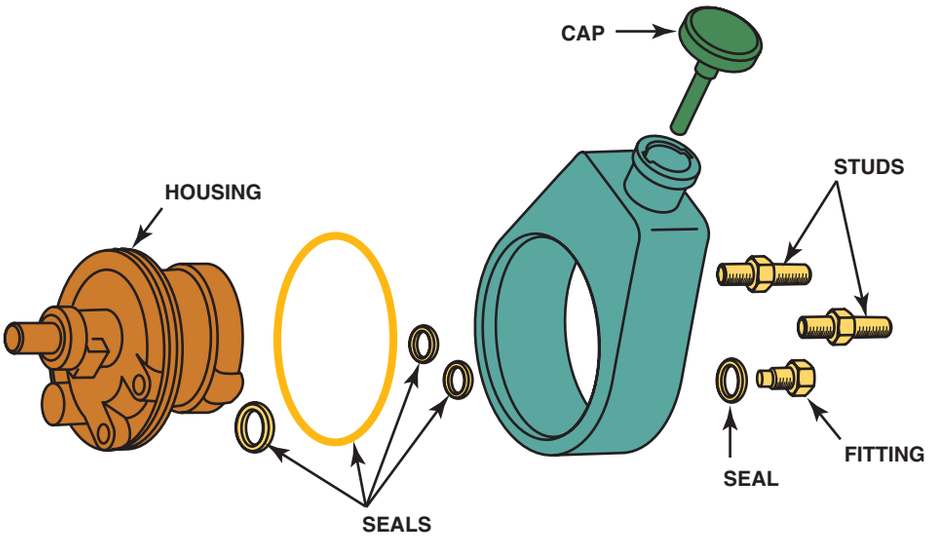


FIGURE 118–45 A typical submerged-type power steering pump. The pump is housed inside the fluid reservoir. (*Courtesy of Chrysler Corporation*)

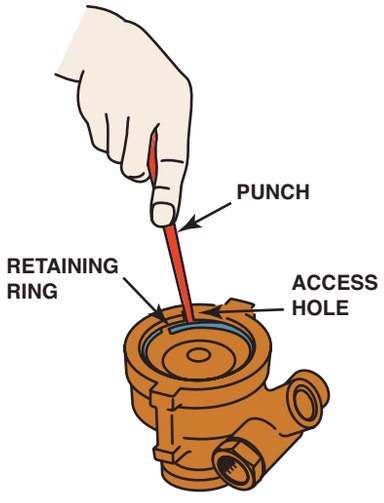


FIGURE 118–46 A punch is used to dislodge the retaining ring.

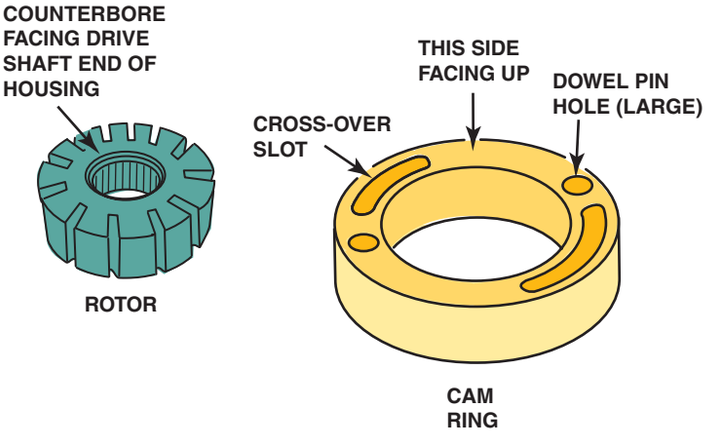


FIGURE 118–48 The pump ring *must* be installed correctly. If it is installed upside down, the internal passages will not line up and the pump will have no output.

CAUTION: Do not hammer the pump shaft or pulley in an attempt to install the pulley. The shock blows will damage the internal components of the pump.

Most vehicle manufacturers recommend replacing rather then overhauling or repairing power steering pumps. If the pump is to be disassembled, follow the vehicle manufactures instructions as found in service information. ● **SEE FIGURES 118–45 THROUGH 118–49** for the disassembly and reassembly of a typical power steering pump.

Clean all parts in power steering fluid. Replace any worn or damaged parts and all seals.

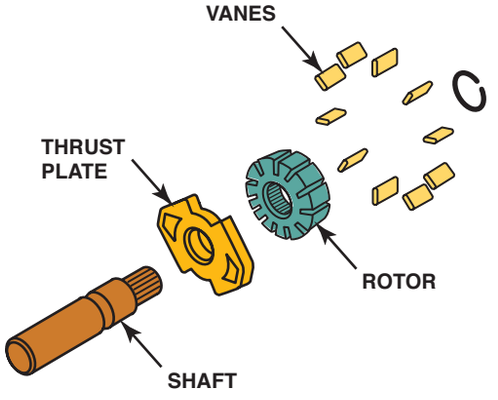


FIGURE 118–47 The driveshaft attaches to the drive pulley at one end and is splined to the pump rotor at the other end. The vanes are placed in the slots of the rotor.

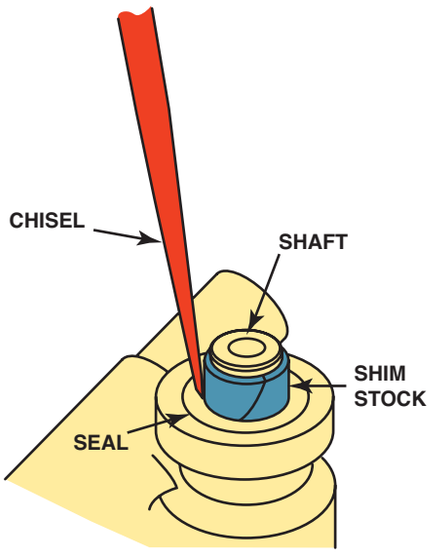


FIGURE 118–49 The shaft seal must be chiseled out. A thin metal shim stock should be used to protect the shaft from damage. Some technicians drill a small hole in the seal, then thread in a self-tapping sheet metal screw. Then pliers are used to pull out the old seal.

TECH TIP

Pocket the Ignition Key to Be Safe

When replacing any steering gear such as a rack-and-pinion steering unit, be sure that no one accidentally turns the steering wheel! If the steering wheel is turned without being connected to the steering gear, the airbag wire coil (clock spring) can become off center. This can cause the wiring to break when the steering wheel is rotated after the steering gear has been replaced. To help prevent this from occurring, simply remove the ignition key from the ignition (make sure the steering wheel is locked) and put it in your pocket while servicing the steering gear.



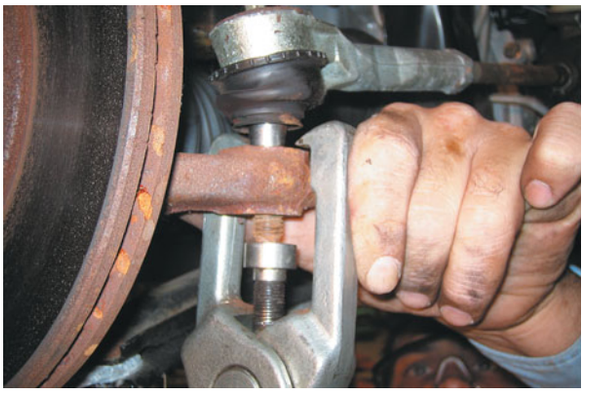
1 The tools required include a tie rod end puller and basic hand tools.



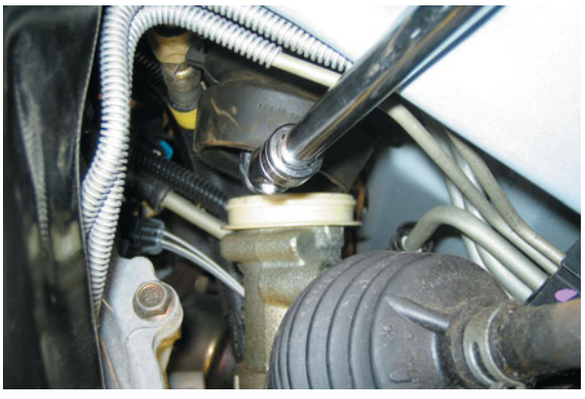
2 To help keep the steering wheel from rotating when the steering rack assembly is removed a steering wheel lock is being used.



3 After safely hoisting the vehicle and removing the front wheels, the outer tie rod end retaining nuts are removed.



4 Using a tie rod taper breaker to separate the outer tie rods from the steering knuckle without harming the rubber grease boots.



5 After moving the protective cover aside, the bolt used to retain the intermediate shaft to the steering gear stub shaft is removed.

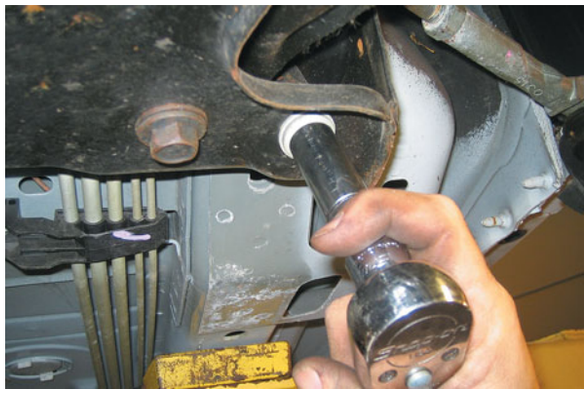


6 The hydraulic lines attached to the steering rack to the power steering rack assembly are removed using a line wrench.

CONTINUED ▶



7 After supporting the engine cradle using a tall safety stand, an air impact wrench with a long extension is used to remove the engine cradle bolts.



8 Removing the lower engine cradle bolts. This will allow the cradle to be lowered to gain access to the steering rack assembly.



9 The screw jack on the tall safety stands is rotated allowing the engine cradle to be lowered.



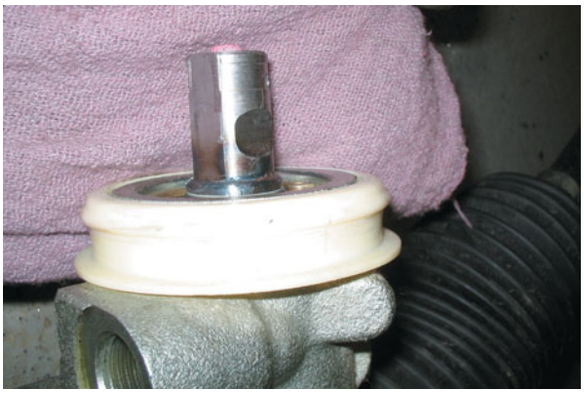
10 Removing the steering rack attachment bolts.



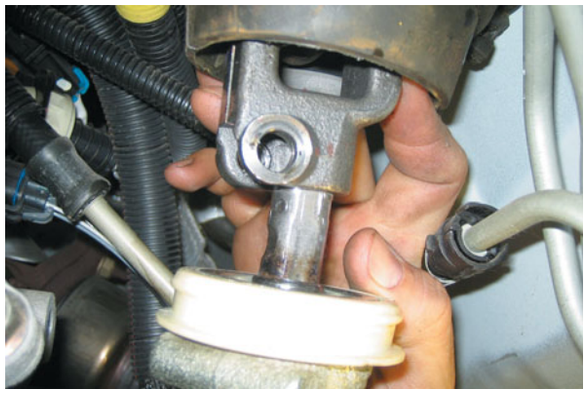
11 The steering rack assembly can be lifted out of the support brackets.



12 On this General Motors vehicle, the steering rack assembly is removed from the driver's side.



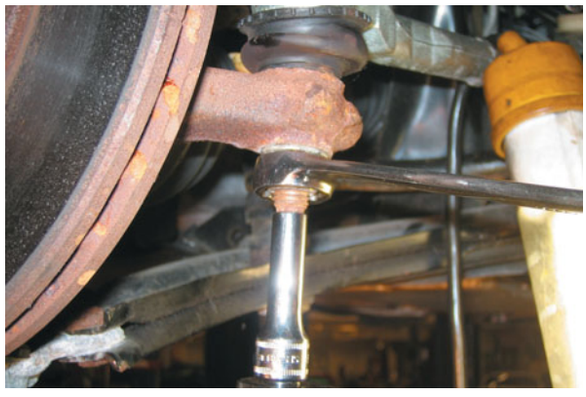
13 Before reinstalling the steering gear assembly, note the notch on the stub shaft. This notch has to be aligned with the intermediate shaft retaining bolt when it is placed back into the vehicle.



14 Installation is the reverse of removal. Be sure that the rack is centered and check that the through-bolt is properly aligned with the notch in the steering rack stub shaft.



15 While using a tall safety stand to support the engine cradle, the retaining bolts are installed.



16 A socket is being used to keep the tapered tie rod end from rotating while the retaining nut is tightened with a wrench.



17 After the hydraulic lines and retaining bolts have been installed, the power steering pump reservoir is filled using the specified fluid.



18 To bleed the trapped air out of the system, the steering wheel is rotated lock to lock with engine off and the wheels off the ground. Check for leaks then perform a test drive to verify a proper repair.

REVIEW QUESTIONS

1. List five possible causes for hard steering.
2. Explain the procedure for flushing a power steering system.
3. Describe how to pressure test a power steering system.
4. Briefly describe adjustment and service procedures for a power rack-and-pinion steering unit.

CHAPTER QUIZ

1. Two technicians are discussing the proper procedure for bleeding air from a power steering system. Technician A says that the front wheels of the vehicle should be lifted off the ground before bleeding. Technician B says that the steering wheel should be turned left and right with the engine off during the procedure. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. A power steering pressure test is being performed, and the pressure is higher than specifications with the engine running and the steering wheel stationary in the straight-ahead position. Technician A says that a restricted high-pressure line could be the cause. Technician B says that internal leakage inside the steering gear or rack-and-pinion unit could be the cause. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. When pressure testing an hydraulic assisted power steering system, the highest pressures were greater than 50 PSI of each other. This indicates a problem with the _____.
   a. Pump rotor
   b. Pump vanes
   c. Flow control valve
   d. Defective hose
4. Integral power steering gears use _____ for lubrication of the unit.
   a. SAE 80W-90 gear lube
   b. Chassis grease (NLGI #2)
   c. Power steering fluid in the system
   d. Molybdenum disulfide
5. What can cause hard steering on a vehicle equipped with hydraulic power assisted steering system?
   a. Low tire pressure
   b. Slipping P.S. pump drive belt
   c. Low or contaminated power steering fluid
   d. Any of the above
6. High-pressure hoses have to be used on the high-pressure side of the power steering system because pressures can reach as high as _____.
   a. 200 PSI
   b. 750 PSI
   c. 1,500 PSI
   d. 2,500 PSI
7. Some vehicles are equipped to signal the computer whenever the power steering pressures increase so that the idle speed can be increased to prevent stalling during turns at low speeds. What component signals the computer?
   a. Pressure-relief valve
   b. Power steering pressure switch
   c. Rotary valve
   d. Flow control valve
8. What type of motor is used in most electric power steering (EPS) systems?
   a. AC brush type
   b. DC brushless
   c. Stepper
   d. DC capacitor start
9. Electronically controlled variable-assist power steering systems vary the amount of boost by _____.
   a. Varying the pump output orifice size
   b. Speeding up or slowing down the power steering pump
   c. Changing the flow of fluid through the steering gear
   d. Bypassing some of the fluid back into the reservoir
10. Two technicians are discussing electric power steering (EPS) systems. Technician A says that some systems operate on 12 volts. Technician B says that some systems operate on 42 volts such as some hybrid electric vehicles. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

chapter 119

WHEEL ALIGNMENT PRINCIPLES

OBJECTIVES: **After studying Chapter 119, the reader will be able to:** • Prepare for ASE Suspension and Steering (A4) certification test content area "D" (Wheel Alignment Diagnosis, Adjustment, and Repair). • Discuss which vehicle handling problems can and cannot be corrected by an alignment. • Define camber, toe, caster, SAI, included angle, scrub radius, turning radius, setback, and thrust line. • Explain how camber, caster, and toe affect the handling and tire wear of the vehicle.

KEY TERMS: BJI 1421 • Camber 1414 • Camber roll 1417 • Caster 1416 • Dog tracking 1425 • Drift 1413 • Four-wheel alignment 1426 • Included angle 1421 • KPI 1421 • Lead 1413 • MSI 1421 • Pull 1413 • Returnability 1417 • Road crown 1413 • SAI 1421 • Scrub radius 1422 • Setback 1424 • Shimmy 1414 • Steering dampener 1418 • Steering offset 1422 • Thrust line 1425 • Toe 1418 • TOOT 1424 • Tramp 1414 • Wander 1413

DEFINITION OF A WHEEL ALIGNMENT

A wheel alignment is the adjustment of the suspension and steering component angles to ensure proper vehicle handling with minimum tire wear. When a vehicle is new, the alignment angles are set at the factory. After many miles and/or months of driving, the alignment angles can change slightly. The change in alignment angles may result from one or more of the following conditions:

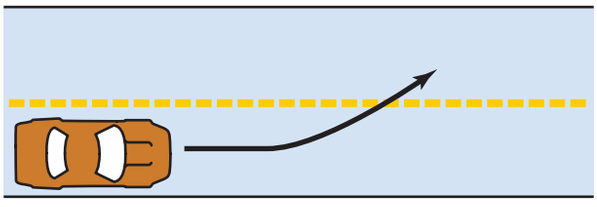
1. Wear of the steering and the suspension components
2. Bent or damaged steering and suspension parts
3. Sagging springs, which can change the ride height of the vehicle and therefore the alignment angles

By adjusting the suspension and steering components, proper alignment angles can be restored. An alignment includes checking and adjusting, if necessary, both front and rear wheels.

ALIGNMENT-RELATED PROBLEMS

Most alignment diagnosis is symptom-based diagnosis. This means that the problem with the alignment is determined from symptoms such as excessive tire wear or a pull to one side of the road. The definitions of alignment symptom terms used in this book are discussed next.

PULL A **pull** is generally defined as a definite tug on the steering wheel toward the left or the right while driving straight on a level road. ● **SEE FIGURE 119–1.** Bent, damaged, or worn suspension and/or steering components can cause this problem, as well as a tire problem.



PULL

FIGURE 119–1 A pull is usually defined as a tug on the steering wheel toward one side or the other.

LEAD OR DRIFT A **lead** or **drift** is a mild pull that does not cause a force on the steering wheel that the driver must counteract. A lead or drift is observed by momentarily removing your hands from the steering wheel while driving on a straight, level road. When the vehicle moves toward one side or the other, this is called a lead or a drift.

CAUTION: When test-driving a vehicle for a lead or a drift, make sure that the road is free of traffic and that your hands remain close to the steering wheel. Your hands should be held away from the steering wheel for just a second or two—just long enough to check for a lead or drift condition.

ROAD CROWN EFFECTS Most roads are constructed with a slight angle to permit water to drain from the road surface. On a two-lane road, the center of the road is often higher than the berms, resulting in a **road crown.** ● **SEE FIGURE 119–2.**

On a four-lane expressway (freeway), the crown is often *between the two sets* of lanes. Because of this slight angle to the road, some vehicles may lead or drift away from the road crown. In other words, it may be perfectly normal for a vehicle to lead toward the right while being driven in the slow lane and toward the left while being driven in the fast (or inside) lane of a typical divided highway.

WANDER A **wander** is a condition where constant steering wheel corrections are necessary to maintain a straight-ahead direction on a straight, level road. ● **SEE FIGURE 119–3.**

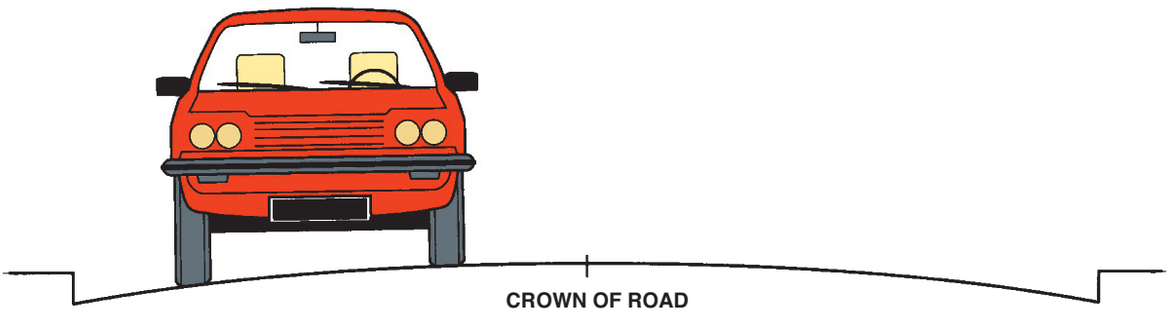
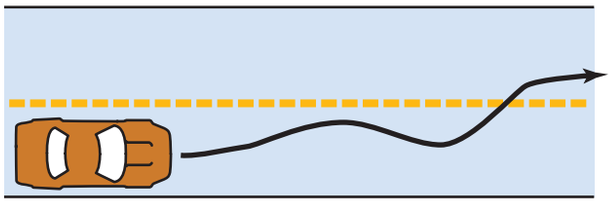


FIGURE 119–2 The crown of the road refers to the angle or slope of the roadway needed to drain water off the pavement. (*Courtesy of Hunter Engineering Company*)



WANDER

FIGURE 119–3 Wander is an unstable condition requiring constant driver corrections.

Worn suspension and/or steering components are the most likely cause of this condition. Incorrect or unequal alignment angles such as caster and toe, as well as defective tire(s), can also cause this condition.

STIFF STEERING OR SLOW RETURN TO CENTER

Hard-to-steer problems are commonly caused by leaks, either low tire pressure (due to the leak of air) and/or lack of proper power steering (due to the leak of power steering fluid). Other causes include excessive positive caster on the front wheels or binding steering linkage.

TRAMP OR SHIMMY VIBRATION

Tramp is a vertical-type (up-and-down) vibration usually caused by out-of-balance or defective tires or wheels. **Shimmy** is a back-and-forth vibration that can be caused by an out-of-balance tire or defective wheel or by an alignment problem.

NOTE: Wheel alignment will not correct a tramp-type vibration.

ALIGNMENT ANGLES

CAMBER

Camber *is the inward or outward tilt of the wheels from true vertical as viewed from the front or rear of the vehicle.*

1. If the top of the tire is tilted out, then camber is positive (+), as shown in ● **FIGURE 119–4.**
2. If the top of the tire is tilted in, then camber is negative (−), as shown in ● **FIGURE 119–5**.
3. Camber is zero (0 degrees) if the tilt of the wheel is true vertical, as shown in ● **FIGURE 119–6**.
4. Camber is measured in degrees or fractions of degrees.
5. *Camber can cause tire wear if not correct.*
   a. *Excessive positive camber* causes scuffing and wear on the outside edge of the tire, as shown in ● **FIGURE 119–7**.
   b. *Excessive negative camber* causes scuffing and wear on the inside edge of the tire, as shown in ● **FIGURE 119–8**.

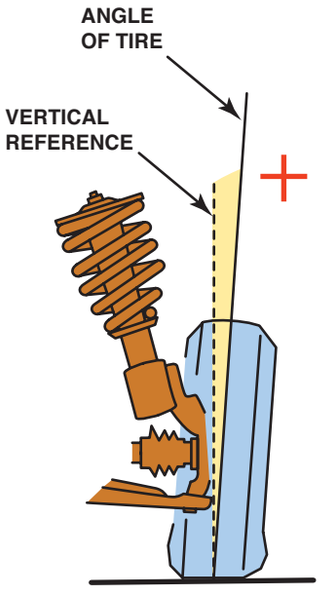


FIGURE 119–4 Positive camber. The solid vertical line represents true vertical, and the dotted line represents the angle of the tire.

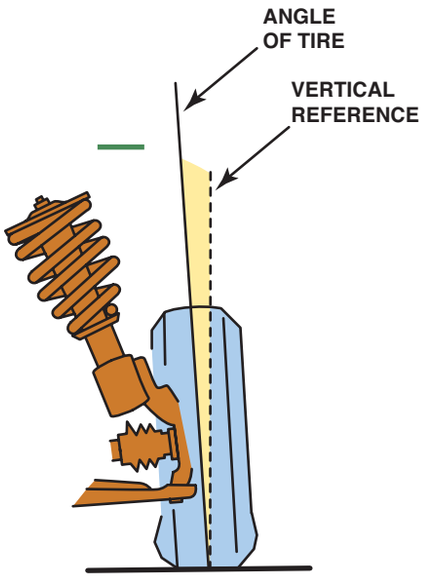


FIGURE 119–5 Negative camber. The solid vertical line represents true vertical, and the dotted line represents the angle of the tire.

6. Camber can cause pull if it is unequal side-to-side. The vehicle will pull toward the side with the most positive camber. A difference of more than 1/2 degree from one side to the other will cause the vehicle to pull. ● **SEE FIGURES 119–9 THROUGH 119–11.**

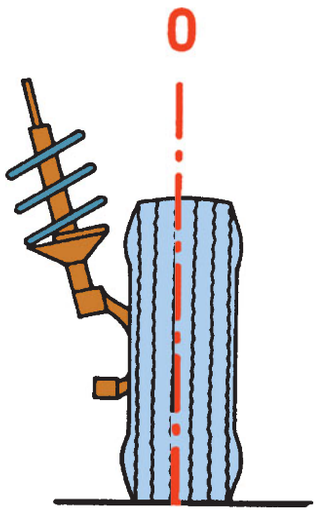


FIGURE 119–6 Zero camber. Note that the angle of the tire is true vertical.

7. Incorrect camber can cause excessive wear on wheel bearings, as shown in ● **FIGURES 119–12 AND 119–13**. Many vehicle manufacturers specify positive camber so that the vehicle's weight is applied to the larger inner wheel bearing and spindle. As the vehicle is loaded or when the springs sag, camber usually decreases. If camber is kept positive, then the running camber is kept near zero degrees for best tire life.

   NOTE: Many front-wheel-drive vehicles that use sealed wheel bearings often specify negative camber.

8. Camber is *not* adjustable on many vehicles.
9. If camber is adjustable, the change is made by moving the upper or the lower control arm or strut assembly by means of one of the following methods:
   a. Shims
   b. Eccentric cams
   c. Slots

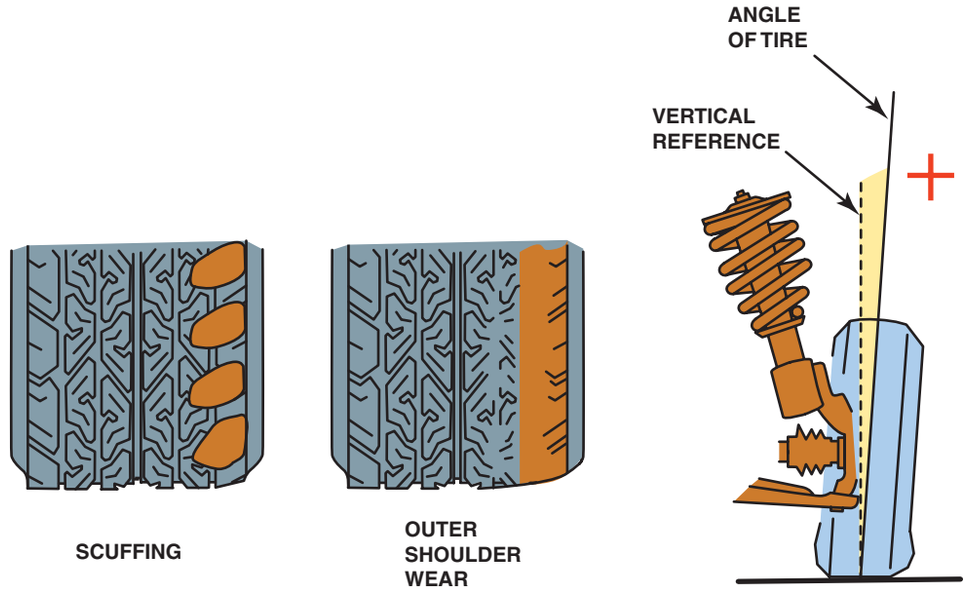


FIGURE 119–7 Excessive positive camber and how the front tires would wear due to the excessive camber.

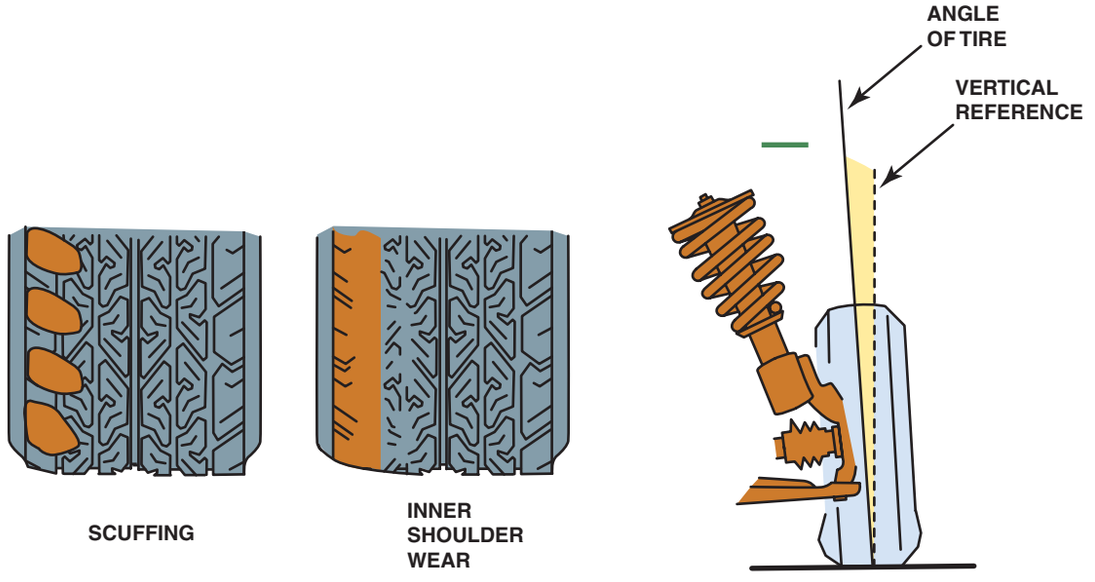


FIGURE 119–8 Excessive negative camber and how the front tires would wear due to the excessive camber.

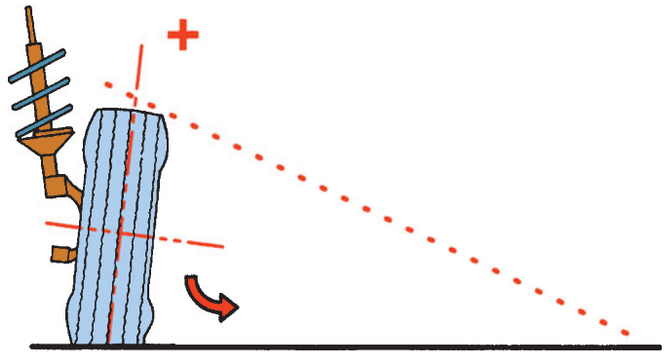


FIGURE 119–9 Positive camber tilts the tire and forms a cone shape that causes the wheel to roll away or pull outward toward the point of the cone.

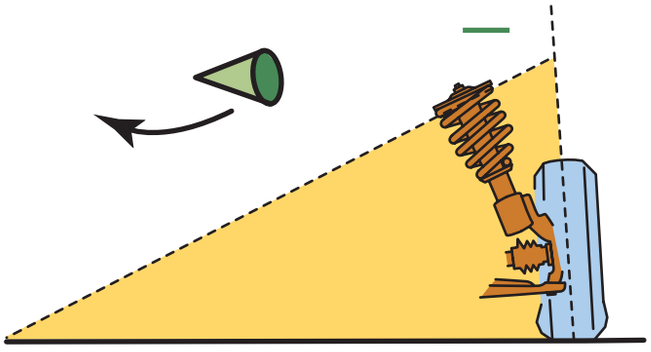


FIGURE 119–10 Negative camber creates a pulling force toward the center of the vehicle.

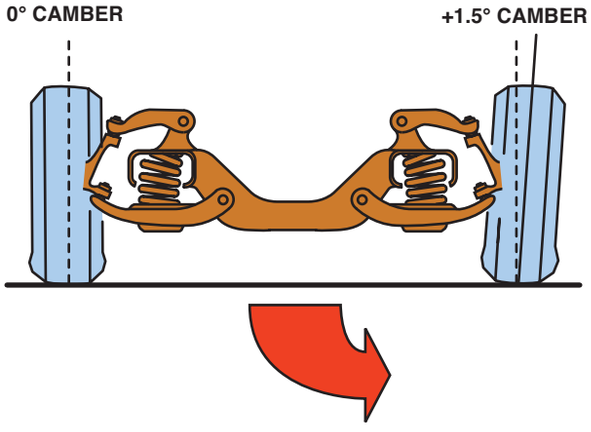


FIGURE 119–11 If camber angles are different from one side to the other, the vehicle will pull toward the side with the most camber.

10. Camber should be equal on both sides; however, if camber cannot be adjusted exactly equal, make certain that there is more camber on the front of the left side to help compensate for the road crown (1/2 degree maximum difference).

CASTER

Caster *is the forward or rearward tilt of the steering axis in reference to a vertical line as viewed from the side of the vehicle.* The steering axis is defined as the line drawn through the upper and lower steering pivot points. On an SLA suspension system, the upper pivot is the upper ball joint and the lower pivot is the lower ball joint. On a MacPherson strut system, the upper pivot is the center of the upper bearing mount and the lower pivot point is the lower ball joint. Zero caster means that the steering axis is straight up and down, also called 0 degrees or perfectly vertical, as shown in ● **FIGURE 119–14.**

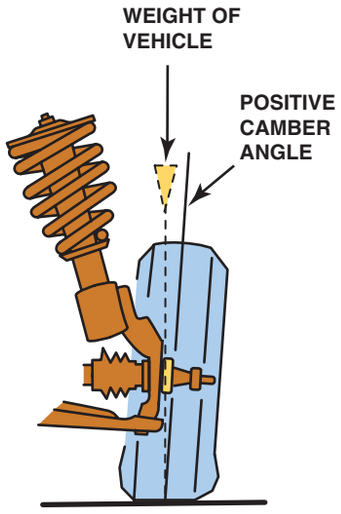


FIGURE 119–12 Positive camber applies the vehicle weight toward the larger inner wheel bearing. This is desirable because the larger inner bearing is designed to carry more vehicle weight than the smaller outer bearing.

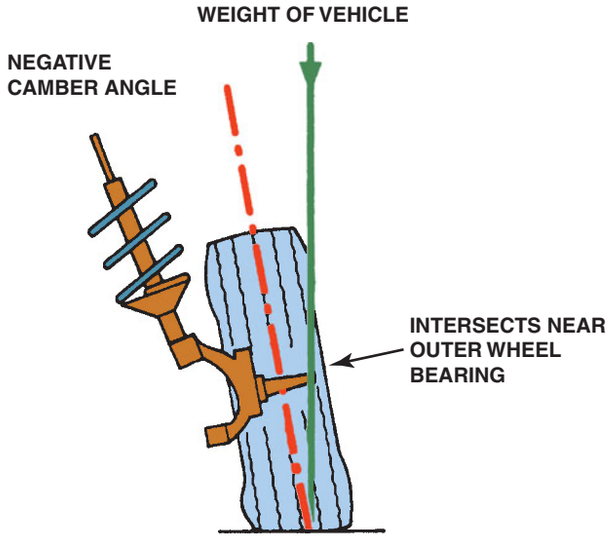


FIGURE 119–13 Negative camber applies the vehicle weight to the smaller outer wheel bearing. Excessive negative camber, therefore, may contribute to outer wheel bearing failure.

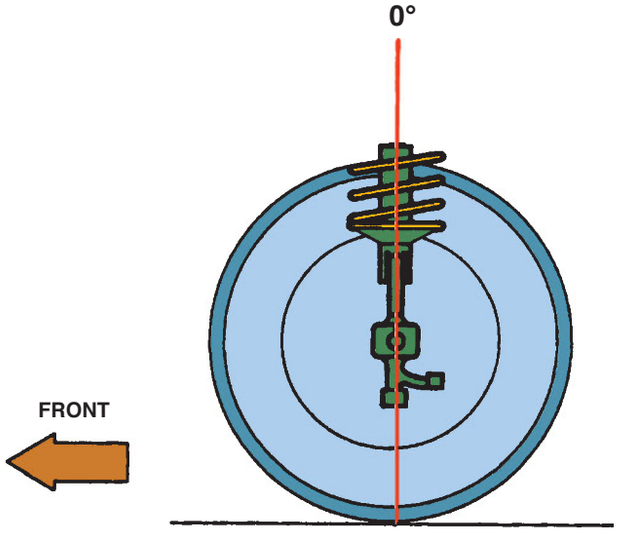


FIGURE 119–14 Zero caster.

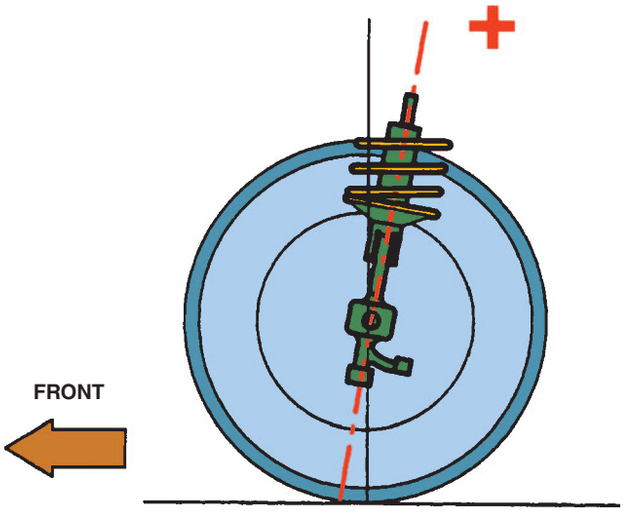


FIGURE 119–15 Positive (+) caster.

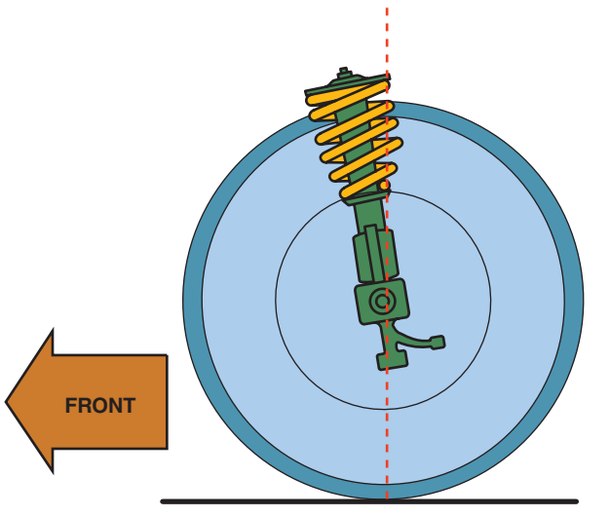


FIGURE 119–16 Negative (−) caster is seldom specified on today's vehicles because it tends to make the vehicle unstable at highway speeds. Negative caster was specified on some older vehicles not equipped with power steering to help reduce the steering effort.

TECH TIP

Think of a Bicycle

How caster affects steering stability and steering wheel returning to the straight ahead position after a turn is made easy by remembering how a bicycle acts. Caster allows a rider to travel straight ahead with their hands off the handle bars because the weight is behind the axle.

1. Positive (+) caster is present when the upper suspension pivot point is behind the lower pivot point (ball joint) as viewed from the side. ● **SEE FIGURE 119–15**.
2. Negative (−) caster is present when the upper suspension pivot point is ahead of the lower pivot point (ball joint) as viewed from the side. ● **SEE FIGURE 119–16**.
3. Caster is measured in degrees or fractions of degrees.
4. Caster is not a tire-wearing angle, but positive caster does cause changes in camber during a turn. ● **SEE FIGURE 119–17**. This condition is called **camber roll** (see the Tech Tip titled "Caster Angle Tire Wear").

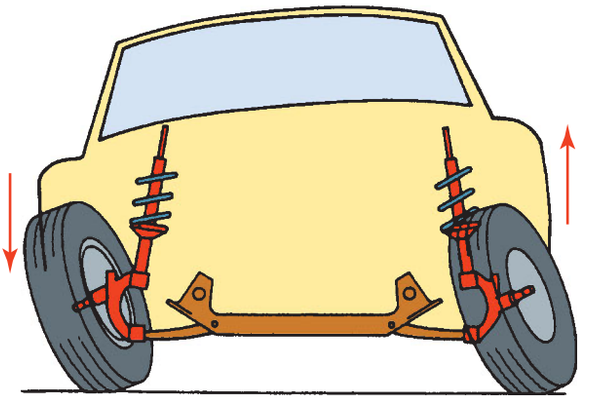


FIGURE 119–17 As the spindle rotates, it lifts the weight of the vehicle due to the angle of the steering axis. (*Courtesy of Hunter Engineering Company*)

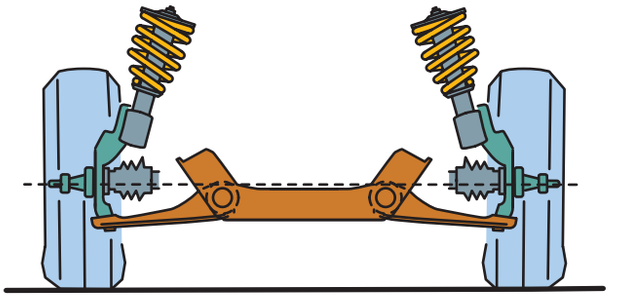


FIGURE 119–18 Vehicle weight tends to lower the spindle, which returns the steering to the straight-ahead position.

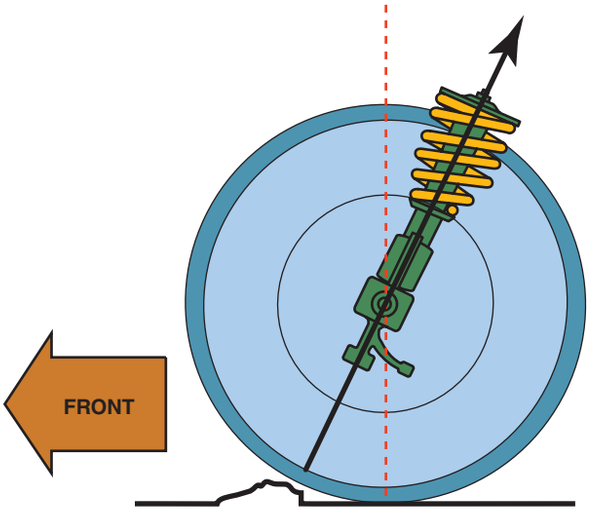


FIGURE 119–19 High positive caster provides a road shock path to the vehicle.

5. Caster is a stability angle.
   a. If caster is positive, the vehicle steering will be very stable (will tend to go straight with little steering wheel correction needed). This degree of caster helps with steering wheel **returnability** after a turn. ● **SEE FIGURE 119–18**.
   b. If the caster is positive, steering effort will increase with increasing positive caster. Greater road shocks will be felt by the driver when driving over rough road surfaces. ● **SEE FIGURE 119–19**. Vehicles with as many as 11 degrees positive caster, such as many Mercedes vehicles, usually use a steering dampener to control possible shimmy at high speeds and to dampen the snap-back of the spindle after a turn. ● **SEE FIGURE 119–20**.

c. If caster is negative, or excessively unequal, the vehicle will not be as stable and will tend to wander (constant steering wheel movement will be required to maintain straight-ahead direction). If a vehicle is heavily loaded in the rear, caster increases. ● **SEE FIGURE 119–21**.

6. Caster can cause pull if unequal; the vehicle will pull toward the side with the least positive caster. However, the pulling force of unequal caster is only about one-fourth the pulling force of camber. It would require a difference of caster of one full degree to equal the pulling force of only 1/4-degree difference of camber.

7. Caster is *not* adjustable on many vehicles.

8. If caster is adjustable, it is changed by moving either the lower or the upper pivot point forward or backward by means of the following:
- **a.** Shims
- **b.** Eccentric cams
- **c.** Slots
- **d.** Strut rods

9. Caster should be equal on both sides; however, if caster cannot be adjusted to be exactly equal, make certain that there is more caster on the right side (maximum 1/2-degree difference) to help compensate for the crown of the road.

TECH TIP

Caster Angle Tire Wear

The caster angle is generally considered to be a *non*-tire-wearing angle. However, excessive or unequal caster can *indirectly* cause tire wear. When the front wheels are turned on a vehicle with a lot of positive caster, they become angled. This is called *camber roll.* (Caster angle is a measurement of the difference in camber angle from when the wheel is turned inward compared to when the wheel is turned outward.) Most vehicle manufacturers have positive caster designed into the suspension system. This positive caster increases the directional stability.

However, if the vehicle is used exclusively in city driving, positive caster can cause tire wear to the outside shoulders of both front tires. ● **SEE FIGURE 119–22.**

NOTE: Caster is only measured on the front turning wheels of the vehicle. While some caster is built into the rear suspension of many vehicles, rear caster is not measured as part of a four-wheel alignment.

TOE **Toe** *is the difference in distance between the front and rear of the tires.* Toe is the most important of the alignment angles. As viewed from the top of the vehicle (a bird's eye view), zero toe means that both wheels on the same axle are parallel, as shown in ● **FIGURE 119–23.**

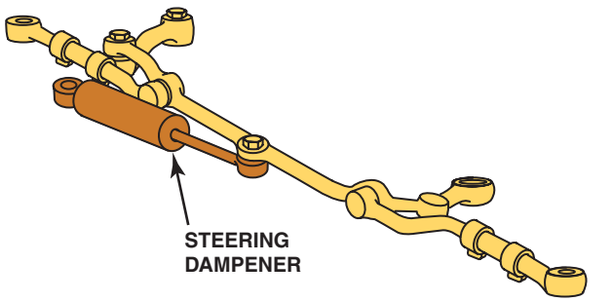


FIGURE 119–20 A **steering dampener** is used on many pickup trucks, sport utility vehicles (SUVs), and many luxury vehicles designed with a high-positive-caster setting. The dampener helps prevent steering wheel kickback when the front tires hit a bump or hole in the road and also helps reduce steering wheel shimmy that may result from the high-caster setting.

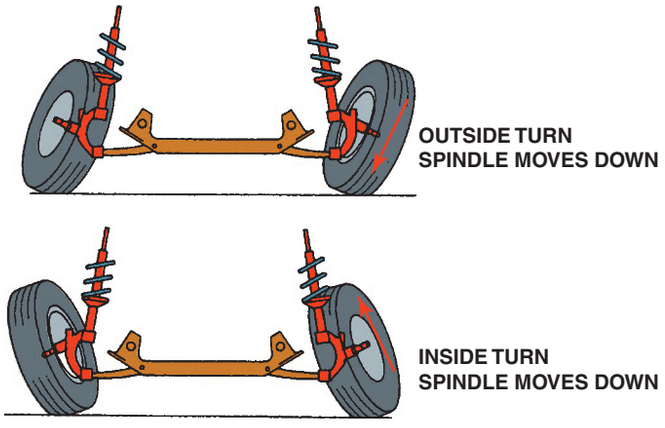


FIGURE 119–22 Note how the front tire becomes tilted as the vehicle turns a corner with positive caster. The higher the caster angle, the more the front tires tilt, causing camber-type tire wear.

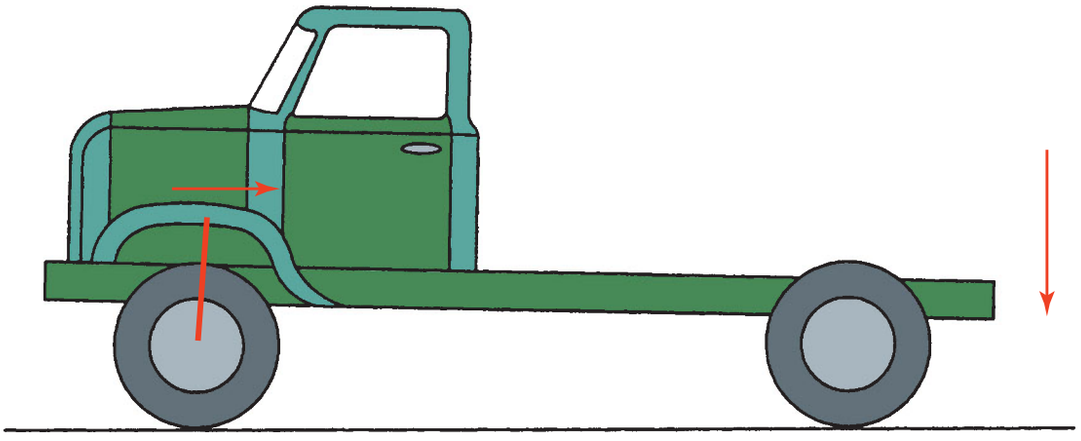


FIGURE 119–21 As the load increases in the rear of a vehicle, the top steering axis pivot point moves rearward, increasing positive (+) caster.

Toe is also described as a comparison of horizontal lines drawn through both wheels on the same axle, as shown in ● **FIGURE 119–24.**

If the front of the tires is closer than the rear of the same tires, then the toe is called *toe-in* or positive (+) toe. ● **SEE FIGURE 119–25.**

If the front of the tires is farther apart than the rear of the same tires, then the wheels are *toed-out,* or have negative (−) toe. ● **SEE FIGURE 119–26.**

The purpose of the correct toe setting is to provide maximum stability with a minimum of tire wear when the vehicle is being driven.

1. Toe is measured in fractions of degrees or in fractions of an inch (usually 1/16s), millimeters (mm), or decimals of an inch (such as 0.06 in.).
2. *Incorrect toe is the major cause of excessive tire wear!* ● **SEE FIGURE 119–27**.

   NOTE: If the toe is improper by just 1/8 in. (3 mm), the resulting tire wear is equivalent to dragging a tire sideways 28 feet (8.5 m) for every mile traveled (1.6 km).

   If not correct, toe causes camber-type wear on one side of the tire. ● **SEE FIGURES 119–28 AND 119–29**. Feather-edge wear is also common, especially if the vehicle is equipped with nonradial tires. ● **SEE FIGURE 119–30**.
3. *Incorrect front toe does not cause a pull condition.* Incorrect toe on the front wheels is split equally as the vehicle is driven because the forces acting on the tires are exerted through the tie rod and steering linkage to both wheels.
4. *Incorrect (or unequal) rear toe can cause tire wear.* ● **SEE FIGURES 119–31 THROUGH 119–33**. If the toe of the rear wheels is not equal, the steering wheel will not be straight and will pull toward the side with the most toe-in.
5. All vehicles can be adjusted for front toe.
6. Front toe adjustment must be made correctly by adjusting the tie rod sleeves. ● **SEE FIGURE 119–34** on page 1421.

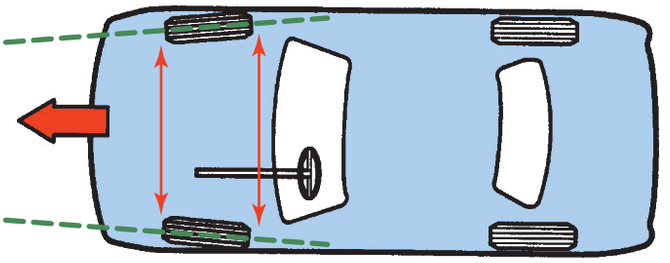


FIGURE 119–25 Toe-in, also called positive (+) toe.

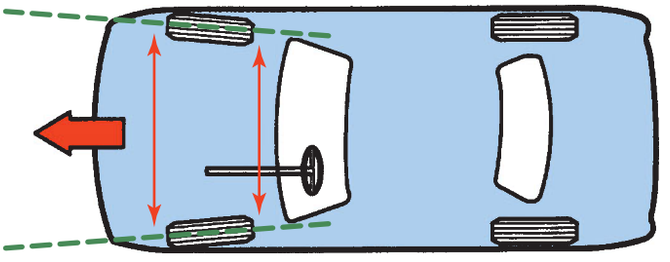


FIGURE 119–26 Toe-out, also called negative (−) toe. (*Courtesy of Hunter Engineering Company*)



FIGURE 119–27 This tire is just one month old! It was new and installed on the front of a vehicle that had about 1/4 inch (6 mm) of toe-out. By the time the customer returned to the tire store for an alignment, the tire was completely bald on the inside. Note the almost new tread on the outside.

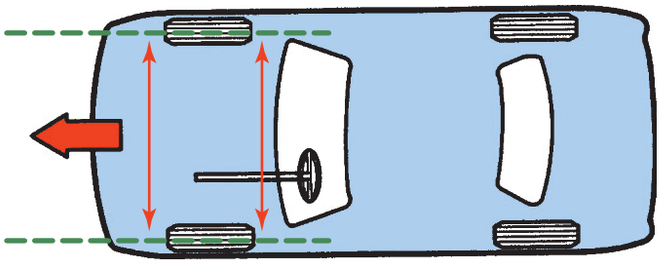


FIGURE 119–23 Zero toe. Note how both tires are parallel to each other as viewed from above the vehicle.

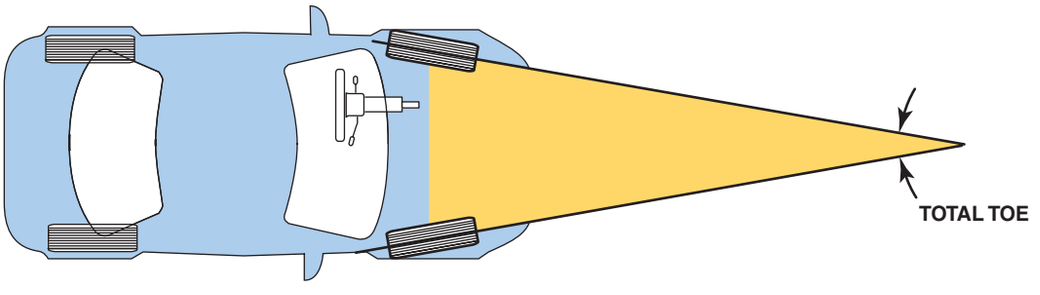


FIGURE 119–24 Total toe is often expressed as an angle. Because both front wheels are tied together through the tie rods and center link, the toe angle is always equally split between the two front wheels when the vehicle moves forward.

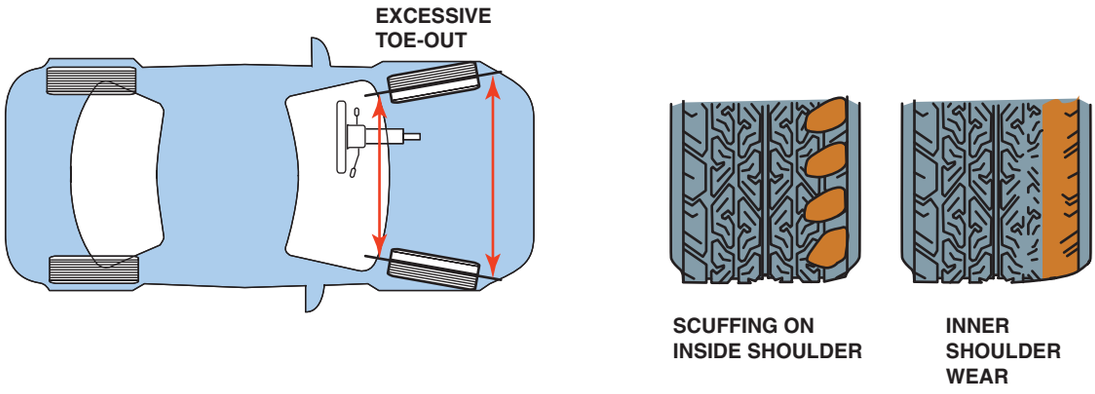


FIGURE 119–28 Excessive toe-out and the type of wear that can occur to the side of both front tires.

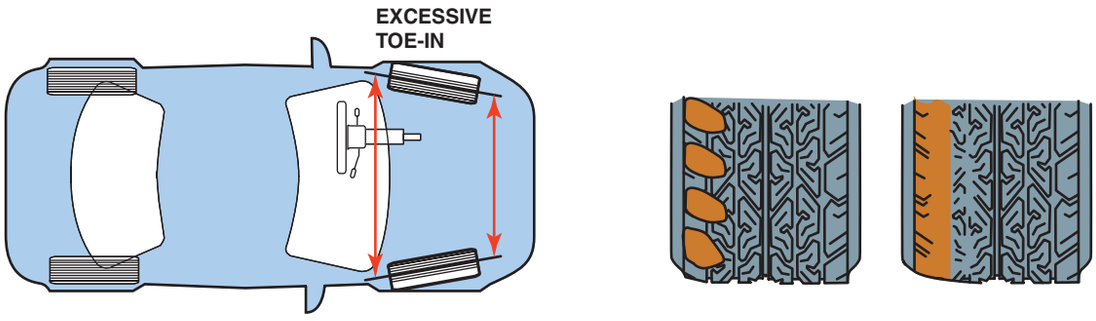


FIGURE 119–29 Excessive toe-in and the type of wear that can occur to the outside of both front tires.

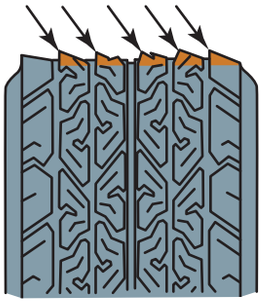


FIGURE 119–30 Feather-edge wear pattern caused by excessive toe-in or toe-out.

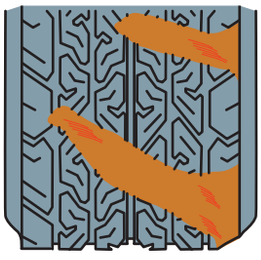


FIGURE 119–32 Incorrect toe can cause the tire to run sideways as it rolls, resulting in a diagonal wipe.

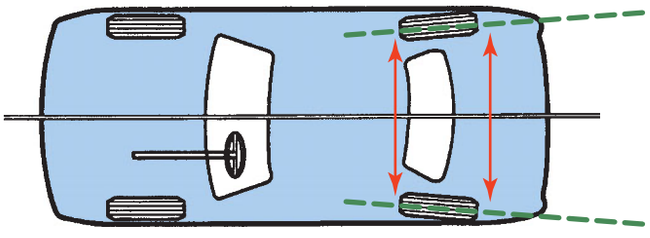


FIGURE 119–31 Rear toe-in (+). The rear toe (unlike the front toe) can be different for each wheel while the vehicle is moving forward because the rear wheels are not tied together as they are in the front. (*Courtesy of Hunter Engineering Company*)

7. Many vehicle manufacturers specify a slight amount of toe-in to compensate for the natural tendency of the front wheels to spread apart (become toed-out) due to centrifugal force of the rolling wheels acting on the steering linkage.

   NOTE: Some manufacturers of front-wheel-drive vehicles specify a toe-out setting to compensate for the toe-in forces created by the engine drive forces on the front wheels.

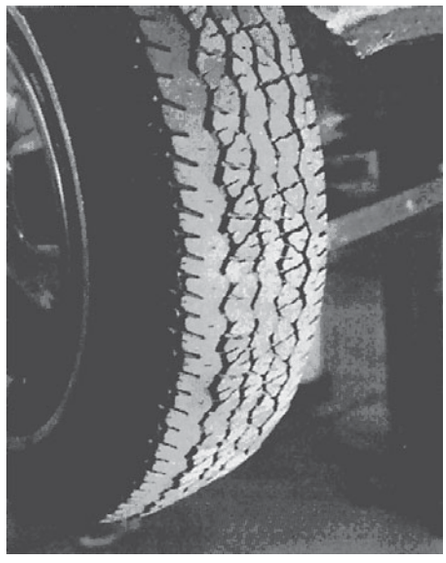


FIGURE 119–33 Diagonal wear such as shown here is usually caused by incorrect toe on the rear of a front-wheel-drive vehicle.

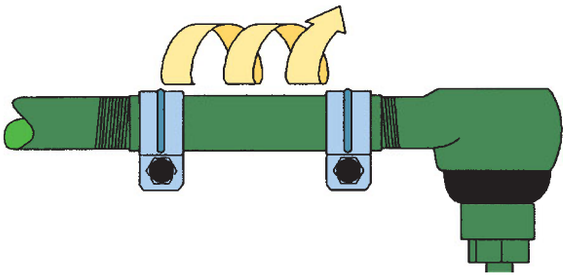


FIGURE 119–34 Toe on the front of most vehicles is adjusted by turning the tie rod sleeve as shown. (*Courtesy of John Bean Company*)

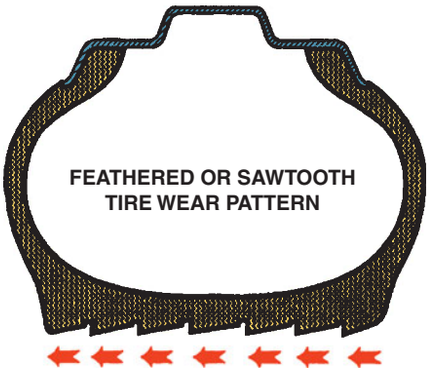


FIGURE 119–35 While the feathered or sawtooth tire tread wear pattern may not be noticeable to the eye, this wear can usually be felt by rubbing your hand across the tread of the tire. (*Courtesy of John Bean Company*)

FREQUENTLY ASKED QUESTION

Why Doesn't Unequal Front Toe on the Front Wheels Cause the Vehicle to Pull?

Each wheel could have individual toe, but as the vehicle is being driven, the forces on the tires tend to split the toe, causing the steering wheel to cock at an angle as the front wheels both track the same. If the toe is different on the rear of the vehicle, the rear will be "steered" similar to a rudder on a boat because the rear wheels are not tied together as are the front wheels.

TECH TIP

Smooth In, Toed-In; Smooth Out, Toed-Out

Whenever the toe setting is not zero, a rubbing action occurs that causes a feather-edge-type wear. ● **SEE FIGURE 119–35.** A quick, easy method to determine if incorrect toe could be causing problems is simply to rub your hand across the tread of the tire. If it feels smoother moving your hand toward the center of the vehicle than when you move your hand toward the outside, then the cause is excessive toe-in. The opposite effect is caused by toe-out. This may be felt on all types of tires, including radial-ply tires where the wear may not be seen as feather edged. Just remember this simple saying: "Smooth in, toed-in; smooth out, toed-out."

8. Normal wear to the tie rod ends and other steering linkage parts usually causes toe-out.

Excessive front toe-out will cause wandering (lack of directional stability), especially during braking. Incorrectly set toe will cause an uncentered steering wheel. If toe is unequal in the *rear,* the vehicle will pull toward the side with the most toe-in.

STEERING AXIS INCLINATION (SAI)

The steering axis is the angle formed between true vertical and an imaginary line drawn between the upper and lower pivot points of the spindle. ● **SEE FIGURE 119–36. Steering axis inclination (SAI)** is the inward tilt of the steering axis. SAI is also known as **kingpin inclination (KPI)** and is the imaginary line drawn through the kingpin as viewed from the front. SAI is also called **ball joint inclination (BJI),** if SLA-type suspension is used, or **MacPherson strut inclination (MSI).**

The purpose of SAI is to provide an upper suspension pivot location that causes the spindle to travel in an arc when turning, which tends to raise the vehicle, as shown in ● **FIGURE 119–37.**

Vehicle weight tends to keep the front wheels in a straight-ahead position when driving, thereby increasing vehicle stability, directional control, and steering wheel returnability. The greater the SAI, the more stable the vehicle. It also helps center the steering wheel after making a turn and reduces the need for excessive positive caster. The SAI/KPI angle of all vehicles ranges between 2 and 16 degrees. Front-wheel-drive vehicles usually have greater than 9 degrees SAI (typically 12 to 16 degrees) for directional stability, whereas rear-wheel-drive vehicles usually have less than 8 degrees of SAI. The steering axis inclination angle and the camber angle together are called the *included angle.*

INCLUDED ANGLE

The **included angle** is the SAI added to the camber reading of the front wheels only. *The included angle is determined by the design of the steering knuckle, or strut construction.* ● **SEE FIGURES 119–38 AND 119–39.**

Included angle is an important angle to measure for diagnosis of vehicle handling or tire wear problems. For example, if the cradle is out of location due to previous service work or an accident, knowing SAI, camber, and the included angle can help in determining what needs to be done to correct the problem. ● **SEE FIGURE 119–40.**

Figure 119–40 shows the included angle is equal on both sides but the camber and SAI are not equal. For best handling both the included angle and SAI should be within 1/2 degree of the other side of the vehicle.

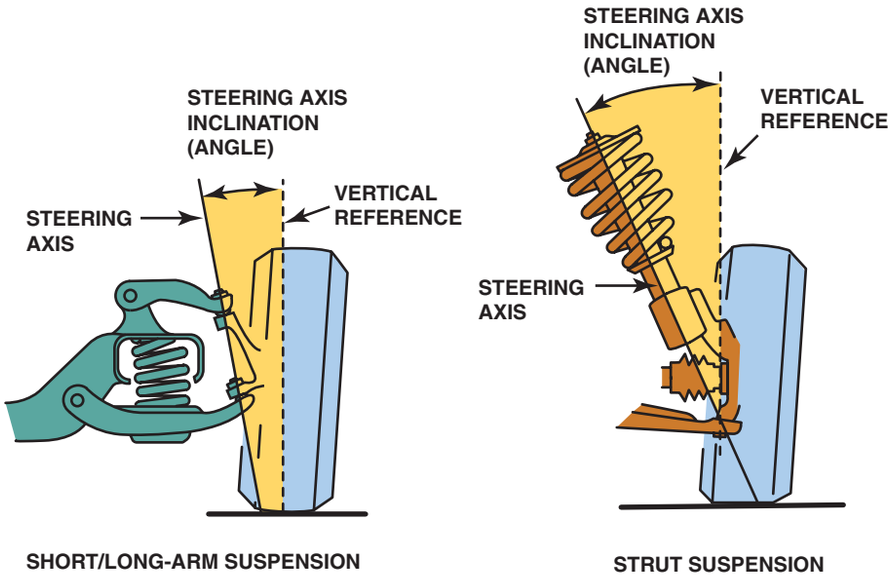


FIGURE 119–36 The left illustration shows that the steering axis inclination angle is determined by drawing a line through the center of the upper and lower ball joints. This represents the pivot points of the front wheels when the steering wheel is rotated during cornering. The right illustration shows that the steering axis inclination angle is determined by drawing a line through the axis of the upper strut bearing mount assembly and the lower ball joint.

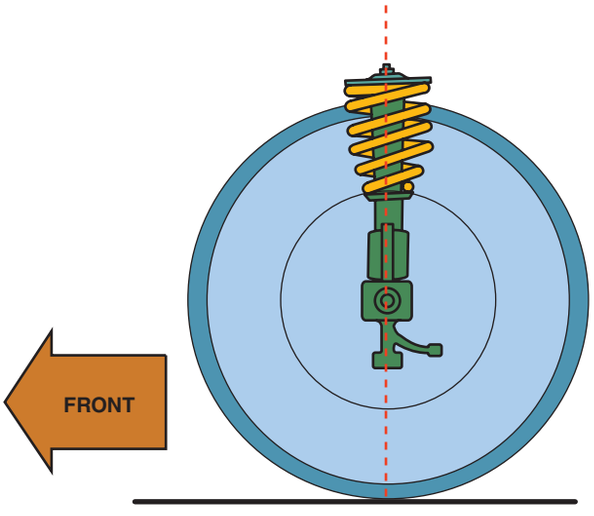


FIGURE 119–37 The SAI causes the spindle to travel in an arc when the wheels are turned. The weight of the vehicle is therefore used to help straighten the front tires after a turn and to help give directional stability.

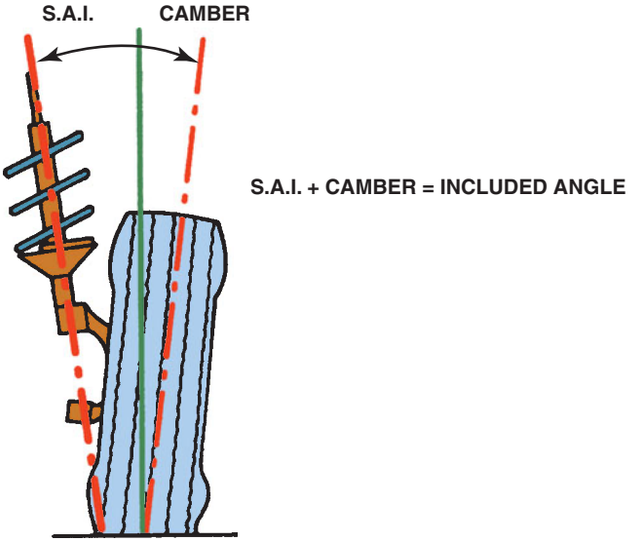


FIGURE 119–38 Included angle on a MacPherson-strut-type suspension.

SCRUB RADIUS

Scrub radius refers to the *distance* between the line through the steering axis and the centerline of the wheel at the contact point with the road surface. ● **SEE FIGURE 119–41.**

Scrub radius is *not* adjustable and cannot be measured. Scrub radius can be zero, positive, or negative. Zero scrub radius means that the line through the steering axis intersects the centerline of the tire at the road surface. Positive scrub radius means that the line intersects the centerline of the tire below the road surface. Negative scrub radius means that the line intersects the centerline of the tire above the road surface. Scrub radius is also called **steering offset** by some vehicle manufacturers. If a wheel is permitted to roll rather than pivot, then steering will be more difficult because a tire can pivot more easily than it can roll while turning the front wheels.

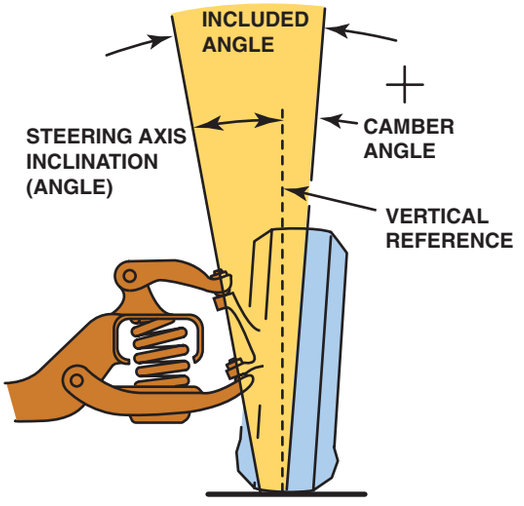


FIGURE 119–39 Included angle on an SLA-type suspension. The included angle is the SAI angle and the camber angle added together.

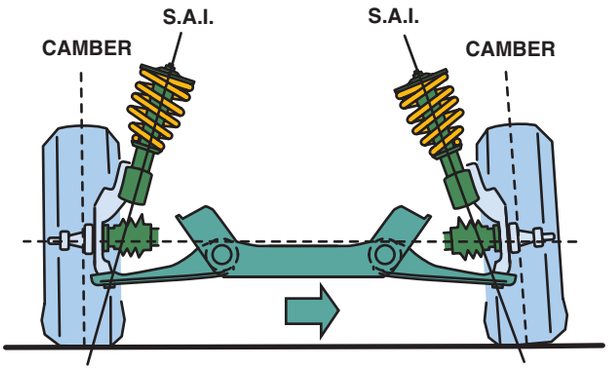


FIGURE 119–40 Cradle placement. If the cradle is not replaced in the exact position after removal for a transmission or clutch replacement, the SAI, camber, and included angle will not be equal side-to-side.

If the point of intersection is inside the centerline of the tire and below the road surface, this creates a toe-out force on the front wheels. Negative scrub radius is required on front-wheel-drive vehicles to provide good steering stability during braking. ● **SEE FIGURES 119–42 AND 119–43.**

Scrub radius is designed into each vehicle to provide acceptable handling and steering control under most conditions. Scrub radius also causes resistance to rolling of the front wheels to exert force on the steering linkage. This tends to dampen the effect of minor movements of the front wheels. Negative scrub radius causes the tire to toe-in during acceleration, braking, or traveling over bumps.

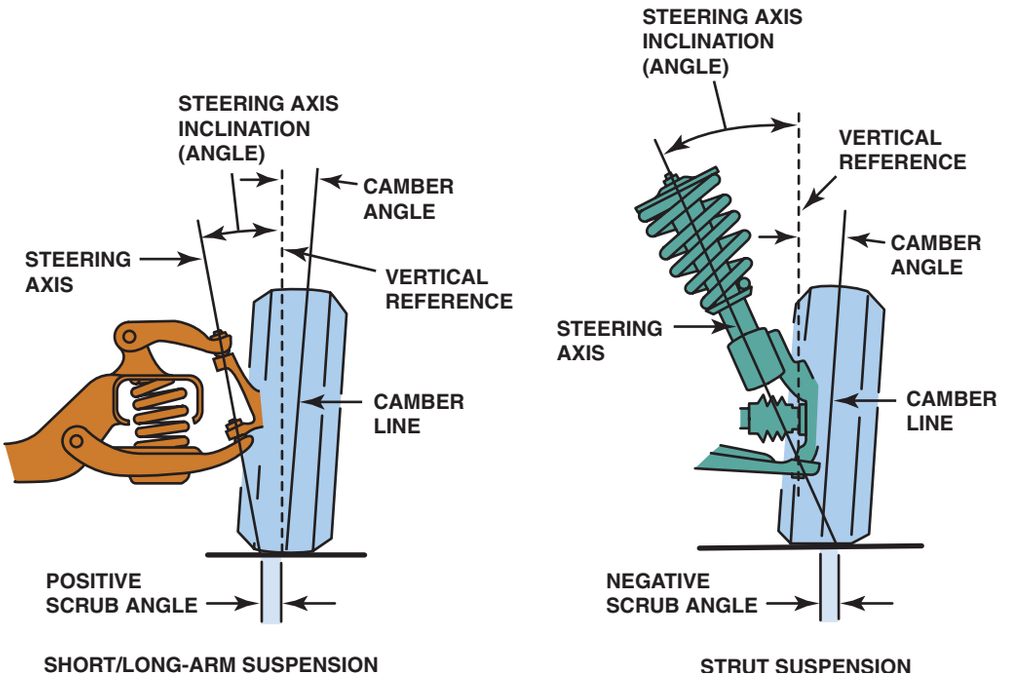


FIGURE 119–41 A positive scrub radius (angle) is usually built into most SLA front suspensions, and a negative scrub radius is usually built into most MacPherson-strut-type front suspensions.

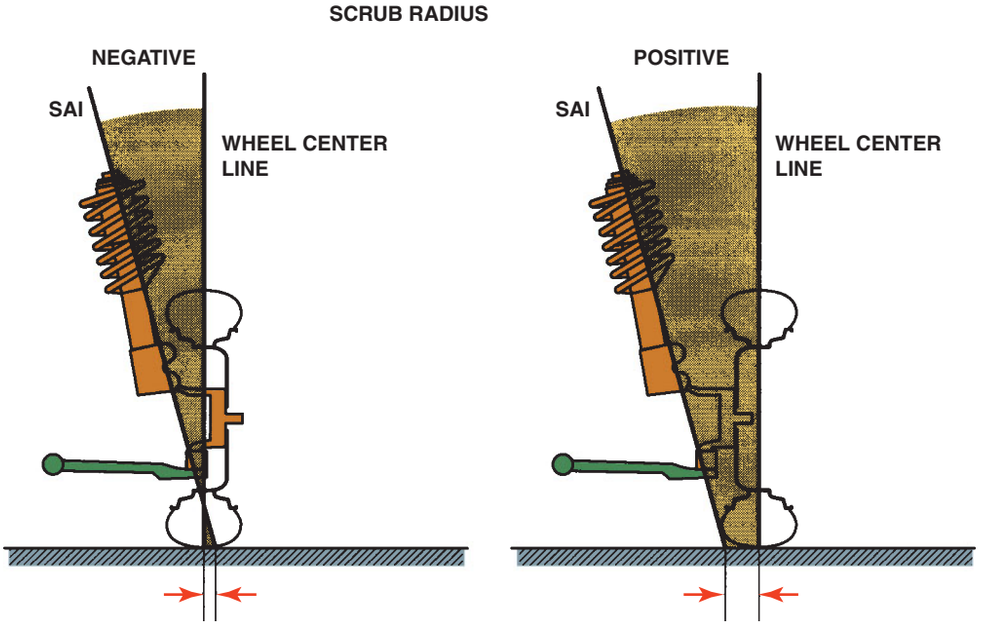


FIGURE 119–42 With negative scrub radius, the imaginary line through the steering axis inclination (SAI) intersects the road outside of the centerline of the tire. With positive scrub radius, the SAI line intersects the road inside the centerline of the tires.

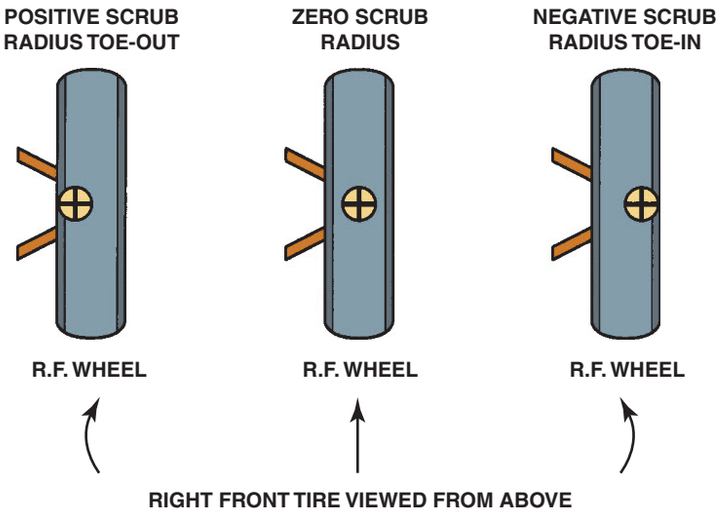


FIGURE 119–43 With a positive scrub radius, the pivot point, marked with a + mark, is inside the centerline of the tire and will cause the wheel to turn toward the outside, especially during braking. Zero scrub radius does not create any force on the tires and is not usually used on vehicles because it does not create an opposing force on the tires, which in turn makes the vehicle more susceptible to minor bumps and dips in the road. Negative scrub radius, as is used with most front-wheel-drive vehicles, generates an inward force on the tires.

NOTE: It is this tendency to toe-in caused by the negative scrub radius and engine torque that requires many front-wheel-drive vehicles to specify a toe-out setting for the front-drive wheels.

Zero scrub radius is acceptable; positive scrub radius is less desirable because it causes the wheel to toe-out during acceleration, braking, or traveling over bumps and causes instability. Positive scrub radius is commonly used on rear-wheel-drive vehicles and requires a toe-in setting to help compensate for the tendency to toe-out.

A bent spindle can cause a change in the scrub radius and could cause hard steering, wander, or pull.

Also, changing tire or wheel sizes can affect the centerline location of the wheel or the height of the tire assembly and will change the scrub radius, which can negatively affect the steering control. When larger-diameter tires and positive-offset wheels are installed, the scrub radius becomes positive and the wheels tend to toe-out, causing wander, poor handling, and tire wear.

TURNING RADIUS (TOE-OUT ON TURNS)

Whenever a vehicle turns a corner, the inside wheel has to turn at a sharper angle than the outside wheel because the inside wheel has a shorter distance to travel. ● **SEE FIGURE 119–44.**

Turning radius is also called **toe-out on turns,** abbreviated TOT or **TOOT,** and is determined by the angle of the steering knuckle arms. **Turning radius is a nonadjustable angle.** The turning radius can and should be measured as part of an alignment to check if the steering arms are bent or damaged. Symptoms of out-of-specification turning angle include the following:

1. Tire squeal noise during normal cornering, even at low speeds
2. Scuffed tire wear

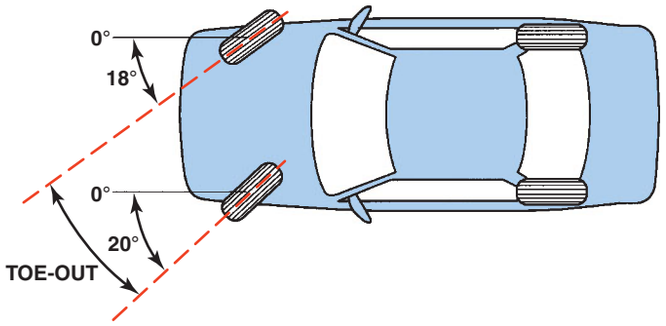


FIGURE 119–44 To provide handling, the inside wheel has to turn at a greater turning radius than the outside wheel.

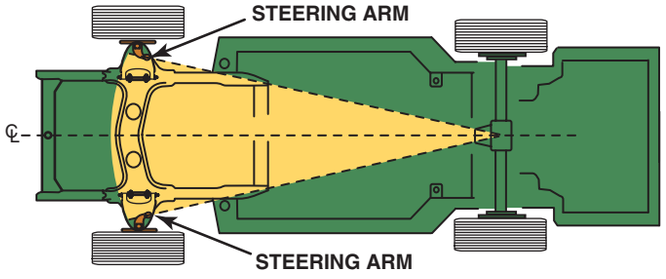


FIGURE 119–45 The proper toe-out on turns is achieved by angling the steering arms.

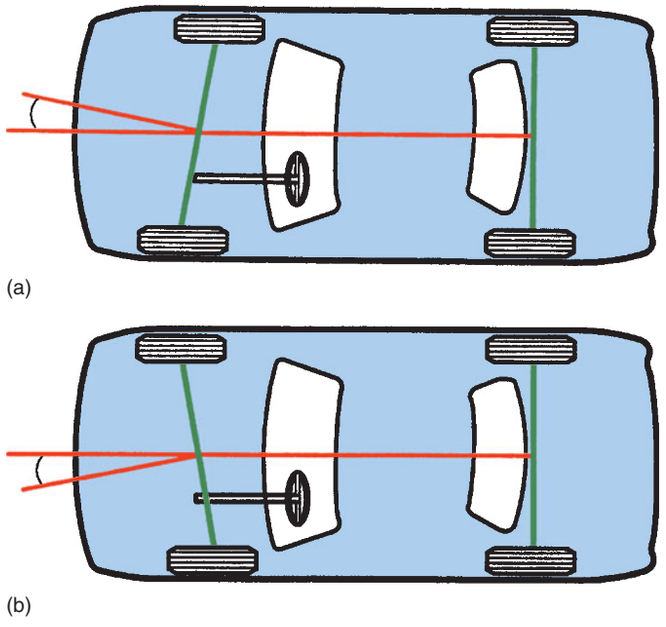


FIGURE 119–46 (a) Positive setback. (b) Negative setback.

The proper angle of the steering arms is where imaginary lines drawn from the steering arms should intersect exactly at the center of the rear axle. ● **SEE FIGURE 119–45.** This angle is called the Ackerman Effect (named for its promoter, an English publisher, Rudolph Ackerman, circa 1898).

SETBACK

Setback is the angle formed by a line drawn perpendicular (at 90 degrees) to the front axles. ● **SEE FIGURE 119–46.**

Setback is a nonadjustable measurement, even though it may be corrected. Positive setback means the right front wheel is set

back farther than the left; negative setback means the left front wheel is set back farther than the right.

Setback can be measured with a four-wheel alignment machine or can be determined by measuring the wheel base on both sides of the vehicle.

NOTE: The wheel base of any vehicle is the distance between the center of the front wheel and the center of the rear wheel on the same side. The wheel base should be within 1/8 in. (3 mm) side-to-side.

The causes of setback include the following:

1. Cradle placement not correct on a front-wheel-drive vehicle. This can be caused by incorrectly installing the cradle after a transmission, clutch, or engine replacement or service. ● **SEE FIGURE 119–47**.

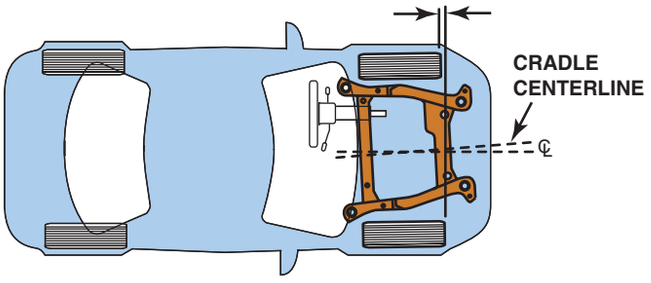


FIGURE 119–47 Cradle placement affects setback.

2. An accident that affected the frame or cradle of the vehicle and was unnoticed or not repaired.

Most vehicle manufacturers do not specify a minimum setback specification. However, a reading of 0.50 degrees or 0.5 in. (13 mm) or less of setback is generally considered to be acceptable.

THRUST ANGLE

Thrust angle is the angle of the rear wheels as determined by the total rear toe. If both rear wheels have zero toe, then the thrust angle is the same as the geometric centerline of the vehicle. The total of the rear toe setting determines the **thrust line,** or the direction the rear wheels are pointed. ● **SEE FIGURE 119–48.**

On vehicles with an independent rear suspension, if both wheels do not have equal toe, the vehicle will pull in the direction of the side with the most toe-in.

TRACKING

The rear wheels should track directly behind the front wheels. If the vehicle has been involved in an accident, it is possible that the frame or rear axle mounting could cause **dog tracking.** ● **SEE FIGURE 119–49.**

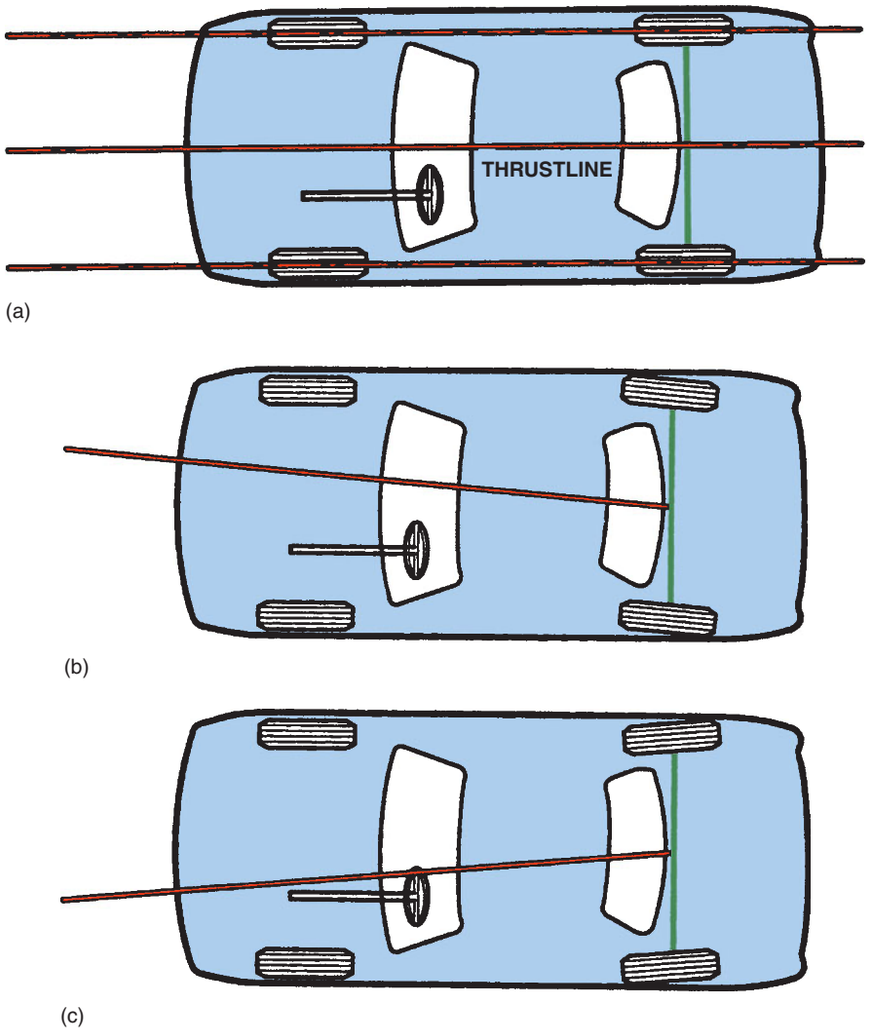
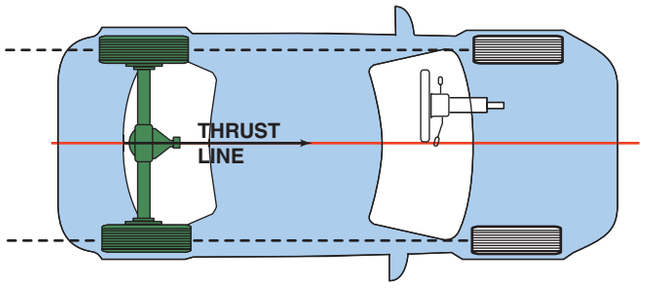
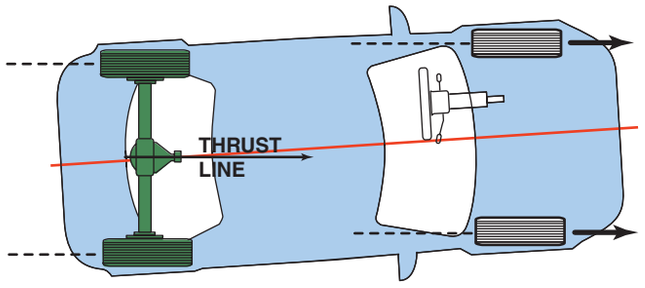


FIGURE 119–48 (a) Zero thrust angle. (b) Thrust line to the right. (c) Thrust line to the left.



(a)



(b)

FIGURE 119–49 (a) Proper tracking. (b) Front wheels steering toward thrust line.

To check the frame for possible damage, two diagonal measurements of the frame and/or body are required. The diagonal measurements from known points at the front and the rear should be within 1/8 in. (3 mm) of each other.

FOUR-WHEEL ALIGNMENT

Four-wheel alignment refers to the checking and/or adjustment of all four wheels. Four-wheel alignment is important for proper handling and tire wear. Some rear-wheel-drive vehicles equipped with independent rear suspension can be adjusted for camber and toe. Rear-wheel caster cannot be measured or adjusted because to measure caster, the wheels must be turned from straight ahead. Since rear wheels are securely attached, a caster *sweep* (turning the wheels to take a caster reading) is not possible. While rear camber can cause tire wear problems, by far the greatest tire wear occurs due to toe settings. *Unequal* toe in the rear can cause the vehicle to pull or lead. The rear camber and toe are always adjusted first before adjusting the front caster, camber, and toe. This procedure ensures that the thrust line and centerline of the vehicle are the same.

REVIEW QUESTIONS

1. Explain the three basic alignment angles of camber, caster, and toe.
2. Describe what happens to tire wear and vehicle handling if toe, camber, and caster are out of specification or *not* equal side-to-side.
3. Explain how knowing SAI, TOOT, and included angle can help in the correct diagnosis of an alignment problem.
4. Explain what thrust angle means.

CHAPTER QUIZ

1. When performing an alignment, which angle is the most important for tire wear?
   a. Toe **c.** Caster
   b. Camber **d.** SAI (KPI)
2. Positive camber means _____.
   a. The top of the tire is tilted outward.
   b. The top of the tire is tilted inward.
   c. Either a or b
   d. Both a and b
3. Which alignment angle is adjustable on all vehicles?
   a. Camber **c.** Toe
   b. Caster **d.** SAI (KPI)
4. Positive (+) toe is _____.
   a. Toe-in **b.** Toe-out
5. If the top of the steering axis is tilted 2 degrees toward the rear of the vehicle, this is _____.
   a. Positive camber **c.** Negative caster
   b. Negative camber **d.** Positive caster
6. A steering dampener may be needed to reduce shimmy on vehicles that have high positive _____.
   a. Camber **c.** Toe
   b. Caster **d.** Included angle
7. If the turning radius (toe-out on turns, or TOOT) is out of specification, what part or component is defective?
   a. The strut is bent.
   b. The steering arm is bent.
   c. The spindle is bent.
   d. The control arm is bent.
8. Which angle determines the thrust angle?
   a. Front toe
   b. Rear toe
   c. Rear camber
   d. Front caster, SAI, and included angle
9. Included angle is _____.
   a. SAI + caster
   b. Camber + caster
   c. Camber + SAI
   d. Toe + camber
10. Two technicians are discussing scrub radius. Technician A says that scrub radius cannot be measured. Technician B says that scrub radius cannot be adjusted. Which technician is correct?
    a. Technician A only **c.** Both Technicians A and B
    b. Technician B only **d.** Neither Technician A nor B

chapter 120

ALIGNMENT DIAGNOSIS AND SERVICE

OBJECTIVES: After studying Chapter 120, the reader will be able to: • Prepare for ASE Suspension and Steering (A4) certification test content area "D" (Wheel Alignment Diagnosis, Adjustment, and Repair). • List the many checks that should be performed before aligning a vehicle. • Describe the proper alignment setup procedure. • Explain how to correct for memory steer, torque steer, pull, drift (lead), and wander. • Describe the use of unit conversion and diagnostic charts. • Discuss tolerance alignment and how to check for accident damage.

KEY TERMS: Degrees 1431 • Eccentric cam 1442 • Five-wheel alignment 1430 • Four-wheel alignment 1436 • Fractional 1431 • Geometric centerline 1434 • Memory steer 1429 • Minutes 1431 • Prealignment checks 1428 • Ride height 1428 • Shim chart 1442 • Spoke angle 1443 • Thrust line 1436 • Tolerance adjustment 1447 • Torque steer 1429 • Total toe 1433

NEED FOR PROPER ALIGNMENT

Proper wheel alignment of all four wheels is important for the safe handling of any vehicle. When all four wheels are traveling the same path and/or being kept nearly vertical, tire life and fuel economy are maximized and vehicle handling is sure and predictable. A complete wheel alignment is a complex process that includes many detailed steps and the skill of a highly trained technician.

PREALIGNMENT CORRECTION TECHNIQUES

There are four basic steps in the correction of any problem:

1. **Verify.** What, when, where, and to what extent does the problem occur? This step usually involves a test drive to verify the problem.
2. **Isolate.** Eliminate known good parts and systems. Always start with the simple things first. For example, checking and correcting tire pressure and rotation of the tires should be one of the first things performed whenever trying to isolate the cause of an alignment-related problem.
3. **Repair the problem.** This step involves replacing any worn or damaged components and making sure that the alignment is within factory specifications. ● **SEE FIGURE 120–1**.
4. **Recheck.** *Always* test-drive the vehicle after making a repair. Never allow the customer to be the first to drive the vehicle after any service work.

A thorough inspection of the steering, suspension, and tires should be performed *before* the alignment of the vehicle is begun.

TECH TIP

Align and Replace at the Same Time

Magnetic bubble-type camber/caster gauges can be mounted directly on the hub or on an adapter attached to the wheel or spindle nut on front-wheel-drive vehicles. ● **SEE FIGURE 120–2.** Besides being used as an alignment setting tool, a magnetic alignment head is a great tool to use whenever replacing suspension components.

Any time a suspension component is replaced, the wheel alignment should be checked and corrected as necessary. An easy way to avoid having to make many adjustments is to use a magnetic alignment head on the front wheels to check camber with the vehicle hoisted in the air *before* replacing front components, such as new MacPherson struts. Then, before tightening all of the fasteners, check the front camber readings again to make sure they match the original setting. This is best done when the vehicle is still off the ground. For example, a typical front-wheel-drive vehicle with a MacPherson strut suspension may have a camber reading of +1/4 degree on the ground and +2 degrees while on the hoist with the wheels off the ground. After replacing the struts, simply return the camber reading to +2 degrees and it should return to the same +1/4 degree when lowered to the ground.

Though checking and adjusting camber before and after suspension service work does not guarantee a proper alignment, it does permit the vehicle to be moved around with the alignment fairly accurate until a final alignment can be performed.



FIGURE 120–1 The owner of this Honda thought that all it needed was an alignment. Obviously, something more serious than an alignment caused this left rear wheel to angle inward at the top.

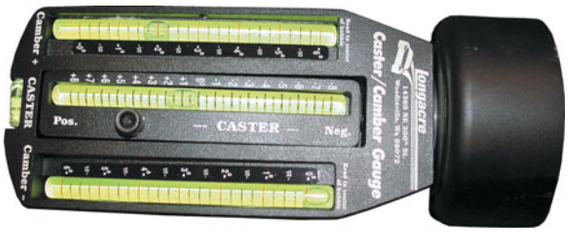


FIGURE 120–2 Magnetic bubble-type camber/caster gauge. To help it keep its strong magnetism, it is best to keep it stored stuck to a metal plate or metal tool box.

PREALIGNMENT CHECKS

Before checking or adjusting the front-end alignment, the following items should be checked and corrected, if necessary, as part of the **prealignment checks:**

1. Check all the tires for proper inflation pressures. Tires should be approximately the same size and tread depth, and the recommended size for the vehicle. ● **SEE FIGURE 120–3.**

   NOTE: Some alignment technicians think that the vehicle must have new tires installed before an accurate alignment can be performed. Excessively worn tires, especially if only one tire is worn, can cause the vehicle to lean slightly. It is this unequal ride height that is the important fact to consider. If, for example, all four tires are equally worn, then the vehicle *can* be properly aligned. (Obviously, excessively worn tires should be replaced, and it would be best to align the vehicle with the replacement tires installed to be assured of an accurate alignment.)

2. Check the wheel bearings for proper adjustment.
3. Check for loose ball joints or torn ball joint boots.
4. Check the tie rod ends for damage or looseness.
5. Check the center link or rack bushings for play.
6. Check the pitman arm for any movement.
7. Check for runout of the wheels and the tires.
8. Check for vehicle ride height (should be level front to back as well as side-to-side). Make sure that the factory load-leveling system is functioning correctly, if the vehicle is so equipped. Check height according to the manufacturer's specifications. ● **SEE FIGURES 120–4 AND 120–5.**

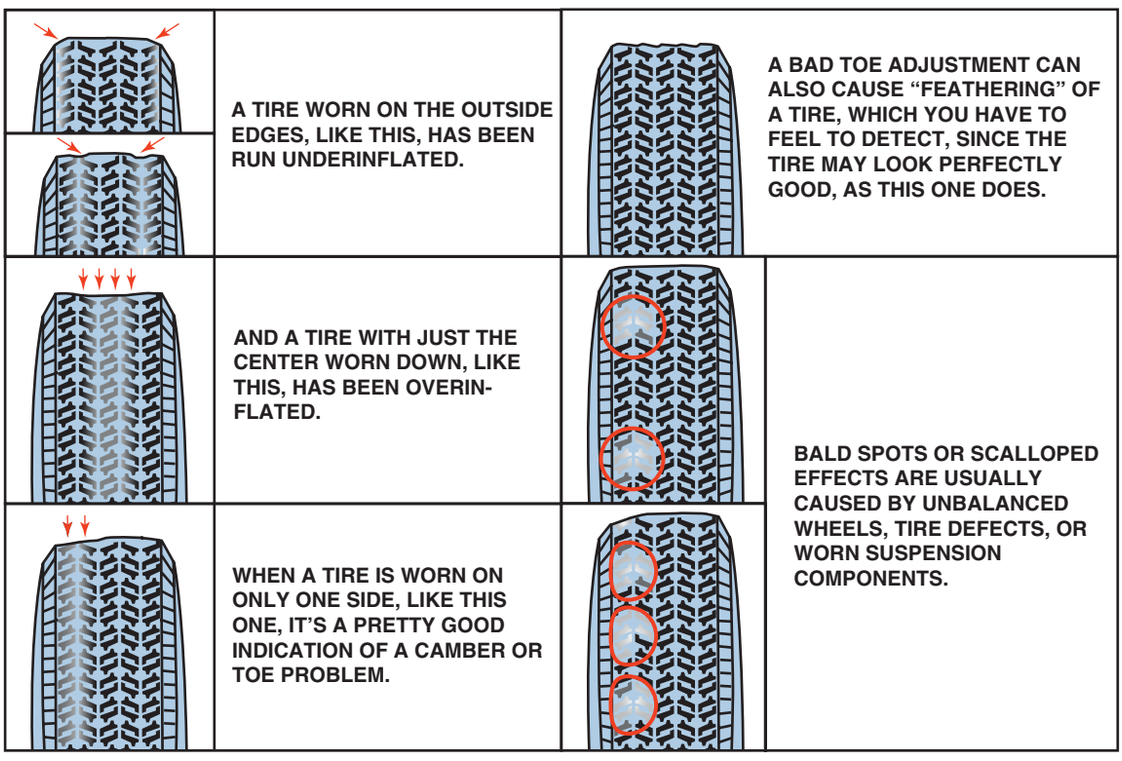


FIGURE 120–3 Typical tire wear chart as found in a service manual. Abnormal tire wear usually indicates a fault in a steering or suspension component that should be corrected or replaced before an alignment is performed.

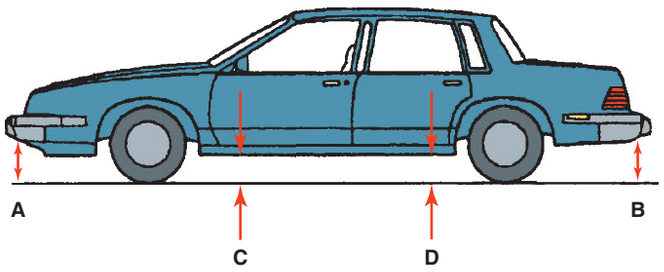


FIGURE 120–4 Measuring points for ride (trim) height vary by manufacturer. (*Courtesy of Hunter Engineering Company*)



FIGURE 120–5 Measuring to be sure the left and right sides of the vehicle are of equal height. If this measurement is not equal side-to-side by as little as 1/8 in. (3 mm), it can affect the handling of the vehicle.

9. Check for steering gear looseness at the frame.
10. Check for improperly operating shock absorbers.
11. Check for worn control arm bushings.
12. Check for loose or missing stabilizer bar attachments.
13. Check the trunk for excess loads.
14. Check for dragging brakes.

NOTE: Checking for dragging brakes is usually performed when installing alignment heads to the wheels prior to taking an alignment reading. A brake dragging can cause the vehicle to pull or lead toward the side with the dragging brake.

LEAD/PULL

DIAGNOSIS Many alignment requests come from customers attempting to have a lead or pull condition corrected. Before aligning the vehicle, verify the customer complaint first, then perform a careful inspection.

1. Inspect all tires for proper inflation. Both tires on the same axle (front and rear) should be the same size and brand. A lead/pull problem could be due to a defect or condition in one or more of the tires, as shown in ● **FIGURE 120–6**. Before attempting to correct the lead/pull condition by changing alignment angles, try rotating the tires front to back or side to side.
2. Road test the vehicle on a straight, level road away from traffic, if possible. Bring the vehicle to about 40 mph (65 km/h), shift into neutral, and feel for a pull in the steering, either to the left or to the right. A lead or drift is less severe than a pull, and may occur only if you momentarily remove your hands from the steering wheel while driving.
3. If the lead/pull problem is sometimes toward the left and other times toward the right, check for a **memory steer** condition. If the lead/pull problem occurs during acceleration and deceleration, check for a **torque steer** condition.

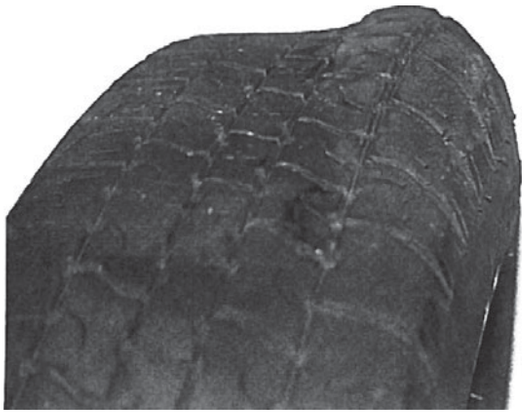


FIGURE 120–6 The bulge in this tire was not noticed until it was removed from the vehicle as part of a routine brake inspection. After replacing this tire, the vehicle stopped pulling and vibrating.

MEMORY STEER

DIAGNOSIS *Memory steer* is a term used to describe the lead or pull of a vehicle caused by faults in the steering or suspension system. Often a defective upper strut bearing or steering gear can cause a pulling condition in one direction after making a turn in the same direction. It is as if the vehicle had a memory and pulled in the same direction. To test for memory steer, follow these simple steps during a test drive:

1. With the vehicle stopped at an intersection or in a parking area, turn the steering wheel completely to the left stop and then straighten the wheel without going past the straight-ahead position.
2. Lightly accelerate the vehicle and note any tendency of the vehicle to lead or pull toward the left.
3. Repeat the procedure, turning the steering wheel to the right.

If the vehicle first pulls to the left, then pulls to the right, the vehicle has a memory steer condition.

CORRECTION A binding suspension or steering component is the most likely cause of memory steer. Disconnect each wheel from its tie rod end and check for free rotation of movement of each wheel. Each front wheel should rotate easily without binding or roughness. Repair or replace components as necessary to eliminate the binding condition.

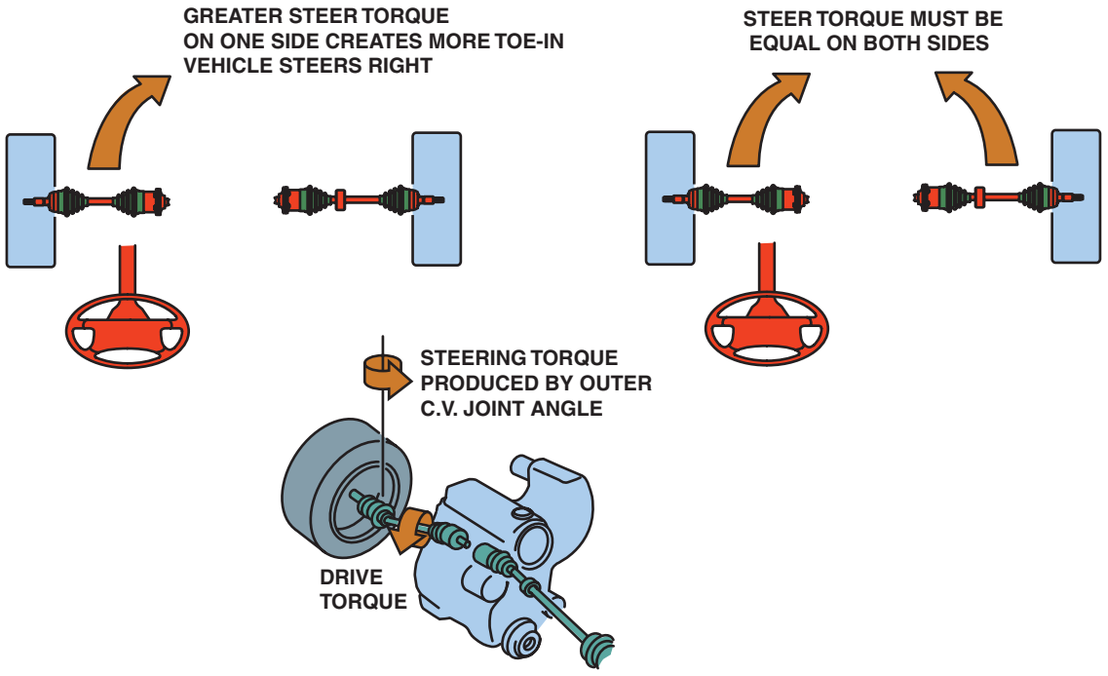


FIGURE 120–7 Equal outer CV joint angles produce equal steer torque (toe-in). If one side receives more engine torque, that side creates more toe-in and the result is a pull toward one side, especially during acceleration.

REAL WORLD FIX

The Five-Wheel Alignment

The steering wheel should always be straight when driving on a straight, level road. If the steering wheel is not straight, the customer will often think that the wheel alignment is not correct. One such customer complained that the vehicle pulled to the right while driving on a straight road. The service manager test drove the vehicle and everything was perfect, except that the steering wheel was not perfectly straight, even though the toe setting was correct. Whenever driving on a straight road, the customer would "straighten the steering wheel" and, of course, the vehicle went to one side. After adjusting toe with the steering wheel straight, the customer and the service manager were both satisfied. The technician learned that regardless of how accurate the alignment, the steering wheel *must* be straight; it is the "fifth wheel" that the customer notices most. Therefore, a **five-wheel alignment** rule includes a check of the steering wheel.

NOTE: Many vehicle manufactures now include the maximum allowable steering wheel angle variation from straight. This specification is commonly ±3 degrees (plus or minus 3 degrees) or less.

NOTE: One of the most common causes of memory steer is the installation of steering or suspension components while the front wheels are turned. Most steering and suspension parts contain rubber, which has a memory if moved from its installed position. If the memory steer condition is only in one direction, then this is the most likely cause. The rubber component exerts a force on the suspension or steering that causes the vehicle to pull toward the side that the wheels were turned toward when the part was installed.

TORQUE STEER

DIAGNOSIS Torque steer occurs in front-wheel-drive vehicles when engine torque causes a front wheel to change its angle from straight ahead. ● **SEE FIGURE 120–7.** This resulting pulling effect is most noticeable during rapid acceleration, especially whenever upshifting of the transmission creates a sudden change in torque being applied to the front wheels. When turning and accelerating at the same time, torque steer has a tendency to straighten the vehicle, so more steering effort may be required to make the turn. Then, if the accelerator is released, a reversing force is applied to the front wheels. Now the driver must take corrective steering motions to counteract the change in steering effect of engine torque.

Torque steer sequence of events	
Torque to wheel	creates a toe-in condition
More torque	creates more toe-in
Unequal torque	creates unequal toe-in
Unequal driveshaft angles	creates unequal torque to the wheels

Most manufacturers try to reduce torque steer in the design of their vehicles by keeping drive axle angles low and equal side-to-side. If the engine and transaxle are level and the drive axle shafts are kept level, then the torque from the engine will be divided equally between the front wheels.

CORRECTION The service technician cannot change the design of a vehicle, but the technician can, and should, check and correct problems that often cause torque steer. **Check to be sure that the condition is not normal.** It is normal for front-wheel-drive vehicles to exert a tug on the steering wheel and steer toward one side (usually to the right) during acceleration. This is especially noticeable when the transmission shifts from first to second gear under heavy acceleration. To determine how severe the problem is, place a strip

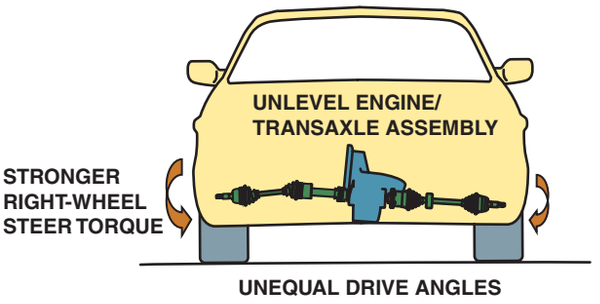


FIGURE 120–8 Broken or defective engine or transaxle mounts can cause the powertrain to sag, causing unequal drive axle shaft CV joint angles.

of masking tape at the top of the steering wheel. Drive the vehicle and observe the amount of movement required to steer the vehicle straight during heavy acceleration. Repeat the test with a vehicle of similar make and model. If the torque steer is excessive, determine and correct the cause by carefully following the prealignment inspection steps and checking for a level powertrain.

A defective engine mount can cause the entire drivetrain to sag on one end. If the engine and transaxle of any front-wheel-drive vehicle is not level, the drive axle shaft angles will not be equal, as shown in ● **FIGURE 120–8.**

Hold a straightedge along the engine's supporting frame and measure up to points along the transaxle pan rail or the drive axle shaft. Side-to-side distances should be equal. Standard alignment shims can be used to shim the mounts and level the drivetrain.

If torque steer is still excessive, check all alignment angles, including SAI and included angle. Unequal alignment angles can cause a pull or a lead condition. SAI and included angle should be within 1/2 (0.5) degree side-to-side for best results. A vehicle will tend to pull toward the side with the least SAI.

ALIGNMENT SPECIFICATIONS

Before attempting any alignment, consider the following:

1. Determine the make, model, and year of the vehicle.
2. Determine if the vehicle is equipped with power steering or manual steering. (Some older models use lower caster specifications for manual steering to reduce steering effort.)
3. Check the trunk and with the customer to determine the normal load being carried. Sometimes customers take out heavy things they normally carry or have something in the vehicle now that they normally do not carry.
4. Determine the correct specifications (if possible, check the specifications from two different sources to ensure correct readings).
5. Compensate for the lack of a full gas tank by placing an equal amount of weight in the luggage compartment. (Gasoline weighs 6 lb per gallon [0.7 kg per l]—a 20-gallon gas tank, when full, weighs 120 lb [80 liters weighs 54 kg].)
6. Determine the correct specifications for the *exact* vehicle being checked.

NOTE: Some alignment specifications are published as guidelines for acceptable values for state or local vehicle inspections. Be sure to use the *service* or *set to* specifications.

TECH TIP

Keep the Doors Closed, but the Window Down

An experienced alignment technician became upset when a beginning technician opened the driver's door to lock the steering wheel in a straight-ahead position on the vehicle being aligned. The weight of the open door caused the vehicle to sag. This disturbed the level position of the vehicle and changed all the alignment angles.

The beginning technician learned an important lesson that day: Keep the window down on the driver's door so that the steering wheel and brakes can be locked without disturbing the vehicle weight balance by opening a door. The brake pedal must be locked with a pedal depressor to prevent the wheels from rolling as the wheels are turned during a caster sweep. The steering must be locked in the straight-ahead position when adjusting toe.

READING ALIGNMENT SPECIFICATIONS

There are several methods used by vehicle manufacturers and alignment equipment manufacturers to specify alignment angles.

MAXIMUM/MINIMUM/PREFERRED METHOD. This method indicates the preferred setting for each alignment angle and the minimum and maximum allowable value for each. The alignment technician should always attempt to align the vehicle to the preferred setting.

PLUS OR MINUS METHOD. This method indicates the preferred setting with the lowest and highest allowable value indicated by a negative (−) and positive (+) sign, as in ● **CHART 120–1.** For example, if a camber reading is specified as +1/2 degree with a + and − value of 1/2 degree, it could be written as +1/2 degree ±1/2 degree. The minimum value would be 0 degree (1/2° − 1/2°= 0°) and the maximum value would be +1 degree (+1/2° + 1/2° = 1°). The range would be from 0 to 1 degree.

NOTE: The angle is assumed positive unless labeled with a negative (−) sign in front of the number.

DEGREES, MINUTES, AND FRACTIONS

Specifications are often published in **fractional** or decimal **degrees,** or in degrees and **minutes.** There are 60 minutes (written as 60′) in 1 degree.

Fractions	Decimal Degrees	Minutes-Seconds
1/4°	0.25°	0°15′
1/2°	0.50°	0°30′
3/4°	0.75°	0°45′
1°	1.0°	1° or 60′

To help visualize the amount of these various units, think of decimal degrees as representing money or cents (100 cents = 1 dollar).

0.75 = 75 cents, or 3/4 of a dollar

Minutes can be visualized as minutes in an hour (60′ = 1 hour).

45′ = 3/4 of an hour

Now which is larger, 35 minutes or 0.40 degrees? The larger angle is 35 minutes because this is slightly greater than 1/2 degree, whereas 0.40 minutes is less than 1/2 degree.

	CASTER	CROSS CASTER (LH-RH)	CAMBER	CROSS CAMBER (LH-RH)	TOE (TOTAL IN) DEGREES	STEERING WHEEL ANGLE	THRUST ANGLE
FRONT	+3°±.5°	0°±.75°	+.2° ±.5°	0°±.75°	0°±.3°	0°±3°	–
REAR	–	–	−.3° ±.5°	0°±.75°	+.1° ±.2°	–	0°±.1°

CHART 120–1

This vehicle alignment specification chart indicates the preferred setting with a plus or minus tolerance.



FIGURE 120–9 Using the alignment rack hydraulic jacks, raise the tires off the rack so that they can be rotated as part of the compensating process.

FINDING THE MIDPOINT OF SPECIFICATIONS Many manufacturers specify alignment angles within a range. If you are using equipment that requires a midpoint to be entered, use the following method to determine easily the midpoint of specifications.

Example 1:

Specification: 55′ to 2° 25′

STEP 1 The first step is to determine the specification range or span, which is the total angle value from lowest to highest:

$$\begin{array}{r} 2°\ 25' \\ -55' \\ \hline 1°\ 30'\ \text{Specification range} \end{array}$$

STEP 2 Dividing the specification range by 2 will give the midpoint of the range:

$$\frac{1°30'}{2} = \frac{90'}{2} = 45'$$

STEP 3 To find the midpoint of the specifications, add the midpoint of the range to the smaller specification (or subtract from the larger specification):

$$\begin{array}{r} 45'\ \text{midpoint of range} \\ +55'\ \text{lowest specification} \\ \hline 1°40'\ \text{midpoint of specification} \end{array}$$

Example 2:

Specification: −0.5° to +0.80°

STEP 1 The total range of the specification is determined by adding 0.5 (1/2) to 0.80, totaling 1.30°.

NOTE: Since the lower specification is a negative number, we had to *add* the 0.5 degree to bring the lower range of the specification to zero. Then the total is simply the upper range specification added to the number required to bring the lower end of the range to zero.

STEP 2 Dividing the specification range by 2 gives the midpoint of the range:

$$\frac{1.30°}{2} = 0.65°$$

STEP 3 To find the midpoint of the specification, add the midpoint of the range to the smaller specification:

$$0.65 + (-0.50) = 0.15$$

ALIGNMENT SETUP PROCEDURES

After confirming that the tires and all steering and suspension components are serviceable, the vehicle is ready for an alignment. Setup procedures for the equipment being used must always be followed. Typical alignment procedures include the following:

STEP 1 Drive onto the alignment rack straight and adjust the ramps and/or turn plates so that they are centered under the tires of the vehicle. ● **SEE FIGURE 120–9.**

STEP 2 Use chocks for the wheels to keep the vehicle from rolling off the alignment rack.

STEP 3 Attach and calibrate the wheel sensors to each wheel as specified by the alignment equipment manufacturer. ● **SEE FIGURE 120–10.** The calibration procedure is required whenever the head of the machine is attached to the wheel of the vehicle. All alignment angles and measurements are taken from the readings of the wheel sensors.

Calibration of these wheel sensors is needed for two reasons:

a. *The wheel may be bent.* If the wheel (rim) is bent, even slightly, this small amount of tilt would be read as an angle of the suspension.

NOTE: Compensating or calibrating the wheel sensor for a bent wheel does *not* correct (or repair) the bent wheel! The bent wheel is still present and can result in a shimmy-type vibration.

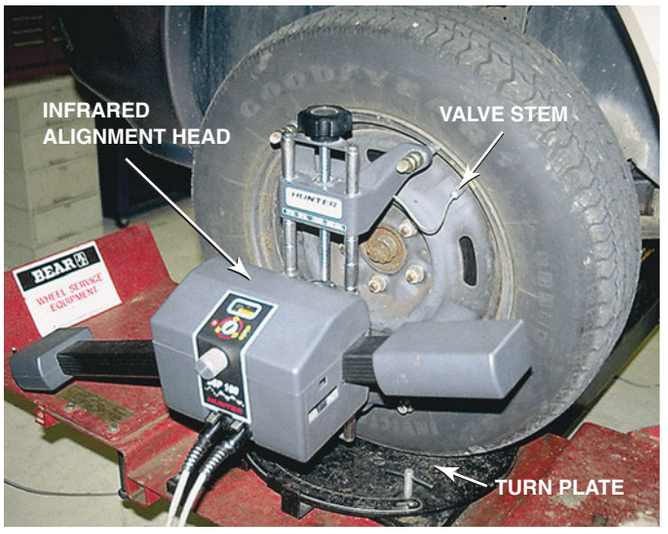


FIGURE 120–10 This wheel sensor has a safety wire that screws to the valve stem to keep the sensor from falling onto the ground if the clamps slip on the wheel lip.

b. *The sensors may not be identically installed on the wheel.* Most sensors use three or four wheel-mounting locations. It is not possible to install all wheel sensors perfectly at the same depth on the wheel in all locations. If a sensor must be removed during the alignment process and reinstalled, it should be recalibrated. Always follow the manufacturer's recommended procedure for compensating the sensors.

STEP 4 Unlock all rack or turn plates.

STEP 5 If raised for compensation, lower the vehicle and jounce the vehicle by pushing down on the front, then rear, bumper. This motion allows the suspension to become centered.

STEP 6 Following the procedures for the alignment equipment, determine all alignment angles.

MEASURING CAMBER, CASTER, SAI, TOE, AND TOOT

CAMBER Camber is measured with the wheels in the straight-ahead position on a level platform. Since camber is a vertical reference angle, alignment equipment reads camber directly.

CASTER Caster is measured by moving the front wheels through an arc inward, then outward, from straight ahead. This necessary movement of the front wheels to measure caster is called *caster sweep.* What the alignment measuring equipment is actually doing is measuring the camber at one wheel sweep and measuring the camber again at the other extreme of the caster sweep. *The caster angle itself is the difference between the two camber readings.*

SAI Steering axis inclination (SAI) is also measured by performing a caster sweep of the front wheels. While this angle can be read at the same time as caster on many alignment machines, most experts recommend that SAI be measured separately from the caster reading. When measuring SAI separately, the usual procedure involves raising the front wheels off the ground and leveling and locking the wheel sensors before performing a caster sweep. The reason for raising the front wheels is to allow the front suspension to extend to its full droop position. When the suspension is extended, the SAI is more accurately determined because the angle itself is expanded.

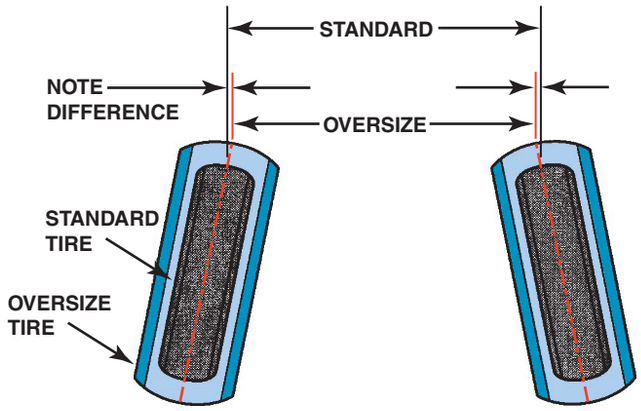


FIGURE 120–11 If toe for an oversize tire is set by distance, the toe angle will be too small. Toe angle is the same regardless of tire size.

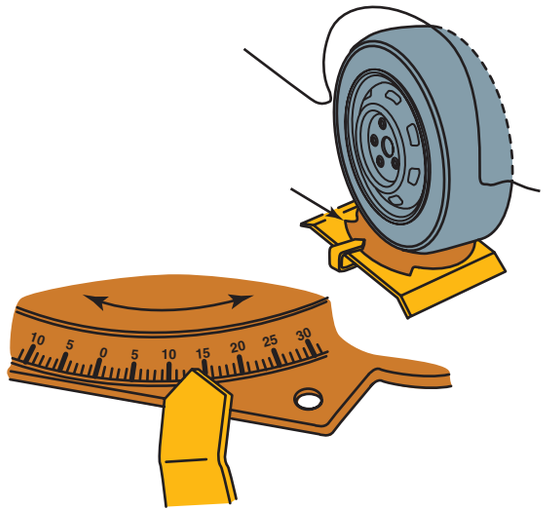


FIGURE 120–12 The protractor scale on the front turn plates allows the technician to test the turning radius by turning one wheel to an angle specified by the manufacturer and observing the angle of the other front wheel. Most newer alignment machines can display turning angle based on sensor readings, and therefore the protractor scale on the turn plate is not needed or used.

TOE Toe is determined by measuring the angle of both front and/or both rear wheels from the straight-ahead (0 degree) position. Most alignment equipment reads the toe angle for each wheel *and* the combined toe angle of both wheels on the same axle. This combined toe is called **total toe.** Toe angle is more accurate than the center-to-center distance, especially if oversize tires are installed on the vehicle. ● **SEE FIGURE 120–11.**

TOOT Toe-out on turns (TOOT) is a diagnostic angle and is normally not measured as part of a regular alignment, but it is recommended to be performed as part of a total alignment check. TOOT is measured by recording the angle of the front wheels as indicated on the alignment machine display or on the front turn plates. ● **SEE FIGURE 120–12.**

If, for example, the inside wheel is turned 20 degrees, then the outside wheel should indicate about 18 degrees on the turn plate. The exact angles are usually specified by the vehicle manufacturer. The turning angle should be checked only after the toe is correctly set. *The turning angle for the wheel on the outside of the turn should not vary more than 1 1/2 degrees from specifications.* For example, if the specification calls for the right wheel to be steered into the turn 20 degrees, the outside wheel should measure 18 degrees. This measurement should be within 1 1/2 degrees (or between 16.5 and 19.5 degrees in this example). If the TOOT is not correct, a bent steering arm is the usual cause. If TOOT is not correct, tire squealing noise is usually noticed while cornering and excessive tire wear may occur.

NOTE: Some front-wheel-drive vehicles use a nonsymmetrical (unequal) turning angle design. This design is found on various makes and models of vehicles to assist in controlling torque steer. The test procedure is the same except that the turning angle specifications include left-wheel and right-wheel angles when turned inward and outward and may be different readings without indicating a problem.

SPECIFICATIONS VERSUS ALIGNMENT READINGS

Secure both the alignment specifications from the manufacturer and the alignment readings and compare the two. Before starting an alignment, the smart technician checks the SAI, included angle, setback, and toe-out on turns to make sure that there is no hidden damage such as a bent spindle or strut that was not found during the prealignment inspection. *Setback is also a diagnostic angle and should be less than 0.5 in. (13 cm or 1/2 degree).* If setback is greater than 0.5 in. (13 cm or 1/2 degree), check the body, frame, and cradle for accident damage or improper alignment.

NOTE: If the SAI or included angle are unequal, suggesting a possible problem such as a bent strut, check the front and rear toe readings. Some alignment equipment cannot show accurate SAI readings if the front or rear toe readings are not within specifications. If the front and rear toe readings are OK and the alignment readings indicate a bent strut, go ahead with the diagnosis and correction as explained later in this chapter.

CHECKING FOR BENT STRUTS, SPINDLES, OR CONTROL ARMS

Even a minor bump against a curb can bend a spindle or a strut housing.

Before attempting to correct an alignment, check all the angles and use the appropriate diagnostic chart to check for hidden damage that a visual inspection may miss.

The chart in ● **CHART 120–2** can be used to determine what is wrong if the alignment angles are known. Simply use the chart that correctly identifies the type of suspension on the problem vehicle. The terms used regarding the specifications in Chart 120–2 include:

At spec	The alignment angle is within specifications.
Over spec	The alignment angle is greater or higher than specified by the manufacturer.
Under spec	The alignment angle is less than or lower than specified by the manufacturer.

TECH TIP

Damage Analysis Tips

To check if a vehicle has been in a collision, technicians should look for the following:

1. Drive the vehicle through a water puddle to see if the tire marks are wider than the tires. If they are, then the front and rear wheels are not tracking correctly.
2. If the setback is out of specifications, then the front of the vehicle may be damaged.
3. If the thrust angle is out of specifications, then rear suspension damage is likely.

CHECKING FRAME ALIGNMENT OF FRONT-WHEEL-DRIVE VEHICLES

Many front-wheel-drive vehicles mount the drive train (engine and transaxle) and lower suspension arms to a subframe or cradle. If the frame is shifted either left or right, this can cause differences in SAI, included angle, setback, and camber. ● **SEE FIGURES 120–13 AND 120–14.** Adjust the frame if SAI and camber angles are different left and right side, yet the included angles are equal.

TYPES OF ALIGNMENTS

There are three types of alignment: geometric centerline, thrust line, and four-wheel alignment.

GEOMETRIC CENTERLINE Until the 1980s, most wheel alignment concerned only the front wheels. Vehicles, such as sports cars, that had independent rear suspensions were often aligned by backing the vehicle onto the alignment rack and adjusting the rear camber and/or toe. This type of alignment is simply an alignment that uses the **geometric centerline** of the vehicle as the basis for all measurements of toe (front or rear). ● **SEE FIGURE 120–15.**

This method is now considered to be obsolete.

DIAGNOSING SAI, CAMBER, AND INCLUDED ANGLE

SLA AND STRUT/SLA SUSPENSIONS

SAI	CAMBER	INCLUDED ANGLE	DIAGNOSIS
Correct	Less than specs	Less than specs	Bent steering knuckle or spindle
Less than specs	Greater than specs	Correct	Bent lower control arm
Less than specs	Greater than specs	Greater than specs	Bent lower control arm and steering knuckle or spindle
Greater than specs	Less than specs	Correct	Bent upper control arm

STRUT SUSPENSIONS

SAI	CAMBER	INCLUDED ANGLE	DIAGNOSIS
Correct	Less than specs	Less than specs	Bent spindle and/or strut
Correct	Greater than specs	Greater than specs	Bent spindle and/or strut
Less than specs	Greater than specs	Correct	Bent control arm or strut tower out at top
Less than specs	Greater than specs	Greater than specs	Bent control arm or strut tower out at top, also bent spindle and/or strut
Less than specs	Less than specs	Less than specs	Bent control arm or strut tower out at top, also bent spindle and/or strut
Greater than specs	Less than specs	Correct	Strut tower in at top
Greater than specs	Greater than specs	Greater than specs	Strut tower in at top and bent spindle and/or bent strut

KINGPIN TWIN I-BEAM SUSPENSION

SAI (KPI)	CAMBER	INCLUDED ANGLE	DIAGNOSIS
Correct	Greater than specs	Greater than specs	Bent spindle
Less than specs	Greater than specs	Correct	Bent I-beam
Less than specs	Greater than specs	Greater than specs	Bent I-beam and spindle
Greater than specs	Less than specs	Correct	Bent I-beam

CHART 120–2

By checking the SAI, camber, and included angle, a damaged suspension component can be determined by using this chart.

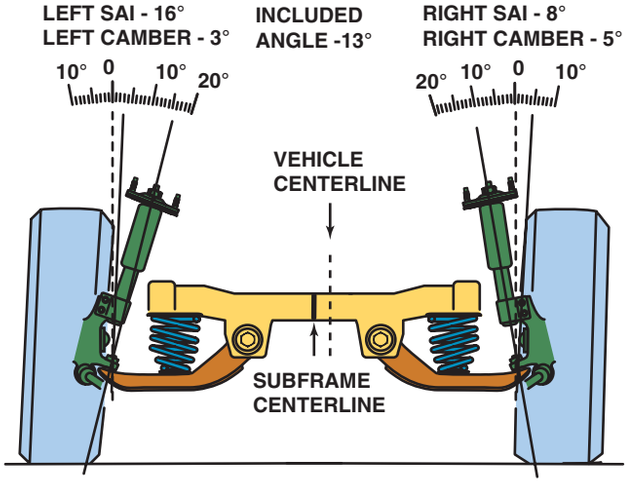


FIGURE 120–13 In this example, both SAI and camber are far from being equal side-to-side. However, both sides have the same included angle, indicating that the frame may be out of alignment. An attempt to align this vehicle by adjusting the camber on both sides with either factory or aftermarket kits would result in a totally incorrect alignment.

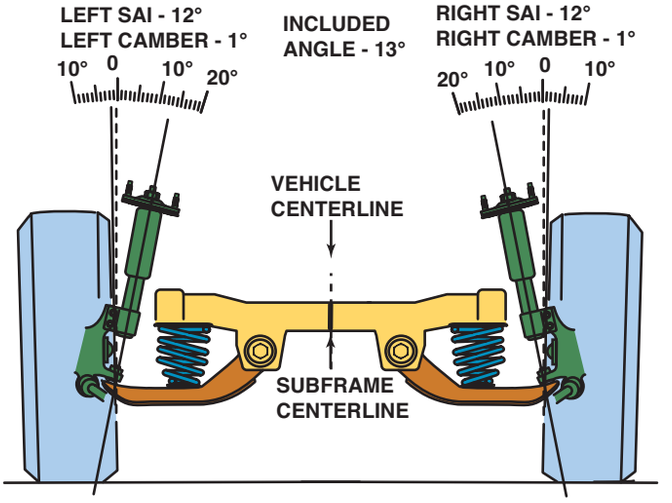


FIGURE 120–14 This is the same vehicle as shown in Figure 120–13, except now the frame (cradle) has been shifted over and correctly positioned. Notice how both the SAI and camber become equal without any other adjustments necessary.

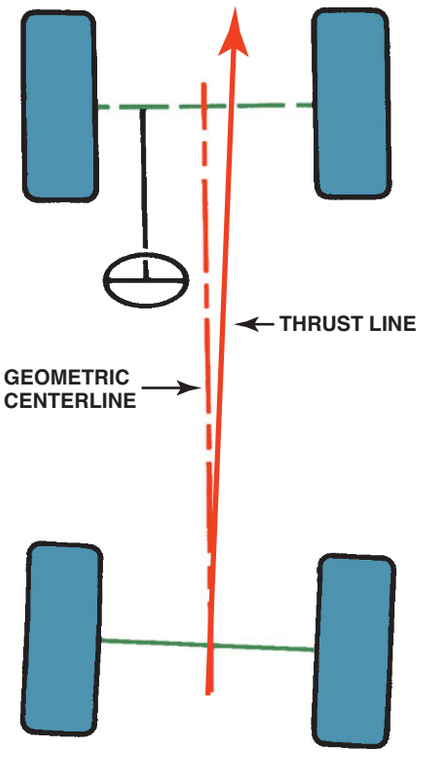


FIGURE 120–15 Geometric-centerline-type alignment sets the front toe readings based on the geometric centerline of the vehicle and does not consider the thrust line of the rear wheel toe angles. (*Courtesy of Hunter Engineering Company*)

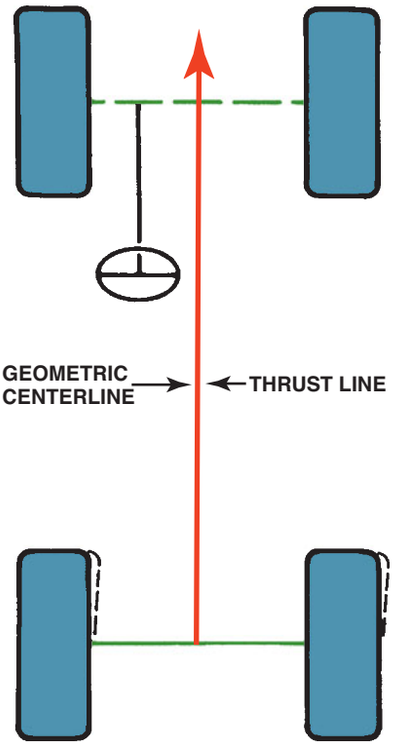


FIGURE 120–17 Four-wheel alignment corrects for any rear-wheel toe to make the thrust line and the geometric centerline of the vehicle both the same. (*Courtesy of Hunter Engineering Company*)

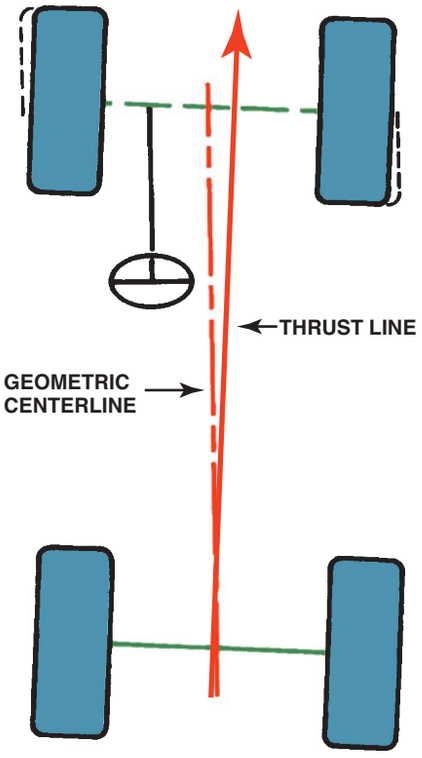


FIGURE 120–16 Thrust line alignment sets the front toe parallel with the rear-wheel toe. (*Courtesy of Hunter Engineering Company*)

THRUST LINE A **thrust line** alignment uses the thrust angle of the rear wheels and sets the front wheels parallel to the thrust line. ● **SEE FIGURE 120–16**

The thrust line is the bisector of rear total toe, or the actual direction in which the rear wheels are pointed. The rear wheels of any vehicle *should* be pointing parallel to the geometric centerline of the vehicle. However, if the rear toe angles of the rear wheels do not total exactly zero (perfectly in a line with the centerline of the vehicle), a thrust condition exists. The front wheels will automatically steer to become parallel to that condition. A crooked steering wheel may also result from an improper thrust condition.

NOTE: It has often been said that while the front wheels steer the vehicle, the rear wheels determine the direction in which the vehicle will travel. Think of the rear wheels as a rudder on a boat. If the rudder is turned, the direction of the boat changes due to the angle change at the rear of the boat.

Thrust line alignment is *required* for any vehicle with a nonadjustable rear suspension. If a vehicle has an adjustable rear suspension, then a four-wheel alignment is necessary to ensure proper tracking.

FOUR-WHEEL ALIGNMENT A **four-wheel alignment** is the most accurate alignment method and is necessary to ensure maximum tire wear and vehicle handling. The biggest difference between a thrust-line alignment and a four-wheel alignment is that the rear toe is adjusted to bring the thrust line to zero. In other words, the rear toe on both rear wheels is adjusted equally so that the actual direction in which the rear wheels are pointed is the same as the geometric centerline of the vehicle. ● **SEE FIGURE 120–17.**

The procedure for a four-wheel alignment includes these steps:

1. Adjust the rear camber (if applicable).
2. Adjust the rear toe (this should reduce the thrust angle to near zero).

3. Adjust the front camber and caster.
4. Adjust the front toe, being sure that the steering wheel is in the straight-ahead position.

SAMPLE ALIGNMENT SPECIFICATIONS AND READINGS

The service technician must know not only all of the alignment angles but also the interrelationship that exists among the angles. As an aid toward understanding these relationships, two examples are presented: Example 1 gives the front wheel angles that are acceptable when compared with the specifications; Example 2 gives four-wheel alignment and readings of a vehicle that are not within specifications.

Example 1: Wheel Alignment

Alignment Specifications

	Left	Right
Camber =	+1/2° ± 1/2°	+1/2° ± 1/2°
Caster =	+1° ± 1/2°	+1° ± 1/2°
Toe (total) =	1/8 in. ± 1/16 in.	

Actual Reading

	Left	Right
Camber =	+1/4°	0°
Caster =	+1°	+1 1/4°
Toe (total) =	1/8 in.	

Answer:

Alignment is perfect:
a. No tire wear
b. No pulling

Explanation:

Camber is within specifications.
Camber is within 1/2-degree difference side-to-side.
Camber is not equal, but there is more camber on the left (1/4 degree) than on the right, thereby helping to compensate for the road crown.
Caster is within specifications.
Caster is within 1/2-degree difference side-to-side.
Caster is not equal, but there is more caster on the right (1/4 degree) than on the left, thereby helping (very slightly) to compensate for road crown.
Toe is within specifications.

Example 2: Four-Wheel Alignment

Specifications

	Left	Right
Front camber =	+1/4° ± 1/2°	0° ± 1/2°
Front caster =	+3° ± 1/2°	+1/2° ± 1/2°
Front toe (total) =	3/16 in. ± 1/16 in.	
Rear camber =	0° ± 1/4°	0° ± 1/4°
Rear toe =	0 in. ± 1/16 in.	

TECH TIP

Ask Yourself These Three Questions

An older technician told a beginning technician that the key to success in doing a proper alignment is to ask yourself three questions about the alignment angles:

Question 1. **"Is it within specifications?"** For example, if the specification reads 1° ±1/2°, any reading between +1/2° and 1 1/2° is within specifications. All vehicles should be aligned within this range. Individual opinions and experience can assist the technician as to whether the actual setting should be at one extreme or the other or held to the center of the specification range.

Question 2. **"Is it within 1/2° of the other side of the vehicle?"** Not only should the alignment be within specifications, but it should also be as equal as possible from one side to the other. The difference between the camber from one side to the other side is called cross camber. Cross caster is the difference between the caster angle from one side to another. Some manufacturers and technicians recommend that this side-to-side difference be limited to just 1/4 degree!

Question 3. **"If the camber and caster cannot be exactly equal side-to-side in the front, is there more camber on the left and more caster on the right to help compensate for road crown?"** Seldom, if ever, are the alignment angles perfectly equal. Sometimes one side of the vehicle is more difficult to adjust than the other side. Regardless of the reasons, if there *has* to be a difference in front camber and/or caster angle, follow this advice to avoid a possible lead or drift problem even if the answers to the first two questions are "yes."

Actual Reading

	Left	Right
Front camber =	−1/2°	−1°
Front caster =	+2 3/4°	+2°
Front toe =	−1/8 in. (toe-out)	
Rear camber =	0°	+1/4°
Rear toe =	1 1/2° (toe-in)	

Answer:

Alignment is incorrect.
a. Left front tire will wear slightly on the inside edge.
b. Right front tire will wear on the inside edge.
c. Vehicle could tend to pull slightly to the left due to the camber difference (may not pull at all due to the pulling effect of the road crown).
d. Vehicle could tend to pull slightly to the right due to the caster difference (3/4 degree more caster on the left).
e. Overall pull could be slight toward the left because it requires four times the caster difference to have the same pulling forces as camber.

FREQUENTLY ASKED QUESTION

How Does Normal Wear Affect the Alignment Angles?

As a vehicle ages, the springs sag and steering and suspension components wear.

- When springs sag the ride height changes and the camber usually is reduced and often becomes negative compared to slightly positive when the vehicle was new in most cases.
- When tie rod ends and other steering components wear, the front wheels tend to toe out.
- Worn suspension components can cause excessive play making the vehicle unstable and cause the tires to wear abnormally.

Alignment alone cannot take the place of worn parts. All an alignment can do is try to compensate for the worn parts.

Toe is the most common angle that needs to be adjusted because any wear in the steering or suspension systems affect the toe.

f. Tires could wear slightly on both the inside edges due to toe-out.
g. The negative camber of the present alignment puts a heavy load on the outer wheel bearing, if RWD, because the load is being carried by the smaller outer wheel bearing instead of the larger inner wheel bearing.

Conclusion:

The vehicle would wear the inside edges of both front tires.
The vehicle may or may not pull slightly to the left.
The vehicle would not act as stable while driving—possible wander.

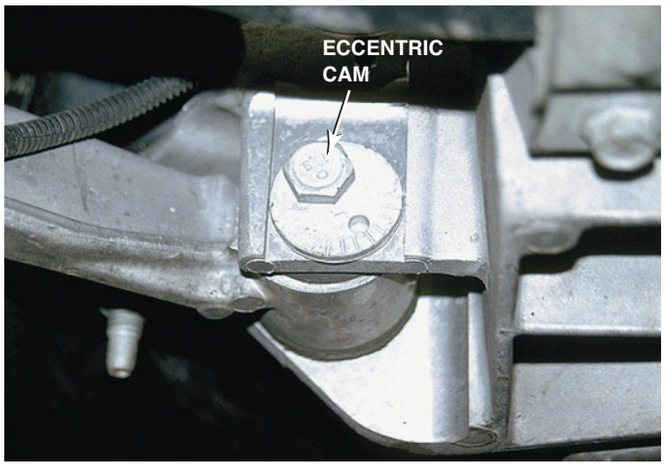


FIGURE 120–18 The rear camber is adjustable on this vehicle by rotating the eccentric cam and watching the alignment machine display.

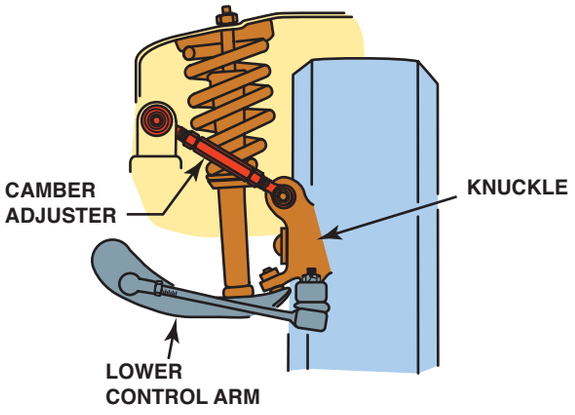


FIGURE 120–19 Some vehicles use a threaded fastener similar to a tie rod to adjust camber on the rear suspension.

ADJUSTING REAR CAMBER

Adjusting rear camber is the first step in the four-wheel alignment process. Rear camber is rarely made adjustable, but can be corrected by using aftermarket alignment kits or shims. If rear camber is not correct, vehicle handling and tire life are affected. Before attempting to adjust or correct rear camber, carefully check the body and/or frame of the vehicle for accident damage, including the following:

1. Weak springs, torsion bars, or overloading (check ride height)
2. Bowed rear axle, trailing arm, or rear control arm
3. Suspension mount or body dimension not in proper location
4. Incorrectly adjusted camber from a previous repair

The cause of the incorrect rear camber could be accident-related and the body or frame may have to be pulled into correct position. ● **SEE FIGURES 120–18 THROUGH 120–20** for examples of various methods used to adjust rear camber.

USING PLASTIC OR METAL ALIGNMENT SHIMS Using plastic or metal alignment shims to correct angles in the rear of the vehicle is relatively simple and includes the following steps:

TECH TIP

The Gritty Solution

Many times it is difficult to loosen a Torx bolt, especially those used to hold the backing plate onto the rear axle on many GM vehicles. ● **SEE FIGURE 120–21.**

A technique that always seems to work is to place some valve grinding compound on the fastener. The gritty compound keeps the Torx socket from slipping up and out of the fastener, and more force can be exerted to break loose a tight bolt. Valve grinding compound can also be used on Phillips head screws as well as other types of bolts, nuts, and sockets.

1. Take alignment readings and determine the change needed.
2. Select proper shims using the easy-to-read chart.
3. Using the template provided, mark and remove tabs to create a proper mounting bolt pattern.
4. Install shim.

ADJUSTING REAR TOE Many vehicle manufacturers provide adjustment for rear toe on vehicles that use an independent rear suspension. Rear toe adjusts the thrust angle. A thrust angle that exceeds 1/2 degree (0.5 degree) on a vehicle with a solid axle is an indication that a component may be damaged or out of place in the rear of the vehicle. Rear toe is often adjusted using an adjustable tie rod end or an eccentric cam on the lower control arm. Check a service manual for the exact method for the vehicle being aligned. Most solid rear axles do not have a method to adjust rear toe except for aftermarket shims or kits. ● **SEE FIGURES 120–22 THROUGH 120–24.**

NOTE: On vehicles equipped with four-wheel steering, refer to the service manual for the exact procedure to follow to lock or hold the rear wheels in position for a proper alignment check.

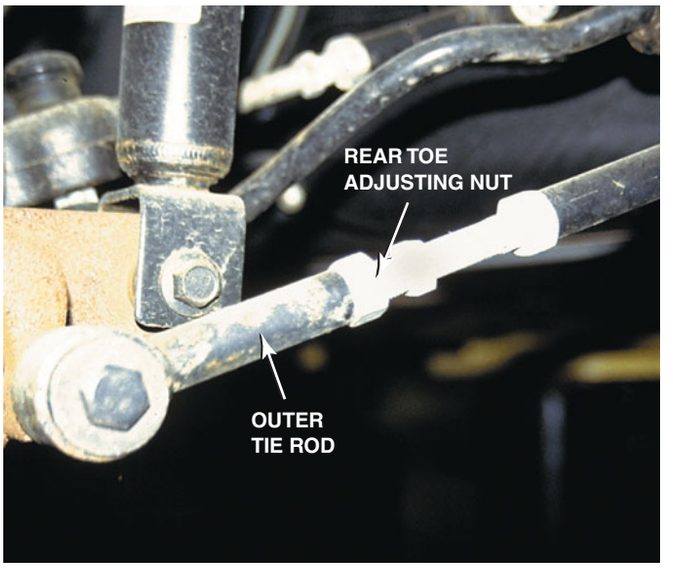


FIGURE 120–22 The rear toe was easily set on this vehicle. The adjusting nuts were easy to get to and turn. Adjusting rear toe is not this easy on every vehicle.

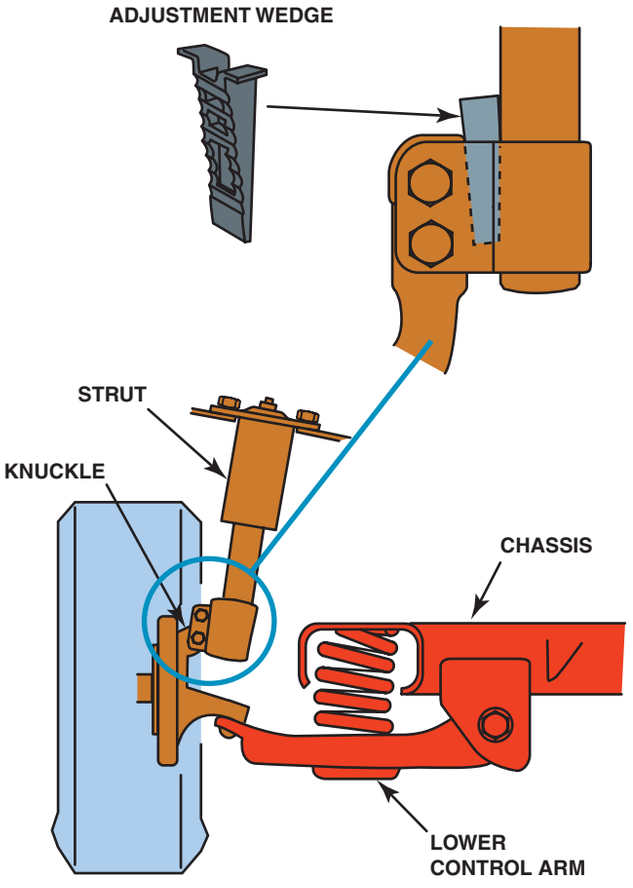


FIGURE 120–20 Aftermarket alignment parts or kits are available to change the rear camber.

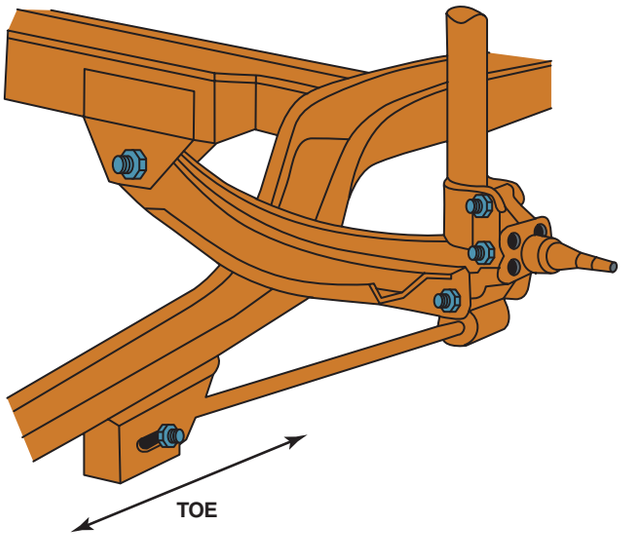


FIGURE 120–23 By moving various rear suspension members, the rear toe can be changed.

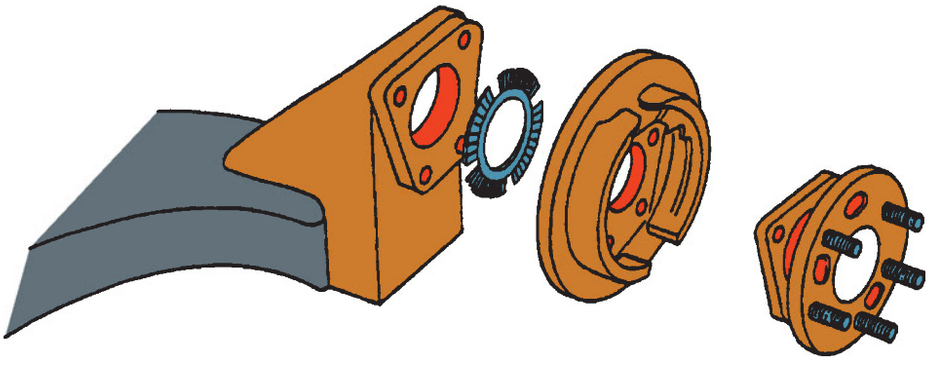


FIGURE 120–21 Full-contact plastic or metal shims can be placed between the axle housing and the brake backing plate to change rear camber, toe, or both. (*Courtesy of Northstar Manufacturing Company, Inc.*)

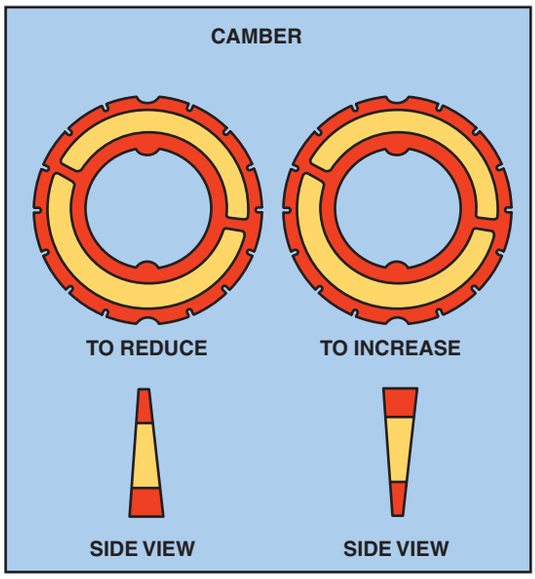


FIGURE 120–24 The use of these plastic or metal shims requires that the rear wheel as well as the hub assembly and/or backing plate be removed. Proper torque during reassembly is critical to avoid damage to the shims.

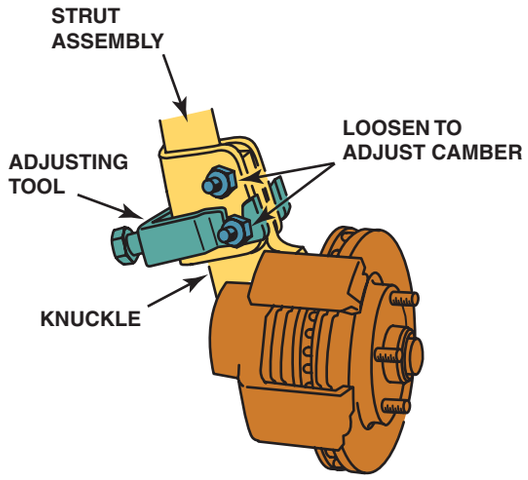


FIGURE 120–25 Many struts allow camber adjustment at the strut-to-knuckle fasteners. Here a special tool is being used to hold and move the strut into alignment with the fasteners loosened. Once the desired camber angle is achieved, the strut nuts are tightened and the tool is removed.

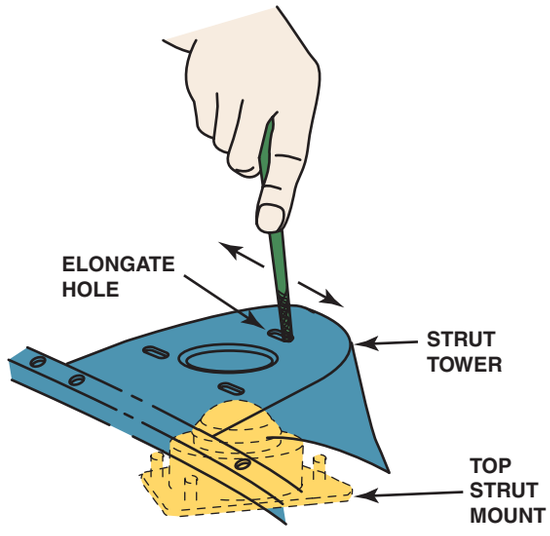


FIGURE 120–26 Some struts require modification of the upper mount for camber adjustment.

GUIDELINES FOR ADJUSTING FRONT CAMBER/SAI AND INCLUDED ANGLE

If the camber is adjusted at the base of the MacPherson strut, camber and included angle are changed and SAI remains the same. ● **SEE FIGURE 120–25.**

If camber is adjusted by moving the upper strut mounting location, included angle remains the same, but SAI and camber change. ● **SEE FIGURE 120–26.**

This is the reason to use the factory alignment methods before using an aftermarket alignment adjustment kit. SAI and included angle should be within 1/2 degree (0.5 degrees) side-to-side. If these angles differ, check the frame mount location before attempting to correct differences in camber. As the frame is changed, camber and SAI change, but the included angle remains the same. Cross camber/caster is the difference between the camber or caster on one side of the vehicle and the camber or caster on the other side of the vehicle.

Alignment Angle	Recommended Maximum Variation
SAI	Within 1/2° (0.5°) side-to-side
Included angle	Within 1/2° (0.5°) side-to-side
Cross camber	Within 1/2° (0.5°) side-to-side
Cross caster	Within 1/2° (0.5°) side-to-side

CAUTION: Do not attempt to correct a pull condition by increasing cross camber or cross caster beyond the amount specified by the vehicle manufacturer.

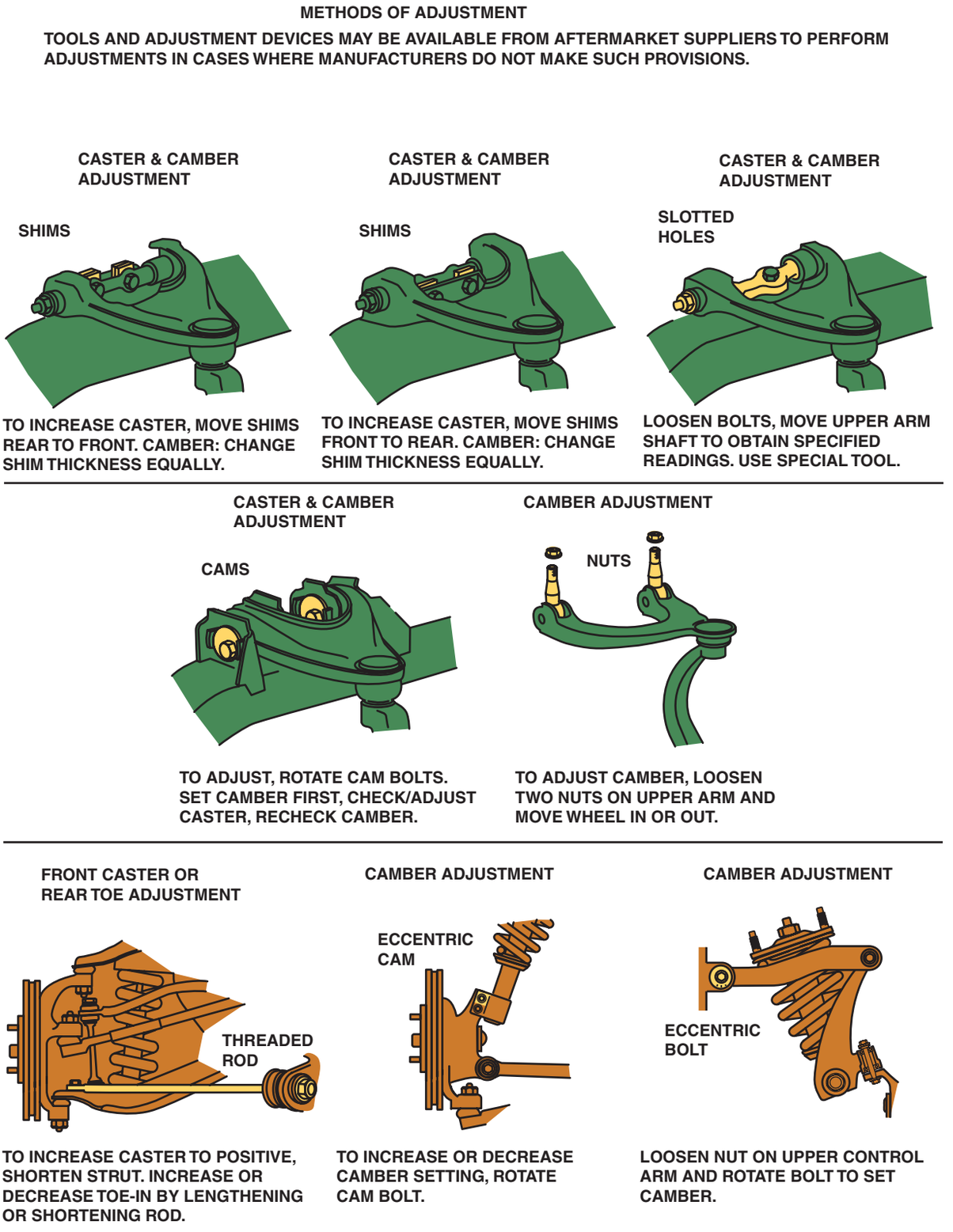


FIGURE 120–27 An example of the many methods that are commonly used to adjust front caster and camber.

FRONT CAMBER/CASTER ADJUSTMENT METHODS

Many vehicles are constructed with only limited camber/caster factory adjustment. ● **SEE FIGURE 120–27** for a summary of which adjustments are *generally* possible for various types of vehicles and suspension systems.

CAUTION: Most vehicle manufacturers warn technicians not to adjust camber by bending the strut assembly. Even though several equipment manufacturers make tools that are designed to bend the strut, most experts agree that it can cause harm to the strut itself.

ADJUSTING FRONT CAMBER/CASTER

Most SLA-type suspensions can be adjusted for caster and camber. Most manufacturers recommend adjusting caster, then camber, before adjusting the toe. As the caster is changed, such as when the strut rod is adjusted as shown in ● **FIGURE 120–28,** the camber and toe also change.

If the camber is then adjusted, the caster is unaffected. Many technicians adjust caster and camber at the same time using shims (● **FIGURES 120–29 AND 120–30**), slots (● **FIGURE 120–31**), or **eccentric cams** (● **FIGURE 120–32**).

Always follow the manufacturer's recommended alignment procedure. For example, many manufacturers include a **shim chart** in their service manual that gives the thickness and location of the shim changes based on the alignment reading. Shim charts are used to set camber and caster at the same time. Shim charts are designed for each model of vehicle. ● **SEE FIGURE 120–33.**

Regardless of the methods or procedures used, toe is always adjusted after all the angles are set because caster and camber both affect the toe.

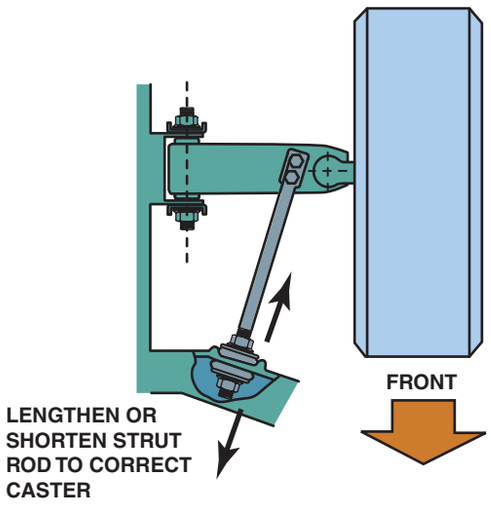


FIGURE 120–28 If there is a nut on both sides of the strut rod bushing, then the length of the rod can be adjusted to change caster.

SETTING TOE

Front toe is the last angle that should be adjusted and is the most likely to need correction. This has led to many sayings in the alignment field:

"Set the toe and let it go."

"Do a toe and go."

"Set the toe and collect the dough."

As wear occurs at each steering joint such as tie rod ends, the forces exerted on the linkage by the tire tend to cause a toe-out condition.

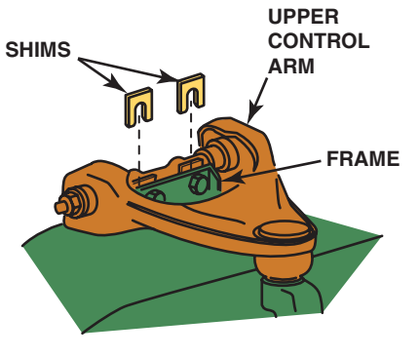


FIGURE 120–30 The general rule of thumb is that a 1/8-in. shim added or removed from both shim locations changes the camber angle about 1/2 degree. Adding or removing a 1/8-in. shim from one shim location changes the caster by about 1/4 degree.

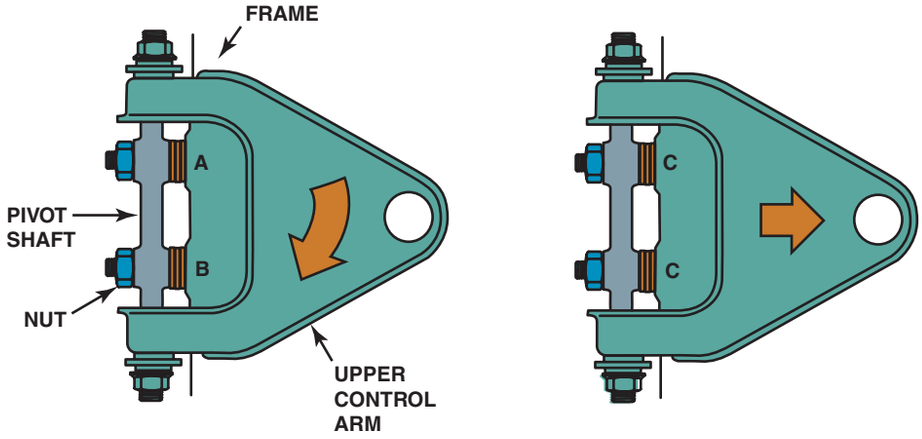


FIGURE 120–29 Placing shims between the frame and the upper control arm pivot shaft is a popular method of alignment for many SLA suspensions. Both camber and caster can be easily changed by adding or removing shims.

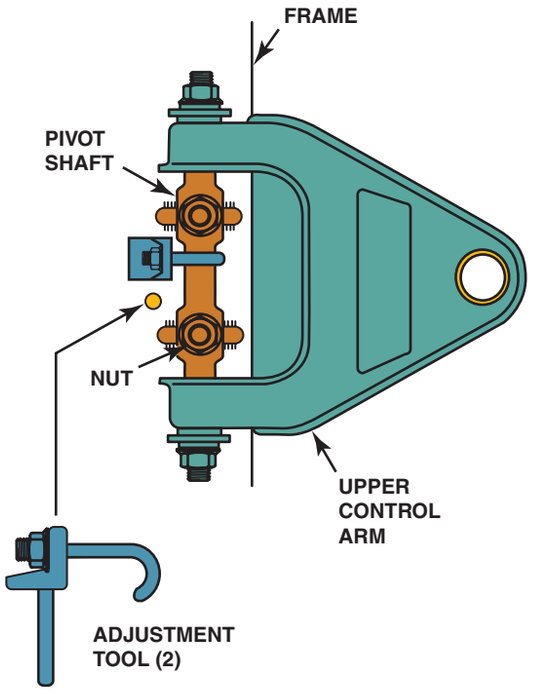


FIGURE 120–31 Some SLA-type suspensions use slotted holes for alignment angle adjustments. When the pivot shaft bolts are loosened, the pivot shaft is free to move unless held by special clamps as shown. By turning the threaded portion of the clamps, the camber and caster can be set and checked before tightening the pivot shaft bolts.

Front-wheel-drive (FWD) vehicles transmit engine power through the front wheels. Many manufacturers of FWD vehicles specify a toe-out setting. This toe-out setting helps compensate for the slight toe-in effect of the engine torque being transferred through the front wheels.

Most newer alignment equipment displays in degrees of toe instead of inches of toe. (See the toe unit conversion chart.) Just remember that positive (+) toe means toe-in and negative (−) toe means toe-out.

Toe Unit Conversions

Units	Conversions			
Fractional inches	1/16 in.	1/8 in.	3/16 in.	1/4 in.
Decimal inches	0.062 in.	0.125 in.	0.188 in.	0.250 in.
Millimeters	1.60 mm	3.18 mm	4.76 mm	6.35 mm
Decimal degrees	0.125°	0.25°	0.375°	0.5°
Degrees and minutes	0°8′	0°15′	0°23′	0°30′
Fractional degrees	1/8°	1/4°	3/8°	1/2°

To make sure the steering wheel is straight after setting toe, the steering wheel *must* be locked in the straight-ahead position while the toe is being adjusted. Another term used to describe steering wheel position is **spoke angle.** To lock the steering wheel, always use a steering wheel lock that presses against the seat and the outer rim of the steering wheel. *Do not* use the locking feature of the steering column to hold the steering wheel straight. Always unlock the steering column, straighten the steering wheel, and install the steering wheel lock. ● **SEE FIGURES 120–34 THROUGH 120–36.**

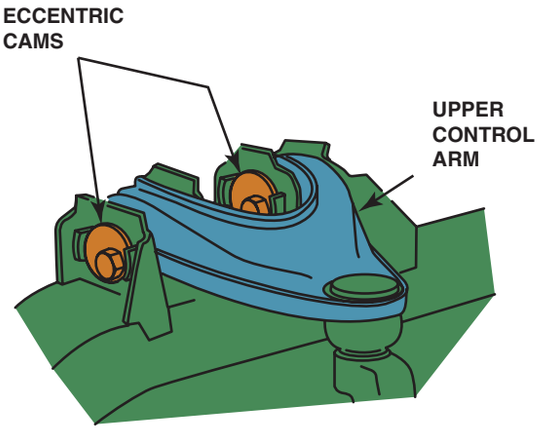


FIGURE 120–32 When the nut is loosened and the bolt on the eccentric cam is rotated, the upper control arm moves in and out. By adjusting both eccentric cams, both camber and caster can be adjusted.

TECH TIP

Race Vehicle Alignment

Vehicles used in autocrossing (individual timed runs through cones in a parking lot) or road racing usually perform best if the following alignment steps are followed:

1. **Increase caster (+).** Not only will the caster provide a good solid feel for the driver during high speed on a straight section of the course, but it will also provide some lean into the corners due to the camber change during cornering. A setting of 5 to 9 degrees positive caster is typical depending on the type of vehicle and the type of course.
2. **Adjust for 1 to 2 degrees of negative camber.** As a race vehicle corners, the body and chassis lean. As the chassis leans, the top of the tire also leans outward. By setting the camber to 1 to 2 degrees negative, the tires will be neutral while cornering, thereby having as much rubber contacting the road as possible.

   NOTE: Though setting negative camber on a street-driven vehicle will decrease tire life, the negative setting on a race vehicle is used to increase cornering speeds, and tire life is not a primary consideration.

3. **Set toe to a slight toe-out position.** When the front toe is set negative (toe-out), the vehicle is more responsive to steering commands from the driver. With a slight toe-out setting, one wheel is already pointed in the direction of a corner or curve. Set the toe-out to −3/8 to −1/2 degree depending on the type of vehicle and the type of race course.

NOTE: The engine must be started and the steering wheel straightened with the engine running to be assured of a straight steering wheel. Lock the steering wheel with the steering lock tool before stopping the engine.

After straightening the steering wheel, turn the tie rod adjustment until the toe for both wheels is within specifications. ● **SEE FIGURE 120–37.**

DEGREES CASTER

DEGREES CAMBER	BOLT	+4.9°	+4.7°	+4.5°	+4.3°	+4.1°	+3.9°	+3.7°	+3.5K	+3.3°	+3.1°	+2.9°	+2.7°	+2.5°	+2.3K	+2.1°
+2.2°	FRONT	+300	+211	+211	+210	+210	+201	+201	+201	+200	+200	+111	+111	+110	+110	+110
	REAR	+101	+101	+110	+110	+111	+200	+200	+201	+210	+210	+201	+211	+300	+301	+301
+2.0°	FRONT	+210	+210	+210	+201	+201	+200	+200	+111	+111	+110	+110	+110	+101	+101	+100
	REAR	+011	+100	+101	+101	+110	+110	+111	+200	+200	+201	+210	+210	+211	+300	+300
+1.8°	FRONT	+201	+201	+200	+200	+111	+111	+110	+110	+110	+101	+101	+100	+100	+100	+011
	REAR	+010	+011	+011	+100	+101	+101	+110	+110	+111	+200	+200	+201	+210	+210	+211
+1.6°	FRONT	+200	+200	+111	+111	+110	+110	+101	+101	+100	+100	+100	+011	+011	+010	+010
	REAR	+001	+001	+010	+011	+011	+100	+100	+101	+110	+110	+111	+200	+200	+201	+210
+1.4°	FRONT	+111	+110	+110	+101	+101	+100	+100	+100	+011	+011	+010	+010	+010	+001	+001
	REAR	+000	+000	+001	+001	+010	+011	+011	+100	+100	+101	+110	+110	+111	+200	+200
+1.2°	FRONT	+110	+101	+101	+100	+100	+011	+011	+010	+010	+010	+001	+001	+000	-000	-000
	REAR	-010	-001	+000	+000	+001	+001	+010	+011	+011	+100	+101	+101	+110	+111	+111
+1.0°	FRONT	+100	+109	+011	+011	+010	+010	+010	+001	+001	+000	-000	-000	-001	-001	-010
	REAR	-011	-010	-010	-001	-000	+000	+001	+001	+010	+011	+011	+100	+101	+101	+110
+0.8°	FRONT	+011	+011	+010	+010	+001	+001	+000	-000	-000	-001	-001	-010	-010	-010	-011
	REAR	-100	-100	-011	-010	-010	-001	-001	+000	+001	+001	+010	+011	+011	+100	+101
+0.6°	FRONT	+010	+001	+001	+001	+000	-000	-001	-001	-010	-010	-010	-011	-011	-100	-100
	REAR	-101	-101	-100	-100	-011	-010	-010	-001	-001	+000	+001	+001	+010	+011	+011
+0.4°	FRONT	+001	+000	+000	-001	-001	-010	-010	-010	-011	-011	-100	-100	-100	-101	-101
	REAR	-111	-110	-101	-101	-100	-100	-011	-010	-010	-001	-000	+000	+001	+010	+010
+0.2°	FRONT	-001	-001	-001	-010	-010	-011	-011	-100	-100	-101	-101	-101	-110	-110	-110
	REAR	-200	-111	-111	-110	-101	-101	-100	-100	-011	-010	-010	-001	-000	+000	+001
+0.0°	FRONT	-010	-010	-011	-011	-100	-100	-100	-101	-101	-110	-110	-111	-111	-111	-200
	REAR	-201	-201	-200	-111	-111	-110	-101	-101	-100	-100	-011	-010	-010	-001	-000
-0.2°	FRONT	-011	-011	-100	-100	-101	-101	-110	-110	-111	-111	-111	-200	-200	-201	-201
	REAR	-210	-210	-201	-201	-200	-111	-111	-110	-101	-101	-100	-100	-011	-010	-010
-0.4°	FRONT	-100	-101	-101	-110	-110	-110	-111	-111	-200	-200	-201	-201	-201	-210	-210
	REAR	-300	-211	-210	-210	-201	-201	-200	-111	-111	-110	-101	-101	-100	-011	-011

1. DETERMINE VEHICLE'S CURRENT CASTER AND CAMBER MEASUREMENTS.
2. USING THE CURRENT CASTER READING, READ DOWN THE APPROPRIATE COLUMN TO THE LINES CORRESPONDING TO THE CURRENT CAMBER READING.
3. CORRECTION VALUES WILL BE GIVEN FOR THE FRONT AND REAR BOLTS.
   EXAMPLE: CURRENT READING +1.6° CASTER +0.4° CAMBER. BY READING DOWN THE CHART FROM +1.6° CASTER TO +0.4° CAMBER YOU WILL FIND THAT THE FRONT BOLT REQUIRES AN ADJUSTMENT OF -101 AND THE REAR BOLT REQUIRES AN ADJUSTMENT OF +010.

FIGURE 120–33 Typical shim alignment chart. As noted, 1/8-in. (0.125) shims can be substituted for the 0.120-in. shims; 1/32-in. (0.0625) shims can be substituted for the 0.060-in. shims; and 1/32-in. (0.03125) shims can be substituted for the 0.030-in. shims.

Test drive the vehicle for proper handling and centerline steering. *Centerline steering* is a centered steering wheel with the vehicle traveling a straight course.

CENTERING THE STEERING WHEEL

Centerline steering *should* be accomplished by adjusting the tie rod length on both sides of the vehicle while the toe is set.

CAUTION: Do not attempt to straighten the steering wheel by relocating the wheel on the steering column on a vehicle with two tie rod end adjusters. The steering wheel is positioned at the factory in the center of the steering gear, regardless of type. If the steering wheel is not in the center, then the variable ratio section of the gear will not be in the center as it is designed. Another possible problem with moving the steering wheel from its designed straight-ahead position is that the turning radius may be different for right- and left-hand turns.

STEERING WHEEL REMOVAL

If the steering wheel *must* be removed, first disconnect the airbag wire connector at the base of the steering column. This reduces the chance of personal injury and prevents accidental airbag deployment.



FIGURE 120–34 Many procedures for setting toe specify that the steering wheel be held in the straight-ahead position using a steering wheel lock, as shown. One method recommended by Hunter Engineering sets toe without using a steering wheel lock.

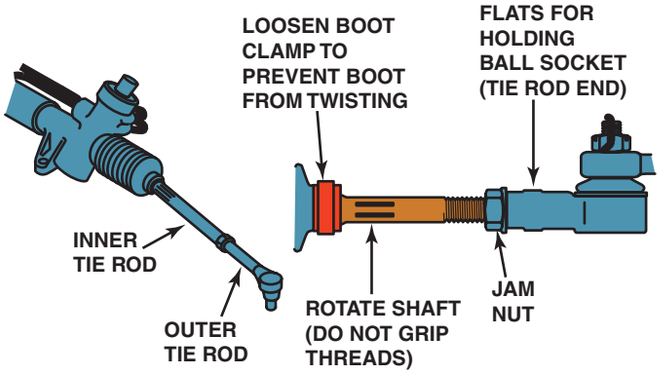


FIGURE 120–35 Adjusting toe by rotating the tie rod on a vehicle equipped with rack-and-pinion steering.

CAUTION: Always follow the manufacturer's recommended procedures whenever working on or around the steering column.

Remove the center section of the steering column by removing the retaining screws, including the inflator module on vehicles equipped with an airbag.

After removal of the airbag inflator module, remove the steering wheel retaining nut. Note the locating marks on the steering wheel and steering shaft. ● **SEE FIGURE 120–38** on page 1446. These marks indicate the proper position of the steering wheel for centerline steering. This means that the steering wheel spoke angle is straight and in line with the centerline position of the steering gear or rack-and-pinion steering unit.

Most steering wheels are attached to the steering shaft with a spline and a taper. After removing the steering wheel nut, use a

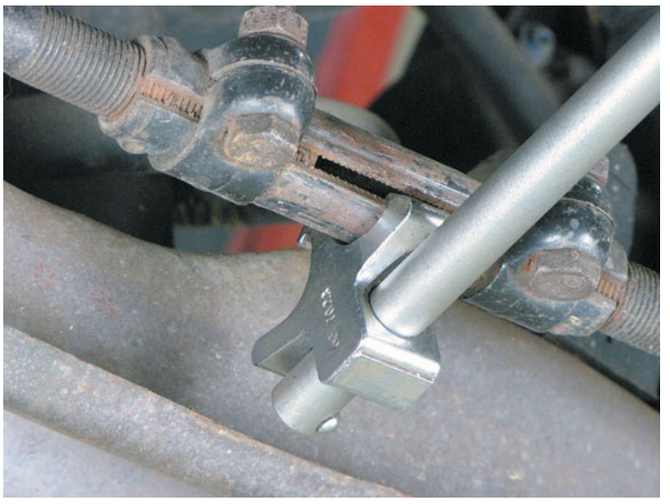


FIGURE 120–37 Special tie rod adjusting tools should be used to rotate the tie rod adjusting sleeves. The tool grips the slot in the sleeve and allows the service technician to rotate the sleeve without squeezing or damaging the sleeve.

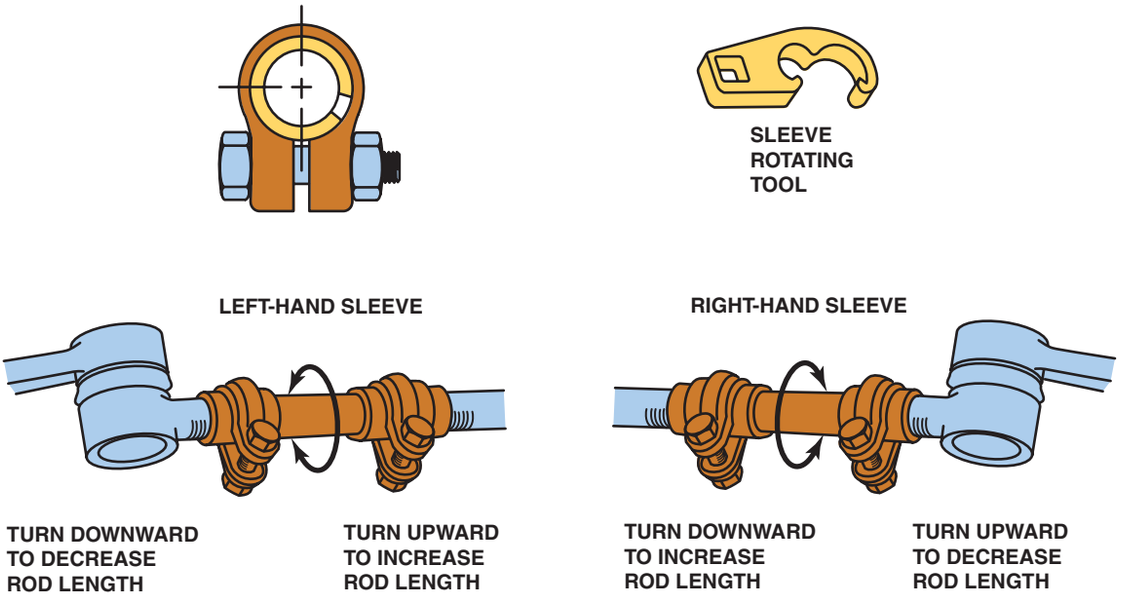


FIGURE 120–36 Toe is adjusted on a parallelogram-type steering linkage by turning adjustable tie rod sleeves. Special tie rod sleeve adjusting tools should be used that grip the slot in the sleeve and will not crush the sleeve while it is being rotated.

TECH TIP

Locking Pliers to the Rescue

Many vehicles use a jam nut on the tie rod end. This jam nut must be loosened to adjust the toe. Because the end of the tie rod is attached to a tie rod end that is movable, loosening the nut is often difficult. Every time force is applied to the nut, the tie rod end socket moves and prevents the full force of the wrench from being applied to the nut. To prevent this movement, simply attach locking pliers (Vise Grips®) to hold the tie rod. Wedge the pliers against the control arm to prevent any movement of the tie rod. By preventing the tie rod from moving, full force can be put on a wrench to loosen the jam nut without doing any harm to the tie rod end.

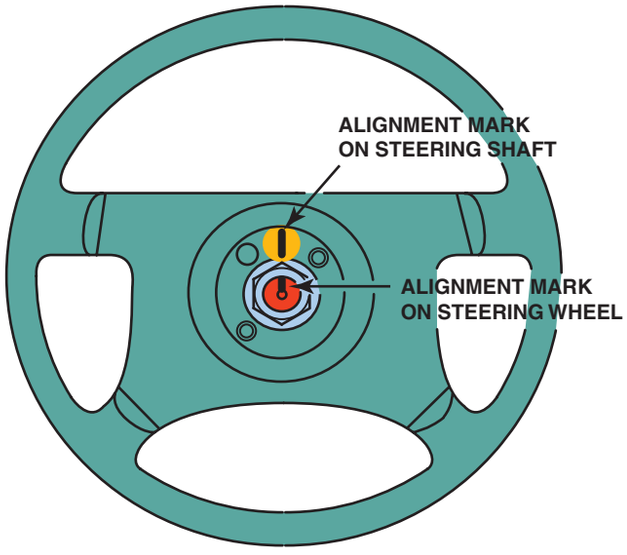


FIGURE 120–38 Most vehicles have alignment marks made at the factory on the steering shaft and steering wheel to help the service technician keep the steering wheel in the center position.

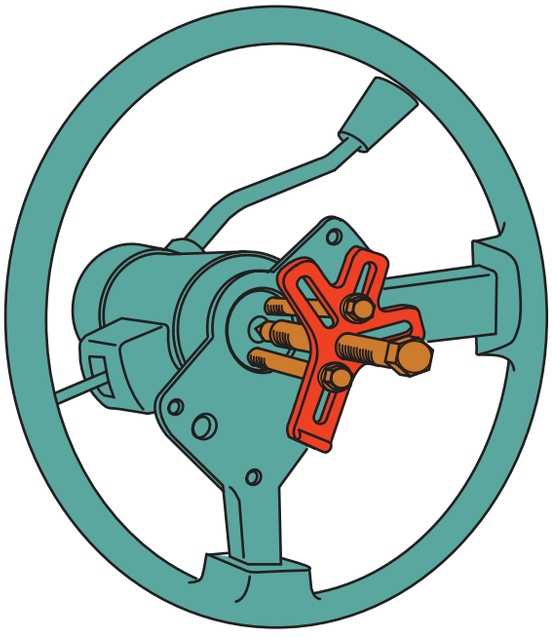


FIGURE 120–39 A puller being used to remove a steering wheel after the steering wheel retaining nut has been removed.

steering wheel puller to remove the steering wheel from the steering shaft. ● **SEE FIGURE 120–39.**

To reinstall the steering wheel, align the steering wheel in the desired straight-ahead position and slip it down over the splines. Install and tighten the retaining nut to specifications.

REAL WORLD FIX

Left Thrust Line, but a Pull to the Right!

A new four-door sport sedan had been aligned several times at the dealership in an attempt to solve a pull to the right. The car had front-wheel-drive and four-wheel independent suspension. The dealer rotated the tires, and it made no difference. The alignment angles of all four wheels were in the center of specifications. The dealer even switched all four tires from another car in an attempt to solve the problem.

In frustration, the owner took the car to an alignment shop. Almost immediately the alignment technician discovered that the right rear wheel was slightly toed-in. This caused a pull to the right. ● **SEE FIGURE 120–40.**

The alignment technician adjusted the toe on the right rear wheel and reset the front toe. The car drove beautifully.

The owner was puzzled about why the new car dealer was unable to correct the problem. It was later discovered that the alignment machine at the dealership was out of calibration by the exact amount that the right rear wheel was out of specification. The car pulled to the right because the independent suspension created a rear steering force toward the left that caused the front to pull to the right. Alignment equipment manufacturers recommend that alignment equipment be calibrated regularly.

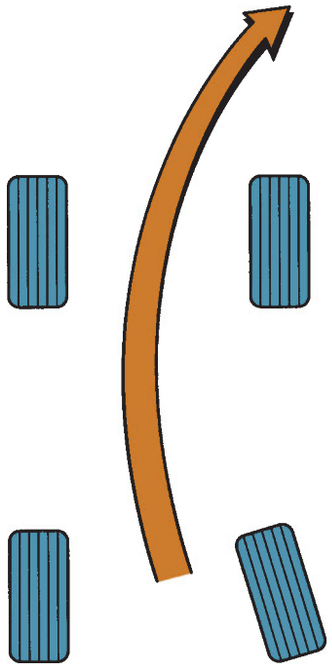


FIGURE 120–40 The toe-in on the right wheel creates a turning force toward the right.

TOLERANCE ADJUSTMENT PROCEDURE

Many vehicles are designed and built without a method to change caster or camber, or both. (All vehicles have an adjustment for toe.) Before trying an aftermarket alignment correction kit, many technicians first attempt to correct the problem by moving the suspension attachment points within the build tolerance. All vehicles are constructed with a slight amount of leeway or tolerance; slight corrections can be made because bolt holes are almost always slightly larger than the bolt diameter, allowing for slight movement. When several fasteners are involved, such as where the powertrain cradle (subframe) attaches to the body of the front-wheel-drive vehicle, a measurable amount of alignment change (often over 1/2 degree) can be accomplished without special tools or alignment kits. The steps for **tolerance adjustment** include the following:

STEP 1 Determine which way the suspension members have to be moved to accomplish the desired alignment—for example, the right front may require more positive camber to correct a pulling or tire wear problem.

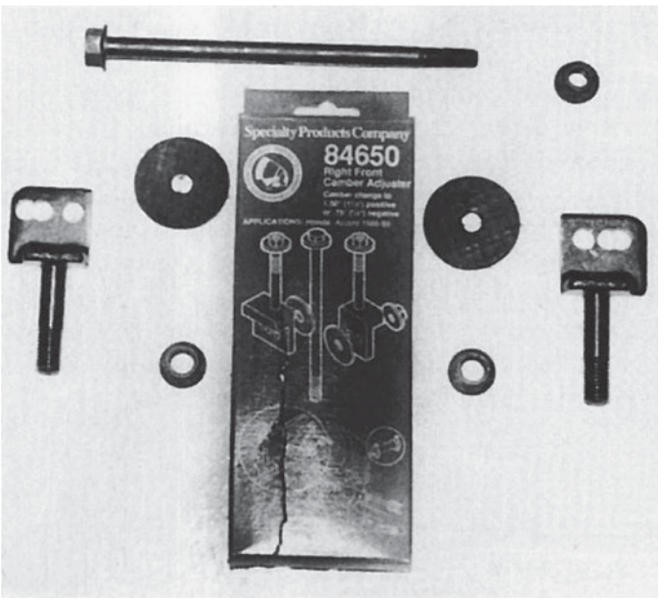
STEP 2 Locate and loosen the cradle (subframe) bolts about four turns each. DO NOT REMOVE ANY OF THE BOLTS.

STEP 3 Using prybars, move the cradle in the direction that will result in an improvement of the alignment angles. Have an assistant tighten the bolts as pressure is maintained on the cradle.

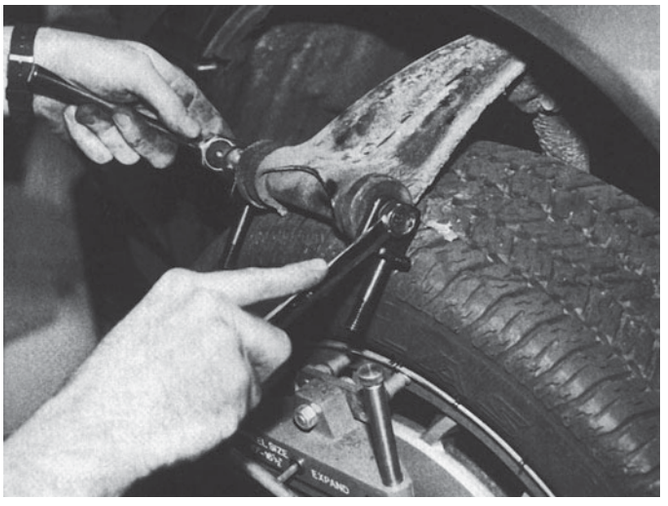
STEP 4 Measure the alignment angles and repeat the procedure if necessary.

AFTERMARKET ALIGNMENT METHODS

Accurate alignments are still possible on vehicles without factory methods of adjustment by using alignment kits or parts. Aftermarket alignment kits are available for most vehicles. Even when there are factory alignment methods, sometimes the range of adjustment is not enough to compensate for sagging frame members or other normal or accident-related faults. ● **SEE FIGURES 120–41 AND 120–42.**



(a)



(b)

FIGURE 120–41 (a) Aftermarket camber kit designed to provide some camber adjustments for a vehicle that does not provide any adjustment. (b) Installation of this kit requires that the upper control arm shaft be removed. Note that the upper control arm was simply rotated out over the wheel pivoting on the upper ball joint.

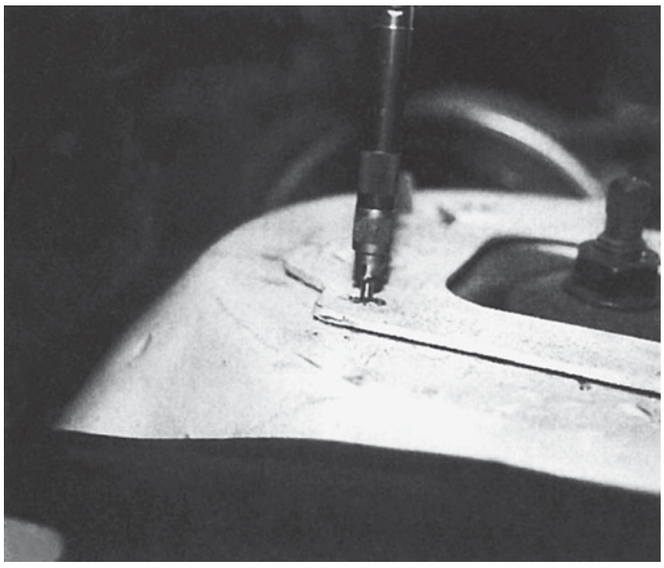
ALIGNING ELECTRONIC-SUSPENSION VEHICLES

When aligning a vehicle equipped with an electronic suspension, several additional steps may be required. Always check service information and read carefully all on-screen instructions on the alignment machine. Some examples of the steps that may be needed include:

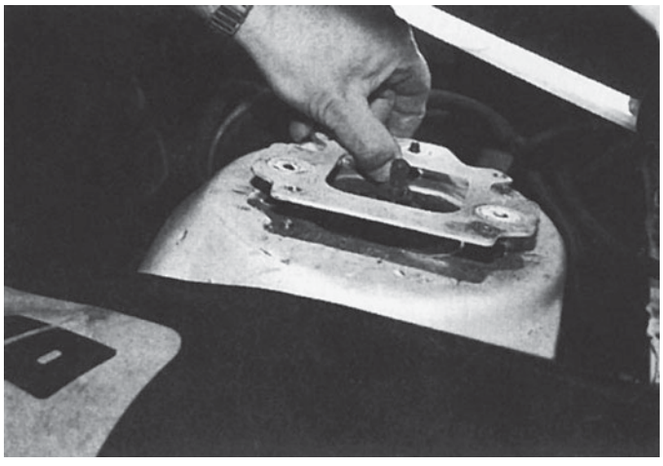
- Verify the exact type of electronic suspension. This step could include checking the regular production order (RPO) code.
- Check that the ride height (suspension height) is within factory specifications.
- The steering wheel angle, as well as the radar cruise control sensor, will often need to be recalibrated using a scan tool. This is needed because the steering wheel may be in a different position after the alignment, and the steering wheel position sensor needs to be reset because the rear toe setting was changed. The rear thrust line could also have been changed. The radar cruise control needs to be calibrated to the revised rear thrust angle using a scan tool.

ALIGNING MODIFIED VEHICLES

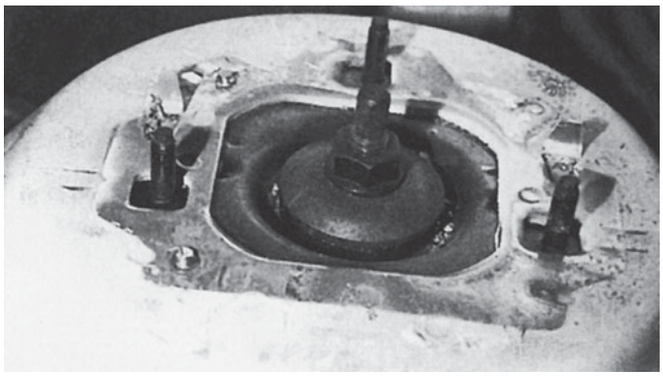
If different springs were installed which in turn changes the suspension height, or if larger or smaller wheels and tires were installed, many alignment shops would reject doing an alignment. If a shop



(a)



(b)



(c)

FIGURE 120–42 (a) The installation of some aftermarket alignment kits requires the use of special tools such as this cutter being used to drill out spot welds on the original alignment plate on a strut tower. (b) Original plate being removed. (c) Note the amount of movement the upper strut bearing mount has around the square openings in the strut tower. An aftermarket plate can now be installed to allow both camber and caster adjustment.

attempted to align a vehicle, handling and tire wear problems were common. Because the ride height is changed from stock factory setting, the following can occur:

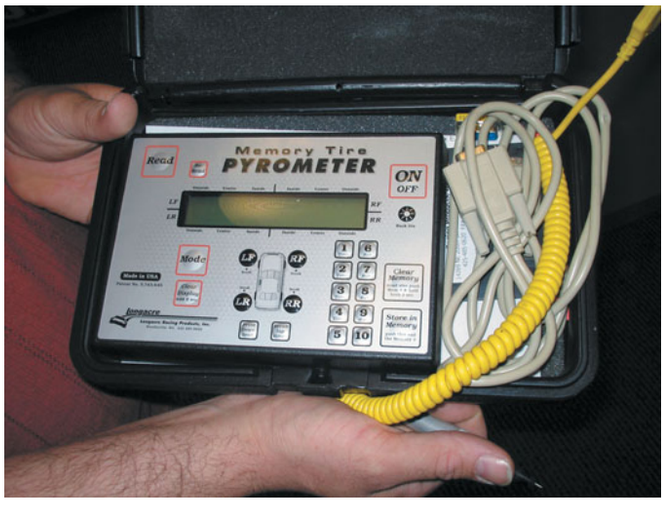


FIGURE 120–43 A typical tire temperature pyrometer. The probe used is a needle that penetrates about 1/4 inch (7 mm) into the tread of the tire for most accurate readings.

1. The steering axis inclination (SAI) is now incorrect.
2. Because the steering linkage and the control arms are no longer parallel, bump steer can occur. Bump steer causes the vehicle to dart to one side when a wheel hits a bump.
3. Because the ride height changed, camber and toe also changed. The camber change is often enough to prevent it from being able to be adjusted to within specifications.

Alignment alone will not correct these concerns. To allow for proper handling, the following aftermarket kits and parts are available:

- **Camber kits**—These kits usually include a replacement control arm or offset cam, which provides additional camber adjustment.
- **Bump steer kits**—A bump steer kit can include a modified steering arm or rack-and-pinion steering gear repositioning components.

The kits available can be found listed on the alignment screen of many newer alignment machines, such as the Hunter Engineering Company's WinAlign Tuner Custom Alignment for Modified Vehicles. During part of this alignment, the technician has to select one of two options:

- Maximum tire wear
- Maximum handling

Therefore, the technician has to determine from the customer which of these two parameters are most important. After the alignment, the instructions often state that the vehicle should be driven and then the temperature of the tires measured and recorded. Using a tire pyrometer, be sure to measure the temperature of each tire at the following locations for each tire:

- Approximately 1.5 inches (38 mm) from the outside edge of the tire in the tread rubber
- In the middle of the tread
- Approximately 1.5 inches (38 mm) from the inside edge of the tire in the tread rubber

The temperatures are then typed into the alignment machine, and the program calculates the final alignment settings. ● **SEE FIGURE 120–43.**

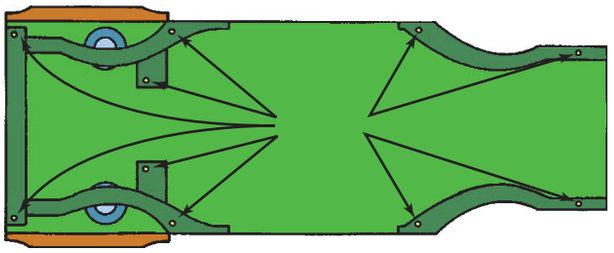


FIGURE 120–44 Jig holes used at the assembly plant to locate suspension and drivetrain components. Check service information for the exact place to measure and the specified dimensions when checking for body or frame damage.

TECH TIP

TSBs Can Save Time

Technical service bulletins (TSBs) are issued by vehicle and aftermarket manufacturers to inform technicians of a situation or technical problem and give the corrective steps and a list of parts needed to solve the problem.

TSBs are often released by new vehicle manufacturers to the dealership service department. They usually concern the current-year vehicle of a particular model. While many of these TSBs concern minor problems covering few vehicles, many contain very helpful solutions to hard-to-find problems.

Most TSBs can be purchased directly from the manufacturer, but the cost is usually very high. TSBs can also be purchased through aftermarket companies that are licensed and available on a web site. Go to the National Automotive Service Task Force (NASTF) web site (www.NASTF.org) for a list of the web addresses for all vehicle manufacturer's sites where TSBs can be purchased directly. Factory TSBs can often save the technician many hours of troubleshooting.

HIDDEN STRUCTURAL DAMAGE DIAGNOSIS

Many accidents result in hidden structural damage that can cause alignment angles to be out of specification. If alignment angles are out of specification tolerances, then accident damage should be suspected. Look for evidence of newly replaced suspension parts, body work, or repainted areas of the body. While a body and/or frame of a vehicle can be straightened, it must be done by a knowledgeable person using body-measuring equipment.

The first thing that must be done is to determine a *datum plane. Datum* means a basis on which other measurements can be based. The datum plane is the horizontal plane.

However, most alignment technicians do not have access to body/frame alignment equipment. The service technician can use a common steel rule to measure several points of the vehicle to determine if the vehicle is or is not damaged or needs to be sent to a frame shop for repair.

FRAME/BODY DIAGONALS If the frame or body is perfectly square, then the diagonal measurements should be within 1/8 in. (3 mm) of each other. ● **SEE FIGURE 120–44.**

While there are specified measurement points indicated by the manufacturer, the diagonal measurements can be made from almost any point that is repeated exactly on the other side, such as the center of a bolt in the suspension mounting bracket.

ALIGNMENT GUIDE

The following chart lists common alignment problems and their probable causes.

Symptom-Based Alignment Guide

Problems	Probable Causes
Pull left/right	Uneven tire pressure, tire conicity, mismatched tires, unequal camber, unequal caster, brake drag, setback, suspension/frame sag, unbalanced power assist, bent spindle, bent strut, worn suspension components (front or rear), rear suspension misalignment.
Incorrect steering wheel position	Incorrect individual or total toe, rear wheel misalignment, excessive suspension or steering component play, worn rack-and-pinion attachment bushings, individual toe adjusters not provided.
Hard steering	Improper tire pressure, binding steering gear or steering linkage, low P/S fluid, excessive positive caster, lack of lubrication, upper strut mount(s), worn power steering pump, worn P/S belt.
Loose steering	Loose wheel bearings, worn steering or suspension components, loose steering gear mount, excessive steering gear play, loose or worn steering coupler.
Excessive road shock	Excessive positive caster, excessive negative camber, improper tire inflation, too wide wheel/tire combination for the vehicle, worn or loose shocks, worn springs.
Poor returnability	Incorrect camber or caster, bent spindle or strut, binding suspension or steering components, improper tire inflation.
Wander/ instability	Incorrect alignment, defective or improperly inflated tires, worn steering or suspension parts, bent spindle or strut, worn or loose steering gear, loose wheel bearings.
Squeal/scuff on turns	Defective or improperly inflated tires, incorrect turning angle (TOOT), bent steering arms, excessive wheel setback, poor driving habits (too fast for conditions), worn suspension or steering parts.
Excessive body sway	Loose or broken stabilizer bar links or bushings, worn shocks or mountings, broken or sagging springs, uneven vehicle load, uneven or improper tire pressure.
Memory steer	Binding steering linkage, binding steering gear, binding upper strut mount, ball joint, or kingpin.
Bump steer	Misalignment of steering linkage, bent steering arm or frame, defective or sagged springs, uneven load, bent spindle or strut.
Torque steer	Bent spindle or strut, bent steering arm, misaligned frame, worn torque strut, defective engine or transaxle mounts, drive axle misalignment, mismatched or unequally inflated tires.



1 Begin the alignment procedure by first driving the vehicle onto the alignment rack as straight as possible.



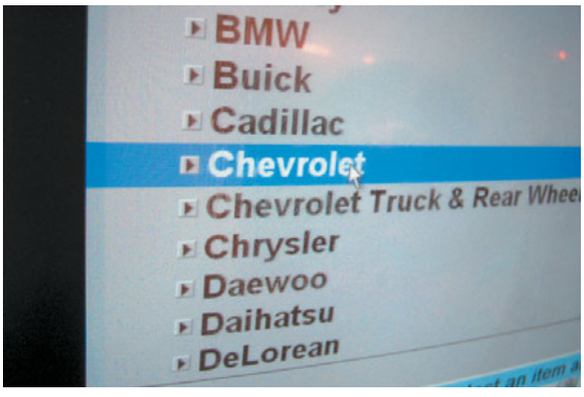
2 Position the front tires in the center of the turn plates. These turn plates can be moved inward and outward to match a vehicle of any width.



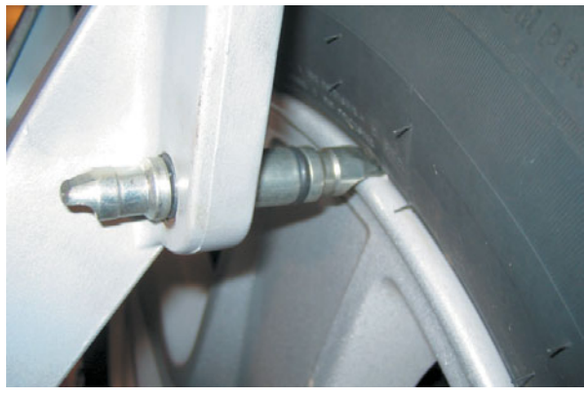
3 Raise the vehicle and position the alignment rack following the rack manufacturer's instructions.



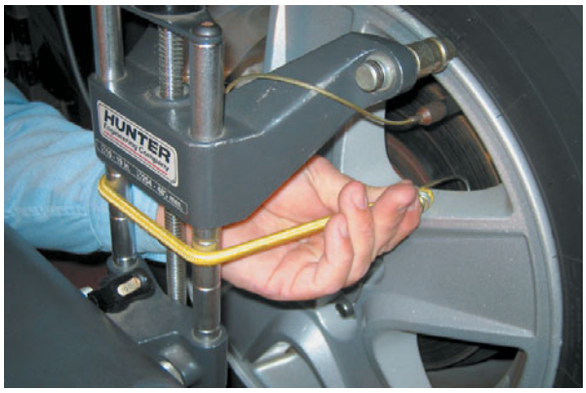
4 Check and adjust tire pressures and perform the prealignment checks necessary to be assured of proper alignment.



5 Select the exact vehicle on the alignment machine.



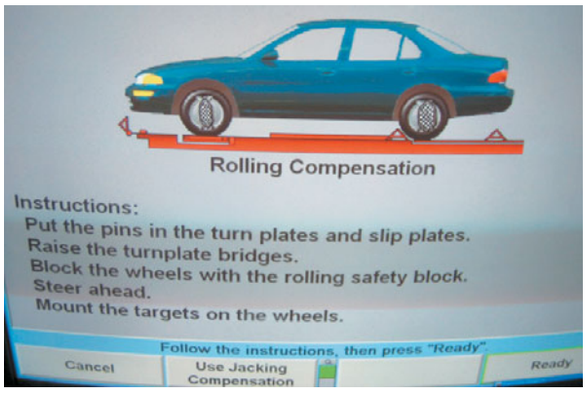
6 Securely mount the alignment heads or target wheels.



7 If mounting a transmitter-type alignment head, be sure to attach the retaining wire to the tire valve.



8 After installation of the heads, follow the specified procedure for compensation, which allows accurate alignment readings.



9 Rolling compensation is used on machines that use lasers and wheel targets.



10 An alignment reading is displayed even though caster has not yet been measured. The readings marked in red indicate that they are not within specifications.

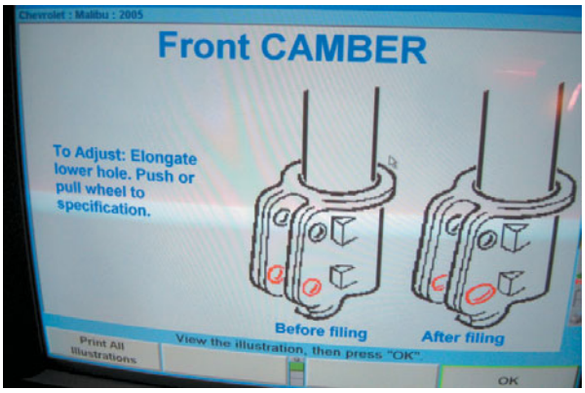


11 Before performing a caster sweep, install a brake pedal depressor to keep the front wheels from rotating when the steering wheel is turned.



12 Perform the caster sweep by turning the front wheels inward, and then outward following the instructions on the screen.

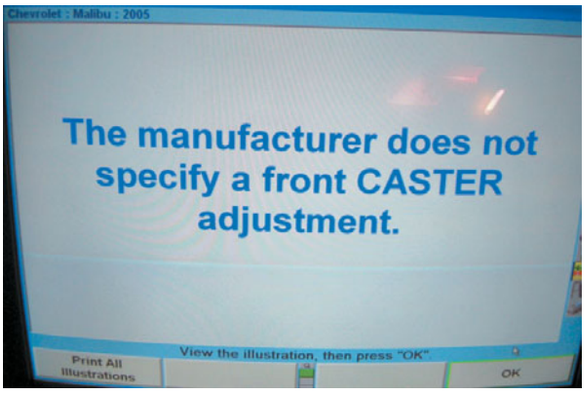
CONTINUED ▶



13 Most alignment machines will display where to make the alignment correction and will often include drawings and live-action videos that show the procedure.



14 The rear toe is being adjusted by rotating the eccentric cam on the lower control arm while watching the display.



15 The alignment machine display indicates that front caster is not a factory-adjustable angle.



16 Adjusting the front toe on this vehicle involves loosening the jam nut (left wrench) and rotating the tie rod using the right wrench.



17 One last adjustment of the left front toe is needed to achieve a perfect alignment. The final alignment reading can be printed and attached to the work order.



18 After disconnecting all of the attachments, reinstalling the valve caps, and removing the steering wheel holder, the vehicle should be test driven to check for proper alignment before returning it to the customer.

REVIEW QUESTIONS

1. List 10 prealignment checks that should be performed before the wheel alignment is checked and/or adjusted.
2. Describe the difference between a lead (drift) and a pull.
3. Explain the causes and possible corrections for torque steer.
4. Explain the causes and possible corrections for memory steer.
5. List the necessary steps to follow for a four-wheel alignment.

CHAPTER QUIZ

1. If the tie rod ends become worn, which angle is most affected?
   a. Camber **c.** Toe
   b. Caster **d.** SAI
2. Technician A says that a vehicle will pull (or lead) to the side with the most camber (or least negative camber). Technician B says that a vehicle will pull (or lead) to the side with the most positive caster. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. Technician A says that the front toe determines the thrust angle. Technician B says that the rear toe angle determines the thrust angle. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. Strut rods, if they are adjustable, can be used to adjust which angle?
   a. Toe **c.** Caster
   b. Camber **d.** Toe-out on turns
5. If metal shims are used for alignment adjustment in the front, they adjust _____.
   a. Camber **c.** Toe
   b. Caster **d.** Both a and b
6. Which angle is largest?
   a. 0.55 degrees **c.** 45 minutes
   b. 1/4 degree **d.** 1/2 degree

Use the following information to answer question 7:

Specifications:	Min.	Preferred	Max.
Camber (degree)	0	1.0	1.4
Caster (degree)	.8	1.5	2.1
Toe (inch)	−.10	.06	.15
Results:	**L**	**R**	
Camber (degree)	−.1	.6	
Caster (degree)	1.8	1.6	
Toe (inch)	1.12	+.12	

7. The vehicle above will _____.
   a. Pull toward the right and feather-edge both tires
   b. Pull toward the left
   c. Wear the outside of the left tire and the inside of the right tire
   d. None of the above

Use the following information to answer questions 8 and 9:

Specifications:	Min.	Preferred	Max.
Camber (degree)	−1/4	+1/2	1
Caster (degree)	0	+2	+4
Toe (inch)	−1/16	1/16	3/16
Results:	**L**	**R**	
Camber (degree)	−0.3	−0.1	
Caster (degree)	3.6	1.8	
Toe (inch)	−1/16	+1/32	

8. The vehicle above will _____.
   a. Pull toward the left
   b. Pull toward the right
   c. Wander
   d. Lead to the left slightly
9. The vehicle above will _____.
   a. Wander
   b. Wear tires, but will not pull
   c. Will pull, but not wear tires
   d. Pull toward the left and cause feather-edge tire wear
10. Which alignment angle is most likely to need correction and cause the most tire wear?
    a. Toe
    b. Camber
    c. Caster
    d. SAI/KPI

SECTION XIII

Manual Drive Train and Axles

121 Clutches
122 Manual Transmissions/Transaxles
123 Drive Axle Shafts and CV Joints
124 Drive Axle Shaft and CV Joint Service
125 Differentials
126 Four-Wheel Drive and All-Wheel Drive

chapter 121

CLUTCHES

OBJECTIVES: After studying Chapter 121, the reader will be able to: • Prepare for ASE Manual Drive Train and Axles (A3) certification test content area "A" (Clutch Diagnosis and Repair). • List the parts that are included in the clutch system. • Describe how the clutch works. • Explain the importance of proper clutch pedal freeplay. • List the steps necessary to replace a clutch. • Describe the characteristic noise each clutch component part makes when defective.

KEY TERMS: Belleville spring 1458 • Bushing 1455 • Candlestick 1461 • Clutch disc 1454 • Coil spring clutch 1458 • Cushioning spring 1457 • Front bearing retainer 1455 • Lever style (pressure plate) 1458 • Marcel spring 1457 • Pilot bearing 1455 • Pressure plate 1454 • Quill 1455 • Quill shaft 1461 • Release bearing 1454 • Slave cylinder 1455 • Throwout bearing 1454 • Torsional dampers 1457

PURPOSE AND FUNCTION OF A CLUTCH

The clutch assembly is located between the engine and the transmission/transaxle. The purpose and function of a clutch include the following:

- To disconnect the engine from the transmission/transaxle to permit the engine to remain running when the vehicle is stopped and to permit the transmission/transaxle to be shifted
- To connect and transmit engine torque to the transmission/transaxle

NOTE: The term *transmission* refers to rear-wheel-drive vehicles and the term *transaxle* usually refers to front-wheel-drive vehicles that have a differential built into the unit. A separate differential is used with a transmission.

- To dampen and absorb engine impulses and drive train vibration
- To provide a smooth engagement and disengagement between the engine and the transmission/transaxle

COMPONENT PARTS AND OPERATION OF A CLUTCH ASSEMBLY

A clutch assembly consists of a **clutch disc** that is splined to the input shaft of the transmission/transaxle. When the driver depresses the clutch pedal, a **throwout bearing** (**release bearing**) is forced against the fingers of the **pressure plate.** The pressure plate is bolted to and rotates with the flywheel. ● **SEE FIGURE 121–1.** When force is exerted on the center of the pressure plate, the pressure is released from the clutch disc that has been forced against the engine flywheel. With

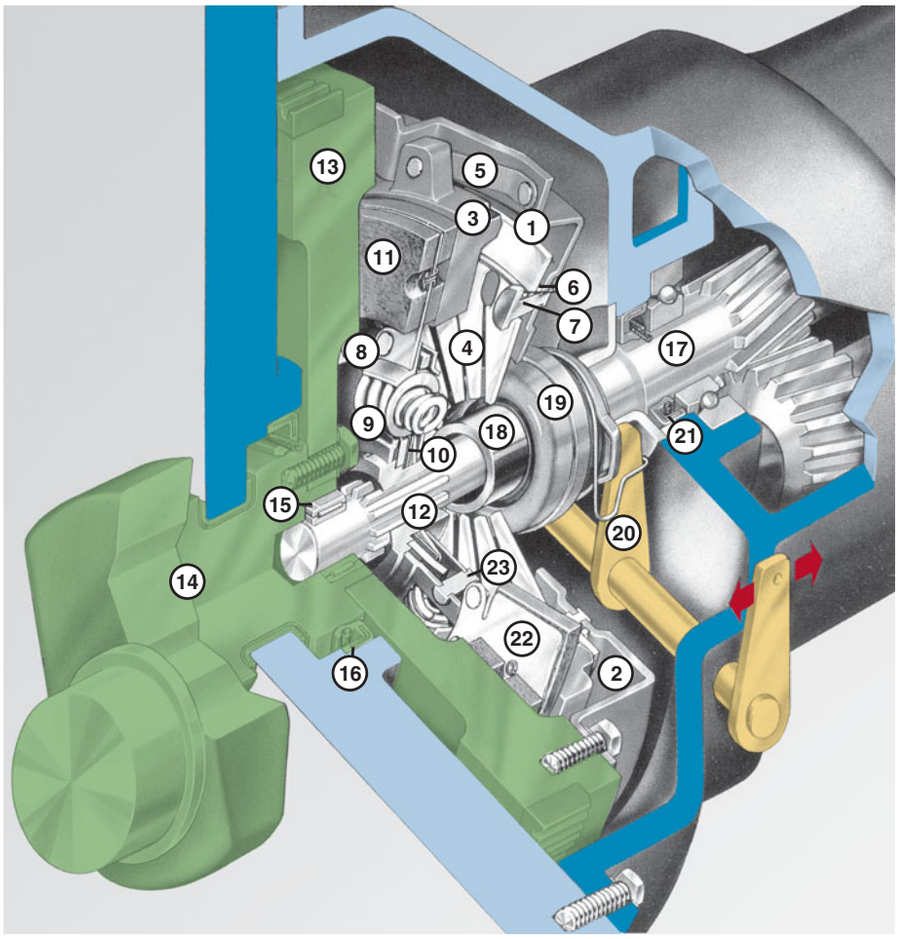


FIGURE 121–1 Typical automotive clutch assembly showing all related parts. (*Courtesy of LUK*)

the pressure removed from the clutch disc, the engine can be operated without transferring torque to the transmission/transaxle. This also permits the transmission/transaxle to be shifted because a shift cannot be made if the transmission/transaxle is transferring engine torque.

When the driver reduces force on the clutch pedal, the pedal return spring and the pressure plate spring combine to return the clutch pedal to its at-rest position (clutch-engaged position). When the clutch pedal moves up, the pressure on the throwout bearing is released and the force against the pressure plate spring(s) is released allowing the force of the pressure plate to clamp the clutch disc tightly between the flywheel and the pressure plate. ● **SEE FIGURE 121–2.**

Additional related parts include the **pilot bearing** (or **bushing**) that supports the front of the transmission input shaft. ● **SEE FIGURE 121–3.** The throwout bearing is often supported and rides on the transmission/transaxle **front bearing retainer** (also called the **quill**).

NOTE: Most front-wheel-drive transaxles do not use a pilot bearing.

To summarize:

- When the clutch pedal is up, the clutch is engaged.
- When the clutch pedal is down, the clutch is disengaged.

CLUTCH PEDAL LINKAGE

There are three methods of transferring the force of the driver's foot to the throwout (release) bearing, including:

- **Levers and rods.** Through a series of levers and rods, the release fork is forced against the throwout bearing. This method was commonly used on many older vehicles.
- **Cable operation.** A cable is used similar to a brake cable used on a bicycle. ● **SEE FIGURE 121–4.**
- **Hydraulic.** A small master cylinder and a **slave cylinder** located near the throwout bearing is a very common method of connecting the clutch pedal to the release fork on vehicles equipped with a manual transmission. ● **SEE FIGURES 121–5 AND 121–6.**

CLUTCH DISC

The clutch disc is round with a splined center hole that slips over the splines of the input shaft of the transmission/transaxle. Friction material is riveted to both sides of the clutch disc—one side touches the flywheel of the engine and the other side touches the friction surface of the pressure plate.

Friction material is either woven or molded from a mixture of other materials. Woven materials are softer and help cushion clutch engagement, but they may not last as long as molded materials.

Friction materials operate in high heat and pressure. For many years, asbestos was the most common material used in both clutch and brake linings. However, it is no longer used because inhaling tiny particles of asbestos causes lung damage. Today, clutch friction material may contain paper, cotton, and bits of copper or brass wire with resin holding the mixture together.

CAUTION: Always take precautions when working around clutch lining material and assume that it contains asbestos. These precautions should include wetting the friction disc before removal and preventing any dust from the lining from becoming airborne.

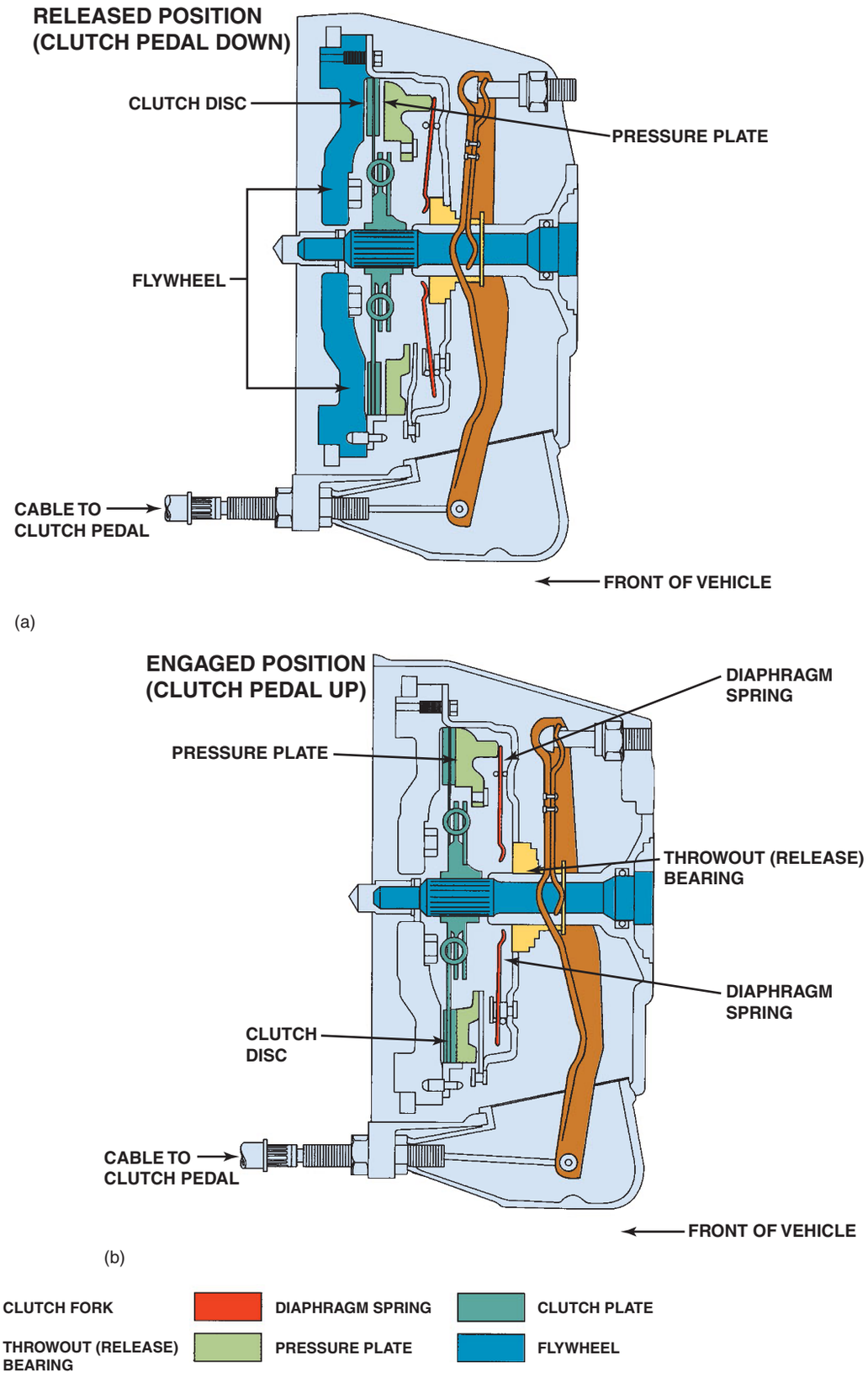


FIGURE 121–2 (a) When the clutch is in the released position (clutch pedal depressed), the clutch fork is applying a force to the throwout (release) bearing, which pushes on the diaphragm spring, releasing the pressure on the friction disc. (b) When the clutch is in the engaged position (clutch pedal up), the diaphragm spring exerts force on the clutch disc, holding it between the flywheel and the pressure plate.

HIGH-PERFORMANCE CLUTCH DISC Another type of friction material is a ceramic and metallic mixture. This creates a hard, long-lasting lining, but is more expensive and does not cushion clutch engagement as much as a softer lining. Instead of a full circle of softer friction material, the disc may have only a few segments or buttons of this ceramic-metallic material. Clutches that use these discs, which are sometimes called "button clutches," are found in racing applications where strength and durability are a greater concern than smooth engagement. ● **SEE FIGURE 121–7.**

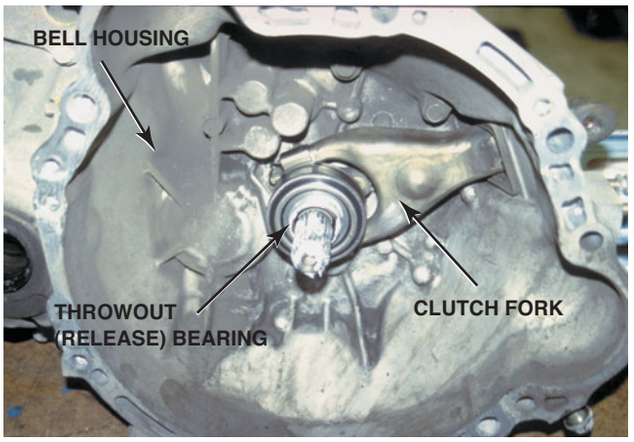


FIGURE 121–3 The transmission has just been removed. Note that this type of transmission incorporates the bell housing, which was therefore removed at the same time as the transmission. The clutch fork and throwout (release) bearing also came off together. All that remained attached to the engine was the flywheel, clutch disc, and pressure plate.



FIGURE 121–6 A typical clutch master cylinder and reservoir mounted on the bulkhead on the driver's side of the vehicle. Brake fluid is used in the hydraulic system to operate the slave cylinder located on the bell housing.

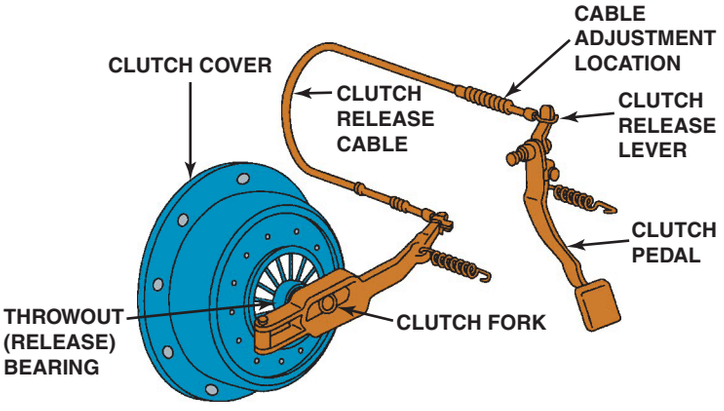


FIGURE 121–4 A typical cable-operated clutch.

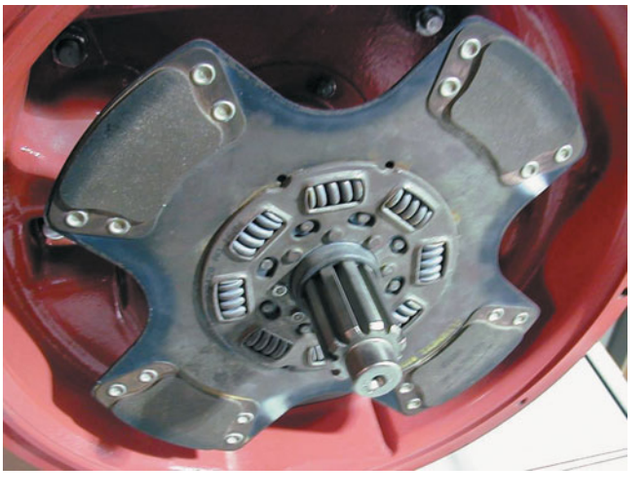


FIGURE 121–7 A racing or high-performance clutch disc lacks the features of a stock clutch disc that help provide smooth engagement.

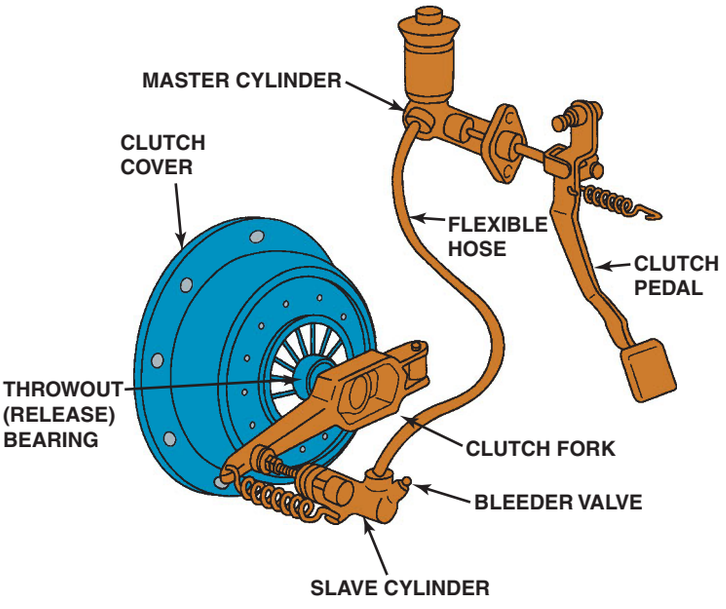


FIGURE 121–5 A hydraulic clutch linkage uses a master cylinder and a slave cylinder.

STOCK CLUTCH DISC Around the center hub of the clutch disc are **torsional dampers** that absorb the initial shock of engagement and help dampen engine-firing in pulses being transmitted into and through the transmission/transaxle. ● **SEE FIGURE 121–8.** The torsional dampers are either coil springs or are made of rubber. In the space between the friction surfaces is a wavy spring steel material called a **cushioning spring** or **marcel spring.** ● **SEE FIGURE 121–9.** The marcel spring also helps to absorb the initial shock of engagement and allows for a smooth engagement of the clutch.



FIGURE 121–8 A typical stock clutch friction disc that uses coil spring torsional dampers.

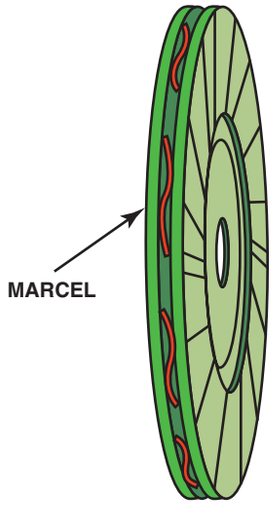


FIGURE 121–9 A marcel is a wavy spring that is placed between the two friction surfaces to cushion the clutch engagement.

HINT: The larger center hub section of the disc must be installed with the thicker portion facing the pressure plate. ● **SEE FIGURE 121–10.**

PRESSURE PLATES

The purpose of the pressure plate is to exert a force on the clutch disc so that engine torque can be transmitted from the engine to the transmission/transaxle. The required strong clamping force is provided by pressure plate spring(s). However, a strong pressure plate spring force must be released by the force of the driver's foot to disengage the clutch. Most pressure plates today are made of stamped steel with a nodular cast iron driving plate. A smooth, machined area on one side forms the friction disc contact surface. When the clutch engages, spring force pushes the pressure plate toward the flywheel so the friction disc is clamped between the flywheel and the pressure plate. Engine torque flows through the clutch to the transmission input shaft. Three or four drive straps or clips connect the pressure plate to the clutch cover. These spring-steel straps or clips help hold the pressure plate away from the flywheel when the clutch disengages. Several styles of pressure plates have been used, including

- **Coil spring style.** This style of pressure plate uses coil springs and three or four release arms. A coil-spring-style pressure plate is also called the **lever style** because it uses levers to compress the coil springs. ● **SEE FIGURE 121–11.**
- **Diaphragm spring style.** This style is the most commonly used pressure plate design. One large, round, spring-steel spring is used to apply even force on the clutch disc called a **Belleville spring**. ● **SEE FIGURE 121–12.** These tend to be smaller

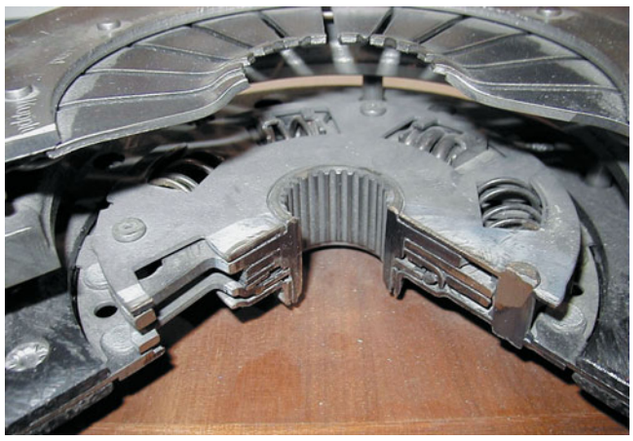


FIGURE 121–10 Cutaway of the center section of a clutch plate showing the various layers of steel plates used in the construction.

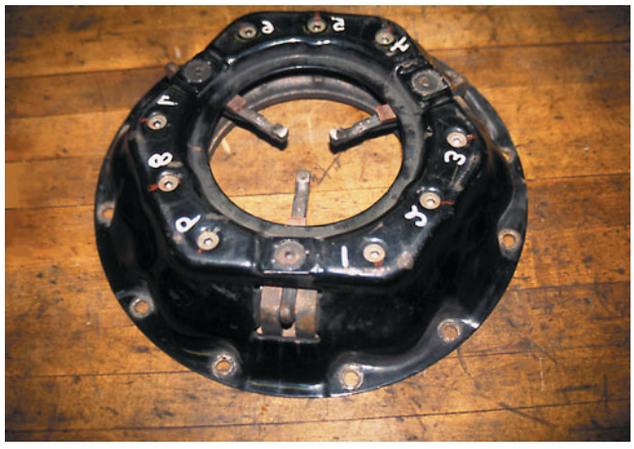


FIGURE 121–11 A coil spring (lever style) clutch pressure plate.



FIGURE 121–12 Typical diaphragm-style pressure plate that uses a Belleville spring.

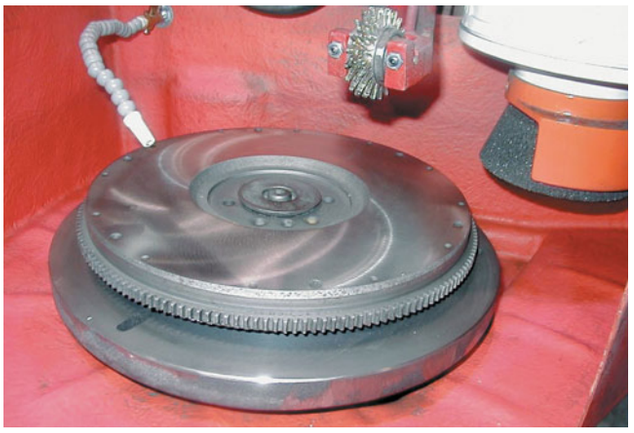


FIGURE 121–13 A flywheel after it has been machined (ground) to provide the correct surface finish for the replacement clutch disc.



FIGURE 121–14 The starter motor will spin but the engine will not crank if the ring gear on the flywheel is broken.

assemblies, weigh less, and have fewer parts than coil spring assemblies. The one-piece diaphragm spring does the job of all the release levers and coil springs in a coil spring clutch.

The driver must push harder on the clutch pedal to disengage a **coil spring clutch** than to disengage a comparable diaphragm spring design. The pedal effort for a coil spring clutch increases the farther down the pedal is pushed. The pedal effort for a diaphragm spring clutch decreases during the second half of pedal travel.

As the friction disc wears, coil springs expand and lose some of their clamping force. In contrast, the design of the diaphragm spring tends to increase its clamping force as the friction disc wears to half its original thickness. Then, as the friction disc continues to wear, the clamping force of the spring gradually returns to its original level. This happens without any obvious change in clutch pedal effort.

In many cases, aftermarket clutch parts manufacturers supply a diaphragm spring pressure plate assembly when an original coil spring assembly must be replaced. If so, carefully compare the new pressure plate to the old one to make sure it is the correct replacement. Physical characteristics, such as dimensions and bolt-hole patterns, must be identical for the assembled clutch to operate properly. Check that the inner edges of the diaphragm spring fingers are the same height as the release levers on the original unit.

FLYWHEELS

The engine flywheel serves four basic purposes:

- Smoothes out or dampens engine power pulses.
- Absorbs some of the heat created by clutch operation.
- Provides the connection point for the starter motor to crank the engine.
- Provides the application surface for the clutch friction disc.

A flywheel is heavy, or has a large mass, which creates inertia. This inertia acts upon crankshaft rotation to smooth out or dampen engine power pulses. On a running engine, the crankshaft speeds up as a cylinder fires, then slows due to internal engine friction until the next cylinder fires. The inertia provided by the flywheel mass tends to keep crankshaft speed more constant.

Whenever friction exists between two moving parts, heat is generated. The flywheel absorbs some of the heat created by clutch operation by acting as a heat sink for the clutch friction disc.

An external ring gear is pressed or welded onto the flywheel along its outer circumference. When the starter motor is engaged, the starter-drive gear meshes with the flywheel ring gear. Through gear reduction, the flywheel transfers starter motor rotation to the crankshaft to crank the engine.

The face on the transmission side of the flywheel has a smooth, machined area that creates the application surface for the clutch friction disc. This surface must be properly finished to allow adequate slippage as the clutch engages and disengages, and to prevent slippage when the clutch is engaged. ● **SEE FIGURE 121–13.**

The flywheel is constructed of cast iron and attaches to the end of the engine crankshaft. The carbon content of the cast iron (about 3%) provides a suitable surface for the clutch disc. The carbon, in the form of graphite, acts as a lubricant to provide a smooth engagement of the clutch. Often the ring gear can be replaced separately without having to replace the flywheel in the event of a failure, as shown in ● **FIGURE 121–14.** The pilot bearing is often installed in the center of the flywheel (or in the end of the crankshaft) to support the end of the input shaft of the transmission.

DUAL-MASS FLYWHEELS. Some vehicles, especially high-performance vehicles and vehicles equipped with diesel engines, use a dual-mass flywheel. The purpose of a dual-mass flywheel is to dampen engine vibrations and keep them from being transmitted to the passenger compartment through the transmission and shift linkage. A dual-mass flywheel consists of two separate flywheels attached with damper springs, friction material, and ball bearings to allow some movement between the primary and secondary flywheel. By allowing a very slight amount of movement between the two flywheels, the damper absorbs engine torque peaks and normal vibration to provide smoother drive train operation. The damper assembly is completely sealed, because it also contains a fluid or lubricant, typically silicone-based, which also helps absorb vibration and transmit torque. Typically, the two flywheels twist out of phase with each other by up to about 60 degrees to absorb torsional oscillations. The starter ring gear mounts on the primary flywheel. Power from the starter motor does not have to flow through the damper assembly to reach the engine crankshaft. The ring gear and pilot bearing are usually attached to the primary flywheel, and the clutch friction surface is usually the secondary flywheel. ● **SEE FIGURE 121–15.**

NOTE: If the dual-mass flywheel fails, the symptom is the same as a slipping clutch. The torque-limiting friction material connecting the primary and secondary flywheels can fail. This failure requires the replacement of the flywheel assembly.

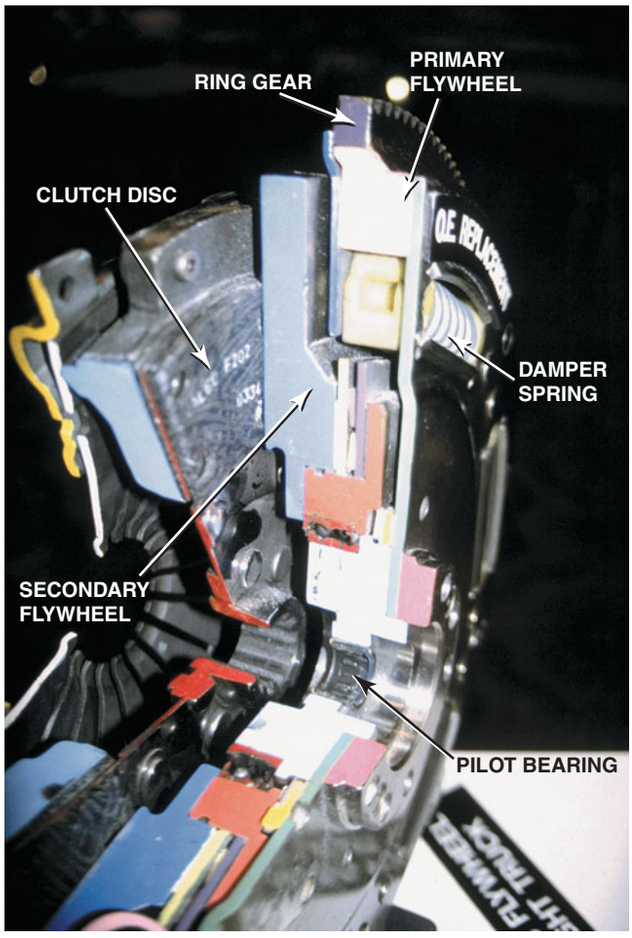
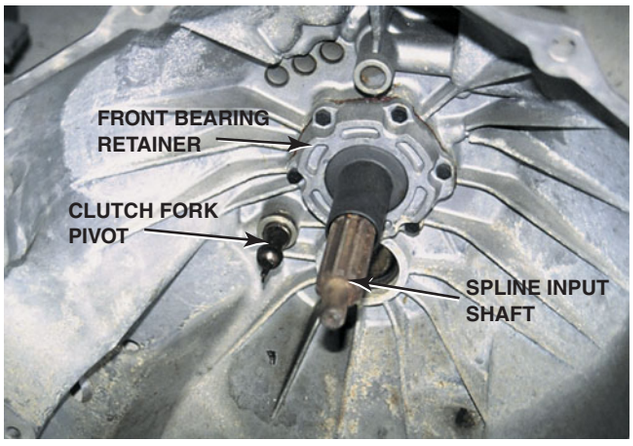
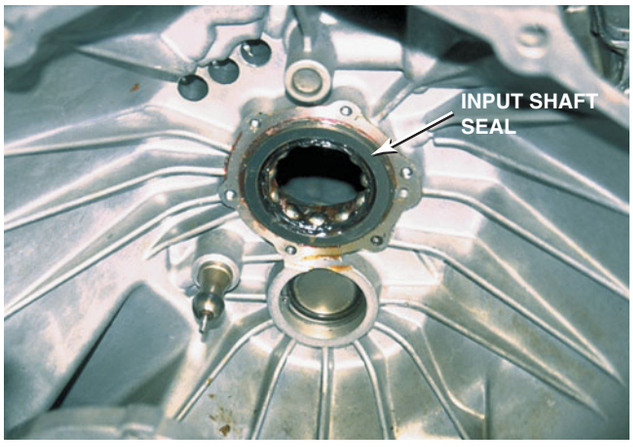


FIGURE 121–15 A cutaway of a dual-mass flywheel used on a Ford diesel pickup truck.



(a)



(b)

FIGURE 121–16 (a) Before replacing the clutch, the bell housing should be cleaned and the clutch fork pivot lightly lubricated. (b) The input shaft seal should also be replaced to prevent the possibility of getting transmission lubricant on the friction surfaces of the clutch.

TECH TIP

Shim It or Replace It

Whenever replacing a clutch, most experts agree that the flywheel should be removed from the engine and resurfaced. When material is removed from the surface of the flywheel, the geometry (relationship) of the clutch parts changes because the pressure plate is now closer to the rear of the engine by the amount removed from the flywheel. Ask your parts supplier for a shim equal in thickness to the amount of material removed during resurfacing. Generally, these round shims are available in 0.020" to 0.100" thicknesses. The shim is installed between the crankshaft flange and the flywheel. If a shim is not used, the flywheel may have to be replaced to properly restore proper clutch operation and service life.

TECH TIP

Repair the Oil Leaks Before Replacing the Clutch

If engine oil or transmission lube gets onto the friction surface of the clutch, the clutch will chatter when engaged. This grabbing and releasing of the clutch is not only harmful to the drive train (transmission, driveshaft, etc.) but also is disturbing to the driver when the vehicle vibrates and shakes while driving. To avoid the possibility of a chattering clutch, always repair oil leaks as soon as possible. Rocker (valve) cover gaskets, intake manifold gaskets, oil galley plugs, rear main seals, as well as the input shaft seal on the transmission/transaxle itself can all lead to clutch contamination. ● **SEE FIGURE 121–16.**

PILOT BEARING OR BUSHING

The transmission input shaft goes all the way from the transmission, through the clutch assembly, to the engine. Transmission bearings support the transmission end of the shaft. Depending on the length of the input shaft, it may also need a pilot bearing or bushing to support it at the engine end.

A front-wheel-drive vehicle with a stepped flywheel, compact clutch assembly, and a transaxle that has a short input shaft that may not reach all the way to the flywheel. This design does not need a pilot bushing or bearing to support the engine end of the input shaft. ● **SEE FIGURE 121–17.**

Other designs, such as a rear-wheel-drive vehicle with a flat flywheel, have a much longer transmission input shaft. At the engine, the transmission input shaft rests inside a small bore in the flywheel or crankshaft flange. The pilot bearing or bushing, which is pressed into this bore, supports the engine end of the input shaft and provides

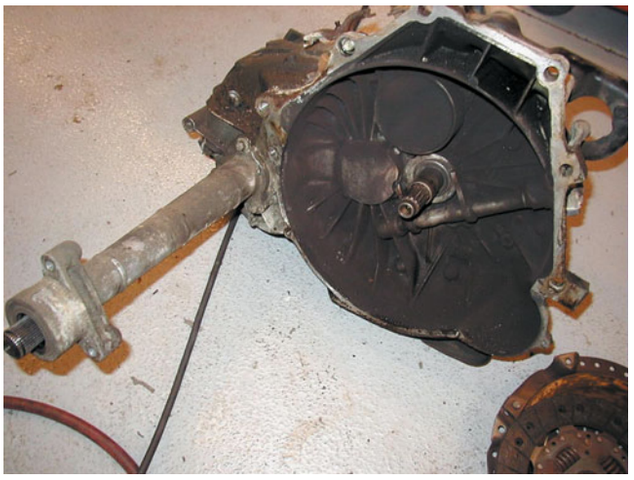


FIGURE 121–17 A transaxle assembly has been removed to replace the clutch. Note the short input shaft. This vehicle did not use a pilot bearing (bushing).

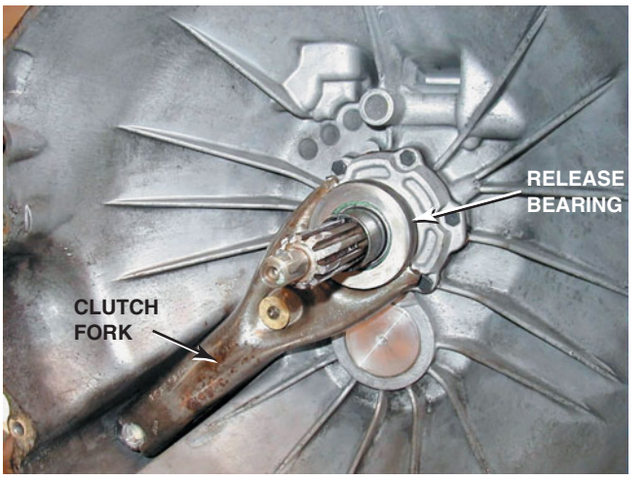


FIGURE 121–18 The clutch pedal linkage moves the clutch fork, which then applies a force against the release bearing, which then releases the clamping force the pressure plate is exerting on the clutch disc.

REAL WORLD FIX

The Mazda Pickup Truck Story

The driver of a Mazda pickup truck complained that it was difficult to shift the manual transmission into first gear and reverse. The hydraulic clutch system was checked and bled and seemed to be operating as designed. A defective clutch was not suspected because the clutch did not slip. The problem continued to worsen. Finally, when the driver had trouble shifting into all gears, the technician decided that the transmission had to be removed and the clutch inspected. When the transmission was removed, the clutch assembly including the pressure plate, throwout bearing, and clutch disc all appeared to be worn but not enough to cause any trouble. Then the pilot bearing was inspected. The needle bearings were broken. The input shaft of the transmission is supported by the pilot bearing located in the center of the flywheel. Apparently, what had happened was that the pilot bearing failed and the pieces of the bearing kept the input shaft to the transmission rotating whenever the engine was running whether or not the clutch was depressed or released. The technician replaced the pilot bearing and the other clutch components at the request of the owner and everything worked perfectly.

a low-friction surface for the shaft to ride on. This keeps the shaft and friction disc perfectly aligned with the flywheel and pressure plate.

The pilot bearing or bushing rotates with the crankshaft when the engine is running. At times, the input shaft does not rotate when the engine is running. The pilot bearing or bushing lowers the friction between these two moving parts. Some pilot bearings use ball bearings while other applications use a caged-needle bearing. The outer race of the bearing is pressed into the crankshaft or flywheel. The input shaft slides freely into the inner race. Pilot bushings are usually a sintered metal sleeve pressed into the bore in the crankshaft flange.

Always follow the manufacturer's transmission/transaxle lubrication instructions. Excess lubricant leaks out onto the clutch friction disc, which causes clutch slippage and early failure. Too little lubricant leads to noisy operation and input shaft damage.

Replacement pilot bearings may need to be packed before installation. Sometimes, the bottom of the bore behind the bearing is also packed with grease. Other pilot bearings are permanently lubricated at the factory. Prelubricated bearings have an oil seal to hold the lubricant. If only one side is sealed, that side faces the transmission when installed.

Some pilot bushings need to be soaked in oil before installation. Others have a permanent lubricant built into the bushing material. With this type, adding another lubricant actually increases friction, by preventing the permanent lubricant from doing its job.

RELEASE BEARING The throwout (release) bearing is attached to the clutch fork and rides on the fingers of the pressure plate. The clutch operating system moves the clutch release bearing when the driver presses or releases the clutch pedal. Most systems move the release bearing toward the flywheel to disengage the clutch. ● **SEE FIGURE 121–18.** However, some systems have a pull-type mechanism that moves the bearing away from the flywheel to disengage the clutch. The release bearing presses against the diaphragm spring fingers or coil spring levers. This takes spring force off the pressure plate so that it no longer clamps the friction disc against the flywheel.

The diaphragm spring fingers or coil spring levers rotate at crankshaft speed, but the clutch operating system is a part of the vehicle chassis and does not rotate. The release bearing is the point where the fixed, stationary clutch operating system meets the rapidly spinning clutch assembly. ● **SEE FIGURE 121–19.**

RELEASE BEARING CONSTRUCTION Most clutch release bearings are ball bearings. The bearing absorbs a thrust load when its outer race presses against the diaphragm spring fingers or coil spring levers. When the outer race contacts the spring fingers or levers, it must rotate with them at engine crankshaft speed. The inner bearing race is pressed onto an iron hub, or sleeve. In some designs, the inner bearing race and sleeve are machined as one piece. The inner bearing race and sleeve are stationary and do not spin when the outer race spins.

RELEASE BEARING INSTALLATION The transmission front bearing retainer has a long, hollow tube extending toward the engine. The release bearing sleeve slides on the outer surface of this tube, which is commonly called the quill, **quill shaft,** or **candlestick.**

In a typical system, the outside of the release bearing sleeve has grooves or raised flat surfaces that fit into the clutch release



FIGURE 121–19 The release bearing rubs against the tips of the diaphragm spring.

FREQUENTLY ASKED QUESTION

What Part Causes What Noise and When?

Many service technicians try to determine which part causes noise before the clutch assembly is removed from the vehicle. Start your noise analysis by starting the engine with the manual transmission in neutral and the clutch engaged (foot off the clutch pedal). If you hear a growl or grinding sound, the cause is the input shaft bearing in the transmission.

If you are hearing a chirping noise, slowly depress the clutch pedal. If the noise stops, the problem is lack of lubrication at the fork and pivot. If the noise gets louder as you depress the clutch, the throwout (release) bearing is the problem.

The pilot bearing is the cause of a squealing noise if the sound changes as the clutch pedal is depressed or released. The sound will be loudest when the difference in speed between the engine and the input shaft is greatest.

fork. A snap ring, spring clips, or lock pins secure the release bearing to the release fork. The clutch operating system pivots the release fork back and forth when the driver presses and releases the clutch pedal. The pivoting motion of the fork slides the release bearing away from or toward the engine to engage or disengage the clutch.

TYPES OF RELEASE BEARINGS If the clutch operating system self-adjusts, then there is no clearance between the release bearing outer race and the diaphragm spring fingers or coil spring levers. The release bearing outer race constantly turns at engine crankshaft speed. This is called a constant-running release bearing. In some self-adjusting systems, a snap ring holds the outer race to the spring fingers. This design is typical of pull-type clutch operating systems that move away from the flywheel to disengage the clutch.

If the clutch operating system does not self-adjust, then there must be some clearance between the release bearing outer race and the spring fingers when the clutch is engaged. The outer race does not contact the spring fingers and so it does not turn. As the driver depresses the clutch pedal, the release bearing moves into contact with the fingers and the outer race begins to rotate with them. This type of release bearing is not designed to rotate constantly. If the clutch is not adjusted properly and there is no clearance, the release bearing spins constantly and wears out quickly.

REAL WORLD FIX

Best to Double-Check Your Parts Before Installation

A beginning technician installed a new clutch in a Chevrolet S-10 pickup truck. After the transmission was installed and the driveshaft connected, the technician started the engine to check the operation of the clutch with the truck still on the lift and off the ground. The drive wheels never turned even though the clutch was released. It was almost as if the clutch disc was left out completely although the clutch pedal felt normal.

The transmission was removed and the clutch parts inspected. Everything looked okay until the technician slid the clutch disc over the splines of the transmission input shaft. The diameter of the hole in the clutch disc was a lot larger than the diameter of the shaft. The clutch also simply revolved without even touching the input shaft. Obviously, the technician received the wrong clutch disc from the parts department. The experienced technician explained that not only should all parts be carefully inspected before installation but that the clutch disc should have been slid over the splines of the input shaft to check for any possible burrs that could prevent the clutch disc from disengaging.

RELEASE BEARING LUBRICATION The ball bearing portion of the release bearing is usually permanently lubricated and sealed during manufacture. This part of the bearing should not be lubricated during service.

The sleeve, or quill shaft, often needs lubrication during clutch service. Typically, a thin film of high-temperature grease coats the sliding surfaces. Always follow the manufacturer's recommendations for release bearing lubrication, and avoid overlubricating. As with pilot bearings, too much lubricant here can lead to early clutch failure.

CLUTCH PROBLEM DIAGNOSIS

If the clutch is slipping, it cannot transfer engine torque to the transmission or drive wheels. A common method used to check for a slipping clutch is the following:

1. Drive the vehicle to a safe location where it can be accelerated safely.
2. Rapidly accelerate the vehicle in first or second gear and rapidly shift the transmission into a higher gear.

The engine speed should drop as the clutch is released after selecting a higher gear. If the clutch is slipping, the engine speed will either rise or not drop after the clutch pedal is released (clutch is engaged).

Another common problem with a clutch is that it sometimes will not fully disengage. The following symptoms will occur if there

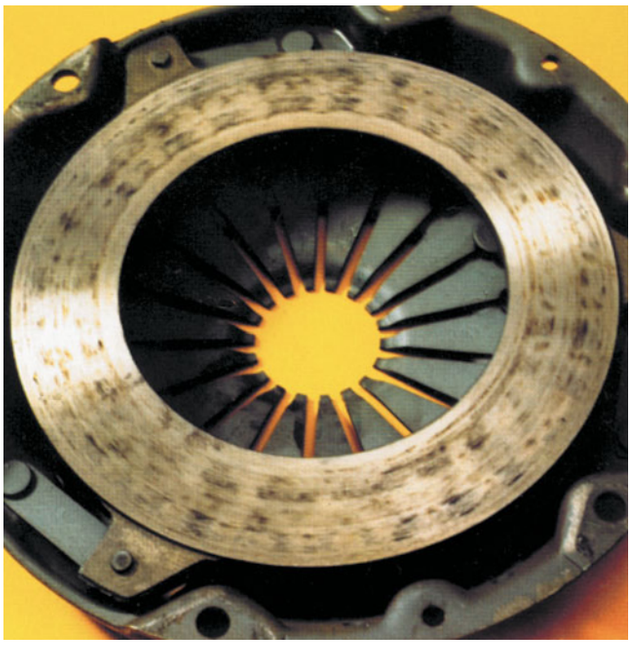


FIGURE 121–20 Heavy chatter marks on the pressure plate indicate that oil or grease has gotten onto the clutch facing. (*Courtesy of LUK*)

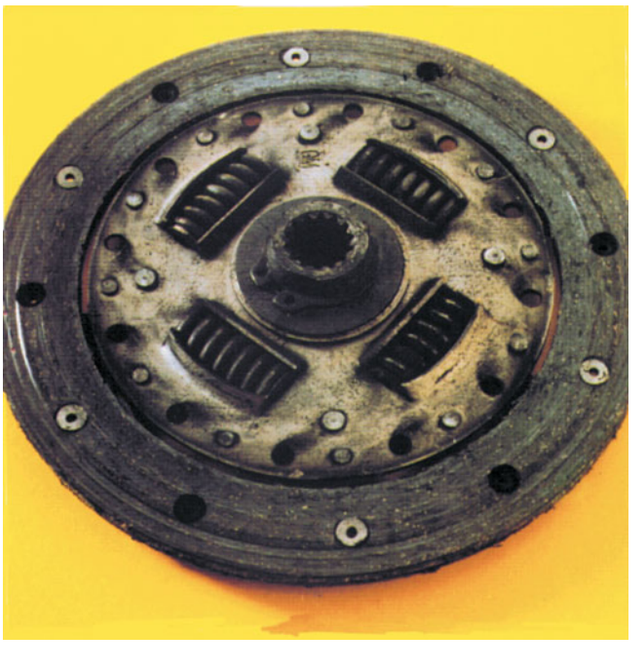


FIGURE 121–22 Friction material (facing) worn down to the rivets. Normal wear can cause this or improper clamping force from a defective pressure plate. (*Courtesy of LUK*)

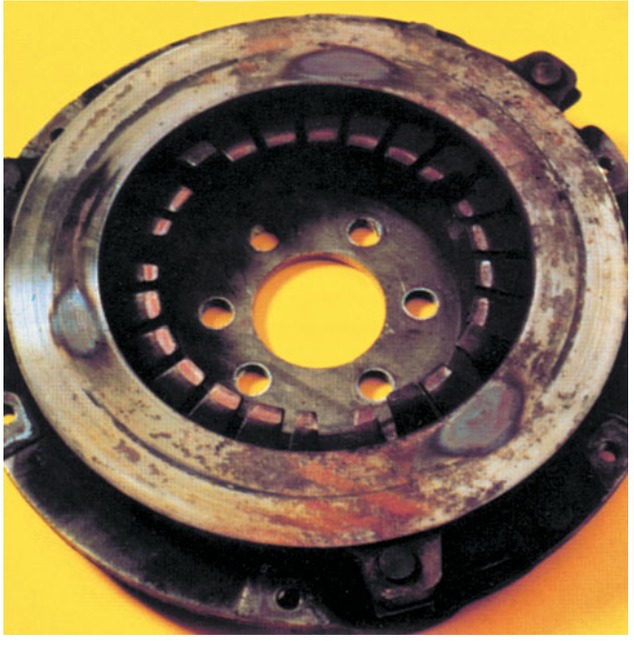


FIGURE 121–21 Hot spots on the pressure plate indicate that this clutch has been slipping or that oil/grease has gotten onto the clutch facing. (*Courtesy of LUK*)



FIGURE 121–23 Friction material (facing) only makes contact with the flywheel on the inner and outer edge. The likely cause is that the flywheel was not resurfaced or replaced during a previous repair. (*Courtesy of LUK*)

is a fault in the clutch or in the linkage or hydraulic system that could prevent the clutch from being fully disengaged:

- The transmission will be difficult (or impossible) to shift into reverse.
- The transmission will be difficult (or impossible) to shift between forward gears.

● **SEE FIGURES 121–20 THROUGH 121–28** for examples of worn clutch components.

SAFETY TIP

Disconnect the Battery Before Work Begins

It is always a safe idea to disconnect the negative (−) battery cable before performing major work to the vehicle as a safety precaution.

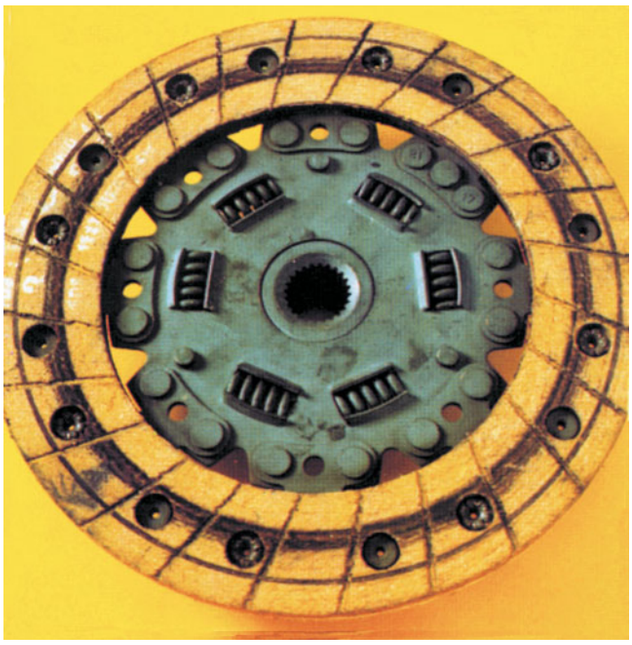


FIGURE 121–24 Deep scoring in the friction material (facing) on the flywheel side indicates that the flywheel was not resurfaced or replaced during a previous repair. (*Courtesy of LUK*)



FIGURE 121–26 A destroyed torsional damper is usually caused by driving at too low an engine speed, which would cause too much strain on the torsional damper. (*Courtesy of LUK*)



FIGURE 121–25 A broken cushion segment caused by movement between the engine and transmission. The most likely cause is a missing or defective pilot bearing. (*Courtesy of LUK*)



FIGURE 121–27 A worn down or broken diaphragm is often caused by a faulty release bearing or a linkage problem that keeps the clutch from fully releasing. (*Courtesy of LUK*)

CLUTCH REPLACEMENT

The clutch replacement for a typical rear-wheel-drive vehicle includes the following steps.

1. Hoist the vehicle safely and mark and remove the driveshaft. This step ensures that the driveshaft will be reinstalled correctly and in phase.
2. Disconnect the shift linkage, speedometer connections, and reverse light switch connection as well as the clutch linkage or cable or slave cylinder.
3. Support the transmission with a transmission jack and then remove the rear crossmember and bell housing bolts.
4. Carefully move the transmission toward the rear. Try to keep the transmission level to avoid causing damage to the pilot bearing or clutch components. A slight wiggling of the transmission is usually necessary to allow the input shaft to slide over the spline of the clutch disc.



FIGURE 121–28 Rusting hub splines indicate that the transmission shaft was not lubricated, which can cause the clutch to not disengage correctly. (*Courtesy of LUK*)

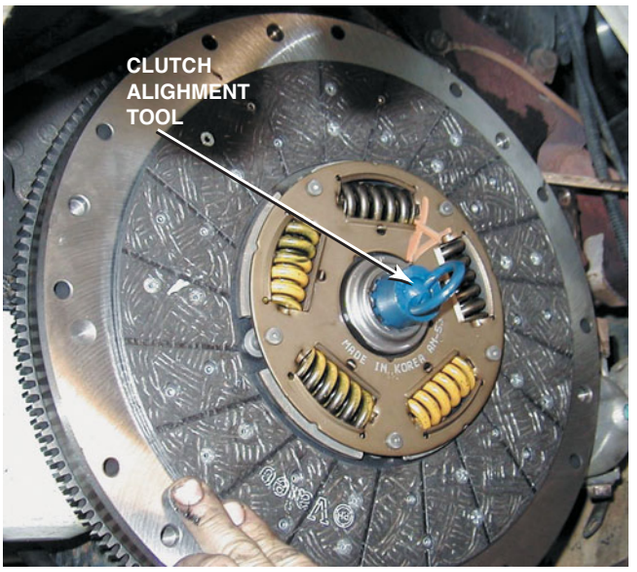


FIGURE 121–29 A clutch alignment tool is inserted into the pilot bearing and over the splines of the clutch disc to keep the disc properly centered before installing the pressure plate. After the pressure plate has been installed and torqued to factory specifications, the alignment tool can be removed because the pressure plate spring force holds the friction disc tightly against the flywheel.

5. After the transmission has cleared the clutch, it can be lowered and inspected before being reinstalled after the clutch assembly has been replaced.
6. Mark the pressure plate and flywheel if they are to be reused to allow them to be reinstalled in the same location to maintain assembly balance.
7. Remove the clutch pressure plate retaining bolts, and remove the clutch assembly including the release bearing, pressure plate, and clutch disc.
8. Clean and inspect the flywheel.

NOTE: Most experts recommend that the flywheel be removed and resurfaced. Always use new flywheel bolts and torque to factory specifications.

9. Replace or lightly lubricate the pilot bearing/bushing.
10. Install the clutch disc and pressure plate using an aligning tool to center the clutch disc and then torque the pressure plate bolts to factory specifications. ● **SEE FIGURE 121–29**.
11. Inspect the clutch release lever and replace if necessary.
12. Attach the replacement release bearing and install the transmission and torque the retaining bolts to factory specifications.
13. Reconnect the clutch linkage and place the transmission into high gear and have an assistant depress the clutch pedal. Grasp the output shaft and turn it with your hand.
    a. The transmission output shaft should be easy to rotate if the clutch is fully disengaged with the clutch pedal held down. ● **SEE FIGURE 121–30**.
    b. If the output shaft cannot be rotated, double-check that the clutch linkage and clutch is correctly installed.
14. Reinstall the rear crossmember and torque the retaining bolts to factory specifications.
15. Reconnect the shift linkage, speedometer, and reverse light connections.



FIGURE 121–30 To check that the clutch is properly installed before replacing all of the components, try to turn the output shaft with the transmission in gear and the clutch pedal depressed by an assistant.

16. Install the driveshaft and torque the U-joint retaining fastener to factory specifications.
17. Lower the vehicle and test-drive it to verify correct clutch operation.

CLUTCH PEDAL ADJUSTMENT

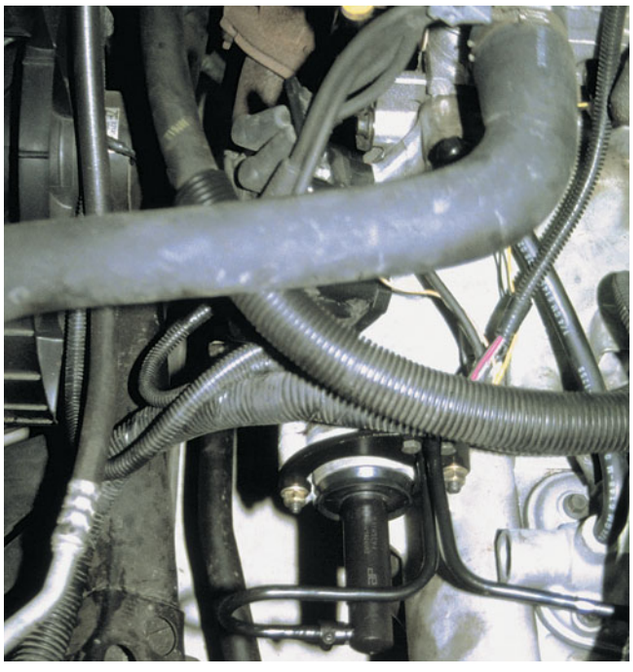
As the clutch disc wears, the pressure plate moves closer to the flywheel. This causes the clutch to engage when the clutch pedal is higher and higher. Eventually, the clutch will start to slip if the



FIGURE 121–31 The clutch slave cylinder is often corroded because of moisture absorbed by the brake fluid used in the hydraulic clutch. This slave cylinder was disassembled to see if it could be overhauled rather than replaced.



(a)



(b)

FIGURE 121–32 (a) The replacement hydraulic clutch for a Saturn includes the master cylinder (shown) with the line and the slave cylinder as an assembly. The assembly is even filled with brake fluid! Do not open the master cylinder cap on this unit because Saturn did not provide any method of bleeding air out of the system. (b) The slave cylinder attaches to the bell housing of the transaxle.

TECH TIP

Check for Bulkhead Flex

Many cable-operated clutch linkage problems are caused by flexing of the bulkhead (firewall) as the clutch pedal is depressed. This movement of the bulkhead can cause the clutch to slip. To prevent unnecessary clutch repairs, have an assistant observe the bulkhead near the clutch cable while the clutch pedal is depressed. If there is movement of the sheet metal bulkhead, add reinforcing steel plate to the area.

linkage is not adjusted to compensate for the normal wear. Most hydraulic clutch linkage is self-adjusting and does not require any adjustment in normal service. Most lever type clutch linkage must be adjusted for proper clutch free pedal setting. Some cable-operated clutches are either self-adjusting or are adjusted easily. For example, one style of clutch linkage is adjusted by simply pulling upward on the clutch pedal until it stops. Some cable-operated clutch linkage is adjusted either at the bulkhead (firewall) where the cable exits the passenger compartment or at the clutch fork. Follow the adjustment procedures specified for the exact vehicle being serviced.

Most adjustment procedures specify a clutch pedal freeplay of 0.5 to 1.0 inch. Freeplay is the distance the clutch pedal can be depressed without encountering any noticeable resistance. This slight amount of freeplay assures that the clutch is fully engaged and not partially engaged as could occur if there is no freeplay in the pedal linkage.

BLEEDING THE HYDRAULIC CLUTCH

If the hydraulic system has been opened to replace either a clutch slave cylinder or master cylinder or both, air has to be bled from the system. ● **SEE FIGURES 121–31 AND 121–32.** Fill the master

cylinder with DOT 3 brake fluid and open the bleeder valve at the slave cylinder. Gravity should force the brake fluid to flow downward, expelling any trapped air that may be in the system. When brake fluid starts to drip from the bleeder valve, close the bleeder valve and check the clutch for normal operation. Sometimes depressing the clutch pedal slowly as an assistant opens the bleeder valve at the slave cylinder will force any trapped air out of the system. This is called *manual bleeding* and should be repeated as necessary until the normal operation of the clutch returns.

NOTE: Most technicians who are experienced in clutch service know that some vehicles are extremely difficult to bleed. Often it is necessary to use special service tools to either vacuum bleed or pressure bleed the system.

CLUTCH SYMPTOM GUIDE

CLUTCH SLIPS Possible causes:

1. Clutch is worn or out-of-adjustment.
2. Clutch disc has oil on the surface.
3. Flywheel height is out-of-specifications.

CLUTCH GRABS Possible causes:

1. Clutch disc has oil on the surface.
2. Clutch linkage is binding.

CLUTCH NOISES Possible causes:

1. Pilot bearing is defective or worn.
2. Release bearing is defective or worn.

CLUTCH REPLACEMENT



1 The first step in the process of replacing the clutch on this Chevrolet S-10 pickup truck is to remove the negative battery cable.



2 Remove the shifter mechanism inside the vehicle. This step may involve removing the center console and other components.



3 Mark and then remove the driveshaft.



4 Remove the exhaust pipe if needed. It was needed in this case, according to service information.



5 Remove the transmission mount fasteners.



6 Using a transmission jack, support the transmission and remove the bell housing bolts.



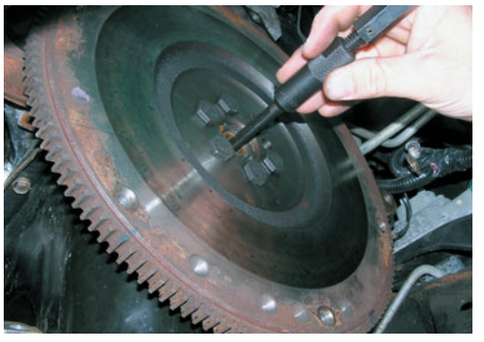
7 A view of the bell housing and throwout bearing as the transmission assembly is removed from the engine.



8 Removing the fasteners holding the pressure plate to the flywheel.



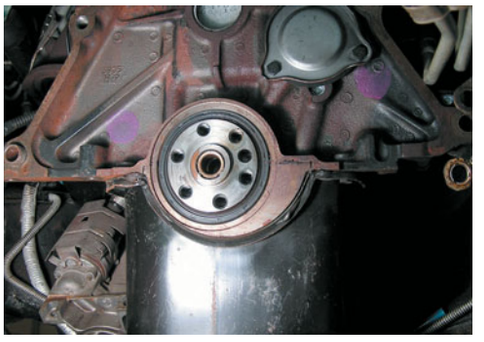
9 Removing the pressure plate and clutch disc.



10 Using a special puller, remove the pilot bearing.

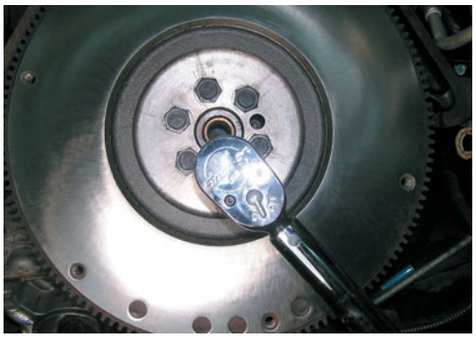


11 The flywheel is being removed to be refinished or replaced as needed.



12 With the flywheel removed, check to see if the rear main seal is leaking and replace if needed.

CONTINUED ▶



13 Installing a reconditioned flywheel and torquing new bolts to factory specifications.



14 Installing a new pilot bearing and lubricate as per instructions in service information.



15 Using a pilot tool to align the clutch disc with the pilot bearing through the center opening of the pressure plate.



16 Installing the transmission assembly with a new throwout bearing.



17 Bleeding the air from the hydraulic clutch circuit.



18 Finish the clutch replacement by reinstalling all components removed and check for proper operation.

REVIEW QUESTIONS

1. List the parts of a typical clutch assembly.
2. Describe what happens when the driver depresses the clutch pedal.
3. Describe how to determine which of the following is the cause of a noise: pilot bearing, throwout (release) bearing, and input shaft bearing.
4. Explain why a dual-mass flywheel is used on some vehicles.
5. What is meant by clutch pedal freeplay?

CHAPTER QUIZ

1. Technician A says that too much clutch pedal freeplay can cause the clutch to slip during acceleration. Technician B says that too little clutch pedal freeplay can cause the clutch to slip. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
2. The engine speed increases when the driver depresses the accelerator pedal and releases the clutch pedal, but the vehicle does not move. Technician A says the clutch may be defective. Technician B says the dual-mass flywheel may be defective. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
3. A growling noise is heard only when the driver exerts force on the clutch pedal. No noise is heard when the clutch pedal is up. Technician A says the pilot bearing is defective. Technician B says the input shaft bearing is defective. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
4. Which part does *not* rotate when the engine is running and the clutch is depressed?
   a. Clutch disc **c.** Pressure plate
   b. Pilot bearing **d.** Flywheel
5. The clutch pedal freeplay is less than specifications. Technician A says that the clutch may slip during hard acceleration. Technician B says that the clutch will "grab" when the clutch pedal is close to the floor when the clutch is engaged. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
6. What part is often *not* used on a front-wheel-drive vehicle with a manual transaxle?
   a. Flywheel **c.** Clutch fork
   b. Throwout (release bearing) **d.** Pilot bearing
7. Most hydraulic clutch systems use what hydraulic fluid?
   a. Mineral (hydraulic) oil **c.** DOT 3
   b. SAE 80W-90 **d.** ATF
8. A clutch is chattering when engaged. Technician A says that too much clutch freeplay is the cause. Technician B says that oil or grease may be on the friction disc. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
9. A manual transmission is difficult to shift or get into gear, especially reverse. Technician A says that the clutch may not be fully releasing. Technician B says that too much clutch pedal freeplay could be the cause. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
10. Two technicians are discussing bleeding a hydraulic clutch. Technician A says to open the bleeder and allow the fluid to gravity bleed. Technician B says to have an assistant slowly depress the clutch pedal as the bleeder valve is opened at the slave cylinder to bleed the air out of the system. Which technician is correct?
    a. Technician A only **c.** Both Technicians A and B
    b. Technician B only **d.** Neither Technician A nor B

chapter 122

MANUAL TRANSMISSIONS/ TRANSAXLES

OBJECTIVES: After studying Chapter 122, the reader will be able to: • Prepare for the ASE Manual Drive Train and Axles (A3) certification test content area "B" (Transmission Diagnosis and Repair) and content area "C" (Transaxle Diagnosis and Repair). • Explain how to calculate gear ratios. • Name the parts of a typical manually shifted transmission/transaxle. • Describe how the synchronizer assembly allows for smooth, clash-free shifting. • Describe the different types of lubricants that may be used in a manual transmission/transaxle. • Diagnose a difficult-to-shift manual transmission/transaxle. • Describe the service and overhaul procedures for manual transmission and transaxles.

KEY TERMS: Axis 1472 • Back taper 1480 • Bell housing 1476 • Bevel gear 1473 • Blocker ring 1477 • Cluster gears 1476 • Cluster shaft 1476 • Clutch 1476 • Constant-mesh gear 1482 • Counter gears 1476 • Countershaft 1476 • Direct drive 1474 • Drive gear 1473 • Driven gear 1473 • Extension housing 1476 • External gears 1472 • Fifth gear 1481 • Final drive assembly 1482 • First gear 1480 • Fourth gear 1481 • Front bearing retainers 1476 • Gear reduction 1474 • Helical gear 1472 • Hypoid gear set 1473 • Hub 1477 • Input shaft 1476 • Internal ring gears 1473 • Keys 1477 • Lay shaft 1476 • Main drive pinion assembly 1476 • Main gear 1476 • Main shaft 1476 • Neutral 1480 • Output shaft 1476 • Overdrive 1474 • Pinion gear 1473 • Quill 1476 • Reverse 1482 • Second gear 1481 • Sliding reverse gear 1482 • Sliding sleeve 1477 • Springs 1477 • Spur gear 1472 • Stop ring 1477 • Synchronizer assemblies 1477 • Synchronizer keys 1478 • Synchronizer ring 1477 • Third gear 1481 • Transmission case 1476

THE NEED FOR A TRANSMISSION

A vehicle requires a lot of torque to start off and to climb hills, yet it does not require as much torque to move on level ground. The source of the torque is the engine. Torque is a twisting or turning force that is exerted on the input shaft of a transmission/transaxle. An engine produces increasing torque as its speed increases up to a certain point where the torque output starts to decrease. Therefore, to get a vehicle moving or to accelerate up a hill, it is desirable to use a transmission that allows the engine speed to be increased even though the vehicle speed may be low. Using gears allows the engine speed to increase at low vehicle speeds yet still permits the engine speed to drop at higher speeds to save fuel and reduce exhaust emissions.

For example,

- First gear: Vehicle speed is low, engine speed is high.
- Second gear: Vehicle speed increases, engine speed decreases as shift is made.
- Third gear: Vehicle speed continues to increase, engine speed is kept in a narrow range.
- Fourth gear: Again, the vehicle speed is increasing, yet engine speed is about the same as in third gear.

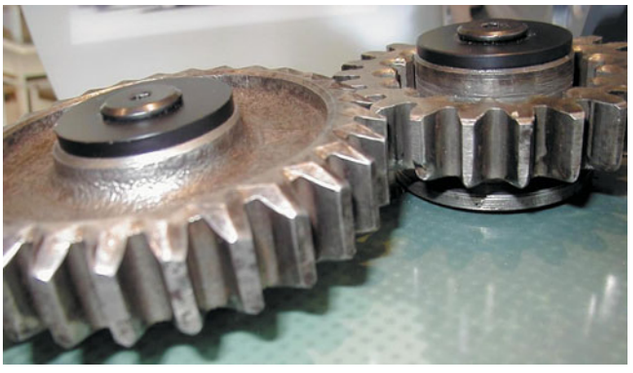


FIGURE 122–1 Spur gears have straight-cut teeth.

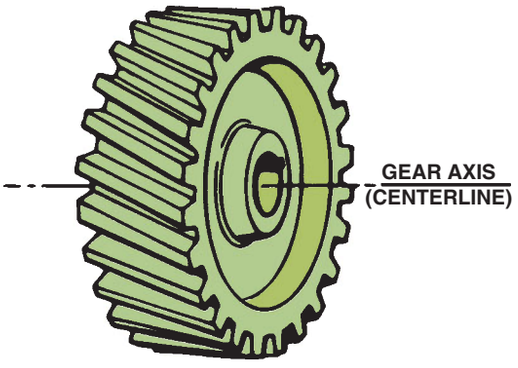


FIGURE 122–2 The teeth of a helical gear are cut at an angle to the gear axis.

GEAR TYPES

The simplest type of gear is the **spur gear.** ● **SEE FIGURE 122–1.** A spur gear consists of a gear blank with straight-cut teeth around its entire circumference. All gear teeth lie parallel to the centerline, or **axis,** of the gear. The teeth are shaped so they can mesh without slippage with a second spur gear's teeth positioned along a parallel axis.

Spur gear design permits 1.5 to 2.5 gear teeth to mesh at a time. The gear teeth make contact with each other over their full width at the same instant. The fact that the gear teeth are in full contact increases the strength of the gear, but also causes spur gear operation to be noisy. Due to their strength, most heavy-duty truck transmissions use spur gears.

A **helical gear,** although similar to a spur gear, has its teeth cut at an angle to the axis of the gear. ● **SEE FIGURE 122–2.** This enables more teeth, 2.5 to 3.5, to mesh at a time than the spur gear. Additionally, the angle allows the teeth to mesh gradually, rather than all at once. As a result, helical gears run quieter than spur gears. Helical gears, however, have two disadvantages. Each gear pushes against its shaft parallel to its axis. Special bearings are needed to protect the gearbox from this type of axial, or thrust, loading. Furthermore, because of the increased contact area, helical gears create more friction than spur gears. ● **SEE FIGURE 122–3.**

Spur and helical gears have gear teeth on their outside circumference and, for this reason, are called **external gears.** This

? FREQUENTLY ASKED QUESTION

What Is the Difference Between a Transmission and a Transaxle?

A transmission is used on rear-wheel-drive vehicles, whereas a transaxle is usually used on front-wheel-drive vehicles. A vehicle equipped with a transmission uses a separate differential to split the torque equally to the drive wheels. A transaxle includes a differential assembly. In a transaxle, the differential, sometimes called the *final drive unit,* is incorporated in the construction of the transmission.

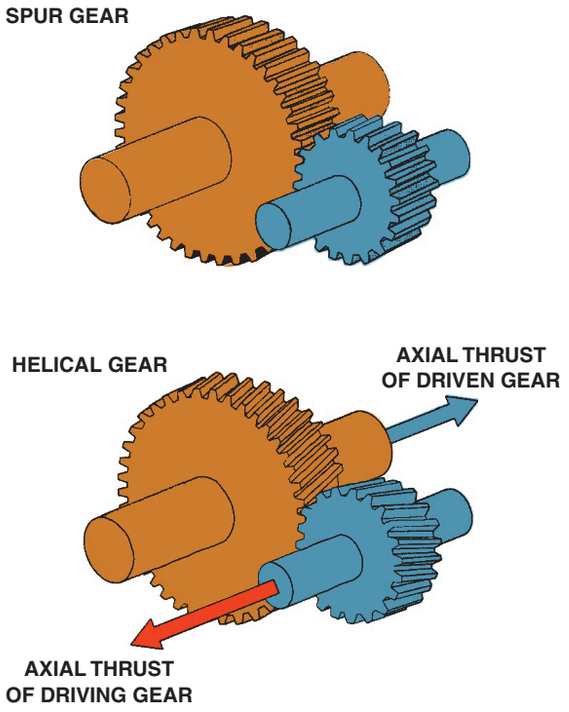


FIGURE 122–3 A spur gear has straight-cut teeth. This design is very strong and is used where strength is important. Spur gears are noisy during operation. Helical-cut gears, on the other hand, operate quietly but create a force in line with the axis of the gears due to the angle of the gear teeth.

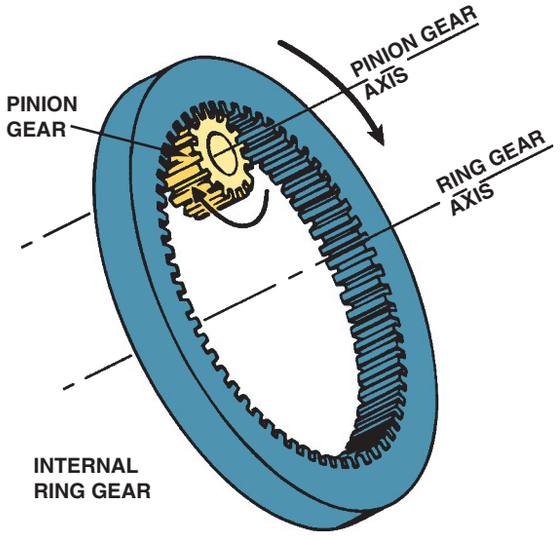


FIGURE 122–4 A pinion gear meshed with an internal ring gear rotates in the same direction around a parallel axis of rotation.

type of gear is the most commonly used in manual transmissions and transaxles.

Gears having teeth along the inside circumference are called **internal ring gears.** ● **SEE FIGURE 122–4.** The teeth of an internal ring gear may be spur or helical teeth. An internal ring gear may mesh with a smaller external gear designed to rotate as it travels around the inside of the internal ring gear. This type of external gear is called a **pinion gear** because of its smaller diameter.

When an external gear meshes with an internal ring gear, both gears rotate in the same direction, but when an external gear meshes with another external gear, the gears rotate in opposite directions as shown in ● **FIGURE 122–5.**

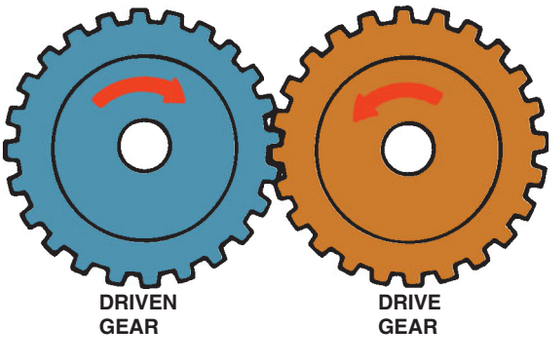


FIGURE 122–5 When two external gears mesh, they rotate in opposite directions.

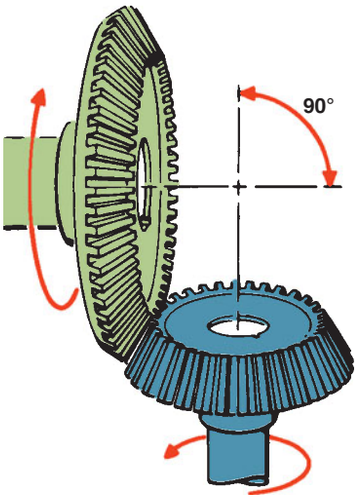


FIGURE 122–6 Bevel gears are often used to change the direction of rotation and are typically used in differentials.

BEVEL GEARS

The teeth of a **bevel gear** are cut at an angle to the outside gear surface. Simple bevel gears have straight-cut teeth similar to those on a spur gear. ● **SEE FIGURE 122–6.** Special gears used in a differential, called spider gears, are a common example of the simple bevel gear.

HYPOID GEARS

Hypoid gear sets have gear teeth that are curved much like the teeth of a spiral bevel gear. The pinion gear is offset below the centerline of the ring gear as shown in ● **FIGURE 122–7.** This design provides maximum gear tooth contact for strength, gradual tooth engagement, and quiet operation. Hypoid gears are generally available only as a matched set.

Hypoid gears are commonly used as the final drive gears in rear axles where load-carrying ability and low noise are important. The offset pinion allows the driveshaft to be positioned lower in the vehicle, reducing the size of the hump in the vehicle's interior.

GEAR RATIOS

When one gear turns another, the speed that the two gears turn in relation to each other is the gear ratio. Gear ratio is expressed as the number of rotations the **drive gear** must make in order to rotate the **driven gear** through one revolution. To obtain a gear ratio, simply

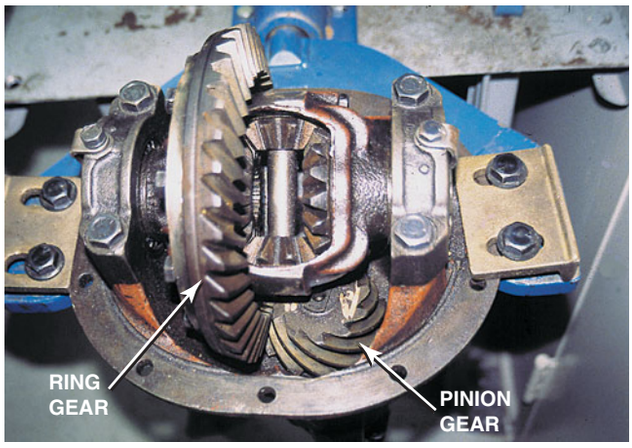


FIGURE 122–7 A differential uses a hypoid gear set to provide a change in the direction of torque and for gear reduction (torque increases) to the drive wheels.

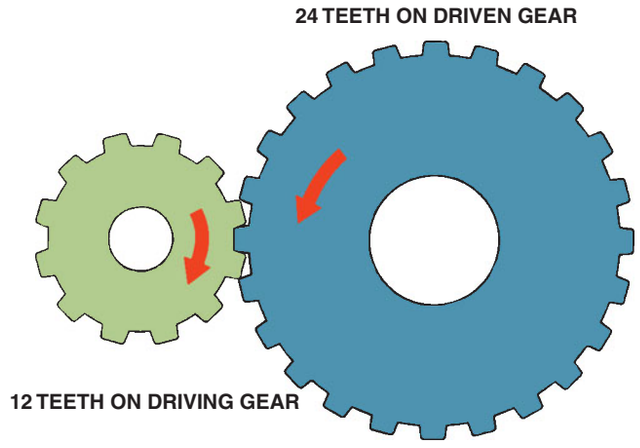


FIGURE 122–8 Gear ratio is determined by dividing the number of teeth of the driven (output) gear (24 teeth) by the number of teeth on the driving (input) gear (12 teeth). The ratio illustrated is 2:1.

divide the number of teeth on the driven gear by the number of teeth on the drive gear. Gear ratios, which are expressed relative to the number one, fall into three categories:

- Direct drive
- Gear reduction
- Overdrive

A gear ratio, is determined by dividing the number of teeth on the driven gear (output) by the number of teeth on the driving gear (input). ● **SEE FIGURE 122–8.**

$$\frac{\text{Number of teeth on the driven gear (24)}}{\text{Number of teeth on the driving gear (12)}} = 2{:}1$$

The gear ratio represents the number of turns of the input gear to one turn of the output gear. A transmission/transaxle usually uses two pairs of gears to achieve each gear ratio, and there may be four, five, or six forward gears plus reverse. When two pairs of gears are used to create a gear, simply multiply the two ratios together to get the gear ratio.

A low first-gear (high numerical) ratio creates a high amount of torque applied to the drive wheels to get the vehicle moving. To summarize what is occurring if the engine speed is constant:

First gear:

- Output shaft speed is a lot lower than engine speed.
- Output torque is a lot higher than the engine is producing.

Fifth gear:

- Output shaft speed is faster than the engine speed.
- Output torque is lower than the engine is producing.

DIRECT DRIVE If two meshed gears are the same size and have the same number of teeth, they will turn at the same speed. Since the drive gear turns once for each revolution of the driven gear, the gear ratio is 1:1; this is called a **direct drive.** When a transmission is in direct drive, the engine and transmission turn at the same speed.

GEAR REDUCTION If one gear drives a second gear that has three times the number of teeth, the smaller drive gear must travel three complete revolutions in order to drive the larger gear through one rotation. ● **SEE FIGURE 122–9.** Divide the number of teeth on the driven gear by the number of teeth on the drive gear and you get a 3:1 gear ratio (pronounced three to one). This type of gear

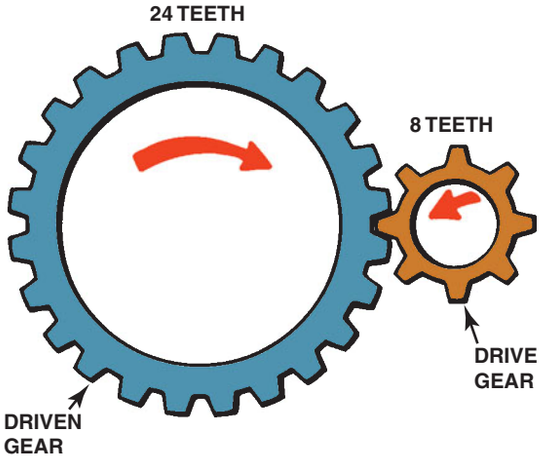


FIGURE 122–9 This gear combination provides a gear reduction of 3:1.

arrangement, where driven gear speed is slower than drive gear speed, provides **gear reduction.** Gear reduction may also be called underdrive as drive speed is less than, or under, driven speed. Both terms mean the same thing and use is a matter of preference.

Gear reduction is used for the lower gears in a transmission. First gear in a transmission is called "low" gear because output speed, not gear ratio, is low. Low gears have numerically high gear ratios. That is, a 3:1 gear ratio is a lower gear than those with a 2:1 or 1:1 gear ratio. These three ratios taken in order represent a typical upshift pattern from low gear (3:1), to second gear (2:1), to third gear (1:1).

OVERDRIVE **Overdrive** is the opposite of a gear reduction condition and occurs when a driven gear turns faster than its drive gear. For the gears shown in ● **FIGURE 122–10,** the driven gear turns three times for each turn of the drive gear. The driven gear is said to overdrive the drive gear. For this example, the gear ratio is 0.33:1. Overdrive ratios of 0.65:1 and 0.70:1 are typical of those used in automotive applications.

NOTE: Ratios always end in one with a colon in between. Therefore, the first number is less than one if it is an overdrive ratio and greater than one if it is a gear reduction ratio.

IDLER GEARS A gear that operates between the drive and driven gears is called a floating gear, or idler gear. ● **SEE FIGURE 122–11.** Idler gears do not affect the speed relationship between the drive

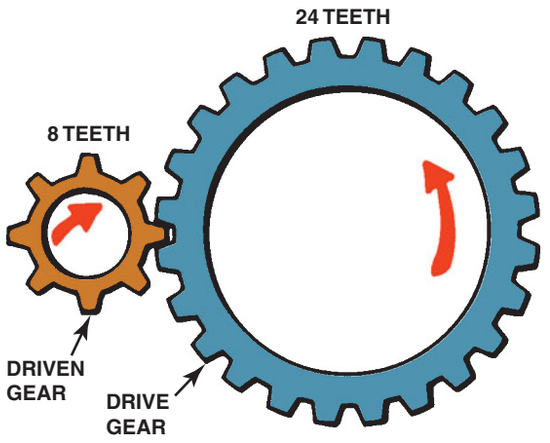


FIGURE 122–10 This gear combination provides an overdrive ratio of 0.33:1.

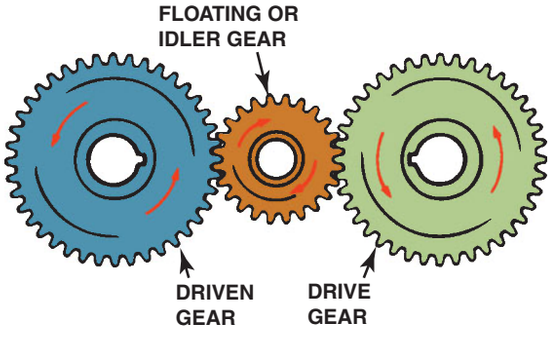


FIGURE 122–11 Idler gears affect the direction of rotation in a gear train, but not the final drive ratio.

and driven gears, although they do affect the direction of rotation. Reverse gear on a manual transmission often uses an idler gear to change the direction of rotation.

When a drive and driven gear mesh directly, they rotate in opposite directions. When an idler gear is installed between the drive and driven gears, both drive and driven gears rotate in the same direction.

TORQUE, SPEED, AND POWER

Torque is a twisting force commonly expressed in pound-feet (lb-ft) or Newton-meters (N-m). Gears apply torque much like a wrench does; each tooth of a gear is actually a lever. On a gear with a 2-foot radius, applying a force of 10 pounds to one gear tooth exerts 20 lb-ft of torque on the center of the shaft to which the gear attaches. ● **SEE FIGURE 122–12.**

TORQUE AND SPEED RELATIONSHIP Torque and speed have an inverse relationship: as one goes up, the other goes down. With a constant input speed, transmission torque decreases as output speed increases. The opposite also applies assuming a constant input speed, transmission torque increases as output speed decreases.

TORQUE MULTIPLICATION Levers can be used to increase or multiply torque. For example, a wheel that is too heavy for a person to turn by muscle power alone turns easily when that same

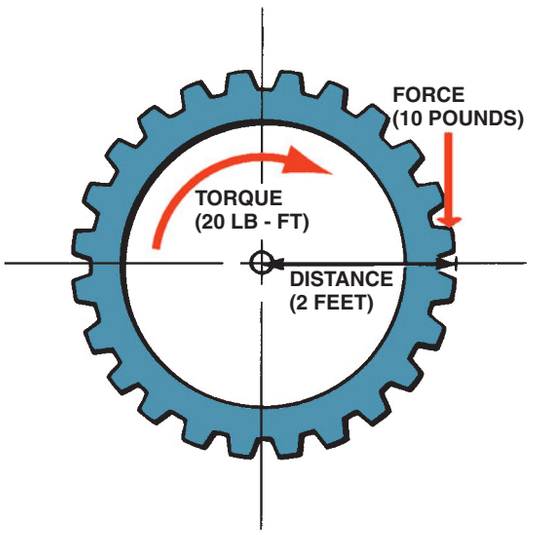


FIGURE 122–12 Gears apply torque in the same way a wrench applies torque—the force applied multiplied by the distance from the center of the gear equals the torque.

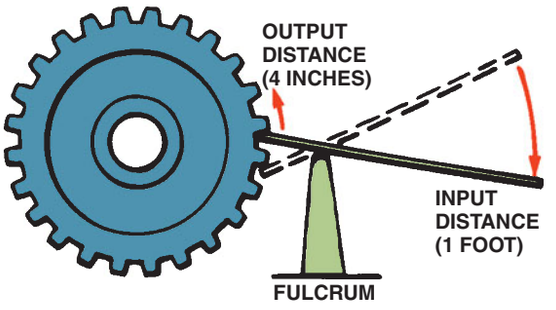


FIGURE 122–13 A lever can be used to multiply torque, but it does so at the expense of distance or speed.

person uses a lever and fulcrum to multiply the applied force. ● **SEE FIGURE 122–13.** The force, or torque, increases at one end, but the lever must be moved a greater distance at the opposite end to obtain the increase in force. Either distance or speed must always be given up in order to increase, or multiply, torque.

When two gears of the same diameter are meshed, the driven gear will turn at the same speed as the drive gear. Since there is no difference in speed, there is no difference in torque between the two gears.

If the drive gear is one-third the diameter of the driven gear, it must rotate three times for each rotation of the larger gear. This means that the larger gear will turn three times slower than the smaller gear. At the same time, the larger gear will exert three times the torque of the smaller gear. When speed decreases, torque increases. Torque multiplication and gear ratios are directly related. When a gear system is in reduction, there is more torque available at the driven gear, but less speed. When the gear system is in overdrive, there is less torque available at the driven gear, but greater speed.

ENGINE TORQUE CHARACTERISTICS The torque curve of an engine shows how much torque is available at different points within a range of engine speeds.

Because of these characteristics, torque multiplication must be provided between the crankshaft and drive axles to enable a vehicle to begin moving from a standstill and to accelerate at low speeds. Once engine RPM rises beyond the torque peak, a change in gear ratio brings engine speed back within the most efficient torque producing range.

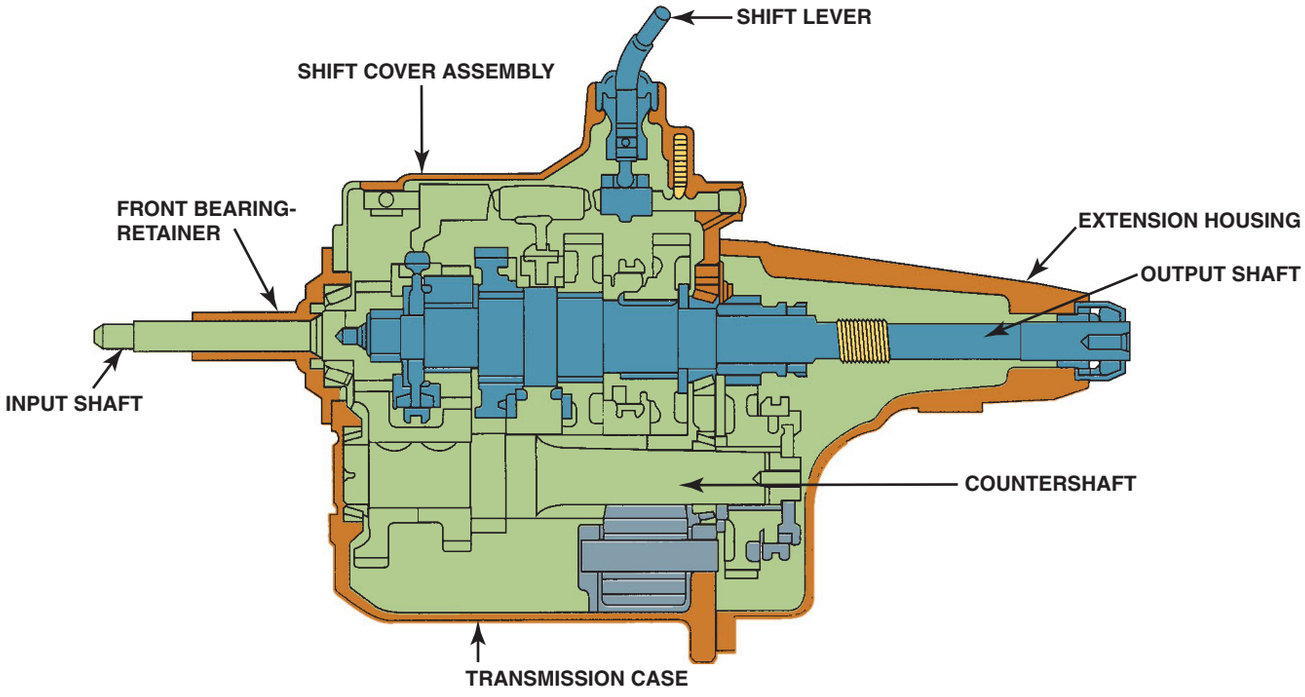


FIGURE 122–14 Cross section of a five-speed manual transmission showing the main parts.

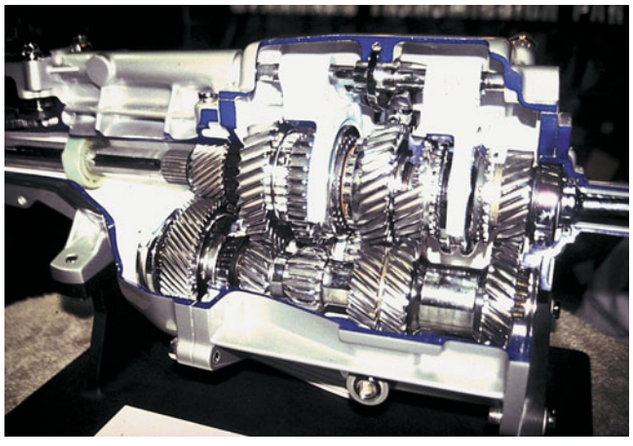


FIGURE 122–15 Cutaway of a six-speed manual transmission showing all of its internal parts.

FREQUENTLY ASKED QUESTION

What Is Meant by a 77 mm Transmission?

The size (77 mm or about 3 inches) is the distance between the center of the input shaft and the center of the countershaft. The greater this distance, the larger the transmission and the more torque it is capable of handling due to the larger gears.

TRANSMISSION CONSTRUCTION

A transmission is usually constructed of cast aluminum machined to accept the internal parts and strong enough to be a structural member of the drive train. The front of the transmission attaches to a separate **bell housing** or includes the bell housing as part of the casting of the transmission itself. At the front of the transmission (toward the engine) is the **front bearing retainer** (sometimes called the **quill**) that supports the clutch throwout (release) bearing and usually houses the front grease seal. The rear of the transmission usually includes a separate casting called the **extension housing.** The center housing is usually referred to as the **transmission case.** ● **SEE FIGURE 122–14.**

The **input shaft** is splined to the clutch disc and is also referred to as the **main gear, clutch gear,** or **main drive pinion assembly.** ● **SEE FIGURE 122–15.** The **main shaft,** also called the **output shaft,** is splined at the end and transmits engine torque to the drive shaft (propeller shaft) through a yoke and universal shaft.

All manual transmissions/transaxles use a **countershaft** (also called a **lay shaft** or **cluster shaft**) to provide the other set of gears necessary to achieve the changes in gear ratios. The gears on the countershaft are called **cluster gears** or **counter gears.**

TORQUE FLOW THROUGH A MANUAL TRANSMISSION

The engine torque is applied to the input shaft when the clutch is engaged (clutch pedal up). This torque is applied to the main gear, which is in constant mesh with the countershaft gear.

HINT: The fact that the countershaft is revolving any time the clutch is engaged makes transmission noise diagnosis easier.

The engine torque is multiplied by the ratio difference between the main gear and the cluster gear. The engine torque is then transferred and multiplied again when first gear is in mesh with the corresponding first gear on the main (output) shaft. Again, the torque is



FIGURE 122–16 Notice that the countershaft and the main shaft both use gears of increasing size that mesh together.

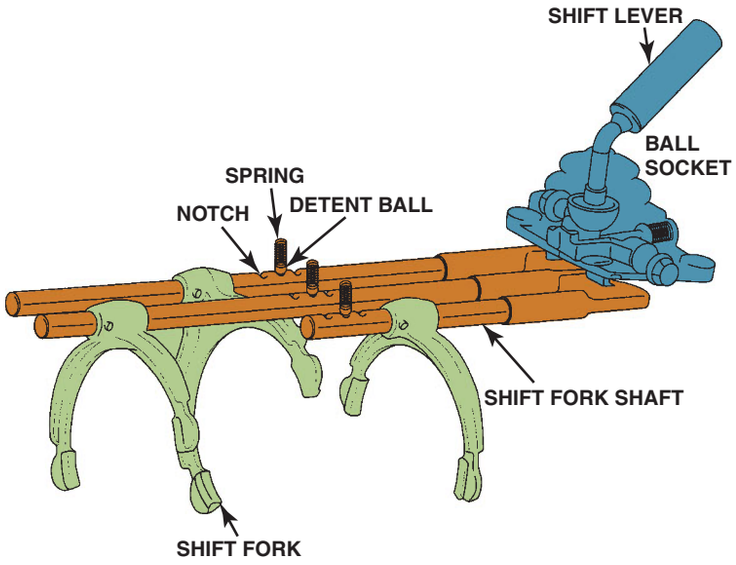


FIGURE 122–17 A typical shift mechanism showing the shift detents designed to not only give the driver a solid feel when shifting but also to prevent two gears from being selected at the same time. The shifter also prevents shifting into reverse except from the neutral position.

multiplied by the ratio difference between the two gears. The engine torque then is applied to the drive wheels through the driveshaft, differential, and drive axles.

SPEED GEARS

All gears on the countershaft are permanently attached to the shaft. When the countershaft rotates, all gears on the countershaft rotate. The input shaft gear is also part of the input shaft. However, the gears on the main shaft are free to move on the shaft and are connected to the main shaft through the synchronizer hub when a shift is made. The gears that rotate on the main shaft are called *speed gears* and are free to rotate on a film of oil or on bearings.

HINT: When assembling the main shaft and the countershaft, just remember that each shaft should look like a Christmas tree (tapered downward from the top). When installed in the transmission, these two "Christmas trees" are meshed together with the small gear end of one shaft meshing with the large gear end of the other shaft. ● SEE FIGURE 122–16.

SYNCHRONIZER PARTS AND OPERATION

Most vehicles today in a manually shifted transmission use a floor-mounted shifter to change gears. The shifting lever either moves cables that transfer the shifting motion to the transmission or transaxle or move the shift forks directly. Inside the transmission/transaxle are shift forks that control shifts between two gears, such as first and second or second and third. Interlocks either in the shifter linkage itself or inside the transmission/transaxle prevent the accidental selection of reverse except when shifting from neutral and also prevent selecting two gears at the same time. ● **SEE FIGURE 122–17.**

Synchronizers are used in manual transmissions/transaxles to make shifting easier. To synchronize means to make two or more events occur at the same time. When the driver depresses the clutch pedal, torque is no longer being transmitted to the input shaft and the drive wheels are "driving" the main shaft of the transmission/transaxle. To achieve a clash-free (no grinding sound) shift, the two gears to be meshed must be rotating at the same speed. The detents and interlocks hold the shift mechanism in position.

The real "shifting" in a synchromesh transmission takes place in the **synchronizer assemblies,** not the gears. Most synchronizer assemblies ride on the output shaft between two gears. A synchronizer assembly is named for the gears on either side of it, which are the two speeds that it engages. For example, a five-speed transmission with constant-mesh reverse uses a 1–2 synchronizer, 3–4 synchronizer, and a 5-reverse synchronizer.

SYNCHRONIZER CONSTRUCTION Although there are a number of design variations, all are similar and include a hub, a **sliding sleeve,** a **stop ring,** (or **blocker rings** or **synchronizer ring**), **keys,** and **springs.** In addition, the tapered cone and coupling teeth machined on the speed gear are part of the synchronizer assembly. ● **SEE FIGURE 122–18.** In a typical synchronizer:

- Splines attach the center **hub** of the synchronizer to the output shaft, so the hub and output shaft rotate together. There are also splines machined on the outer circumference of the hub.
- An outer sliding sleeve rides on the external hub splines with enough clearance so that it slides freely. The splines on the sleeve also match the small coupling teeth of the stop ring and speed gear. Coupling teeth are also called engagement

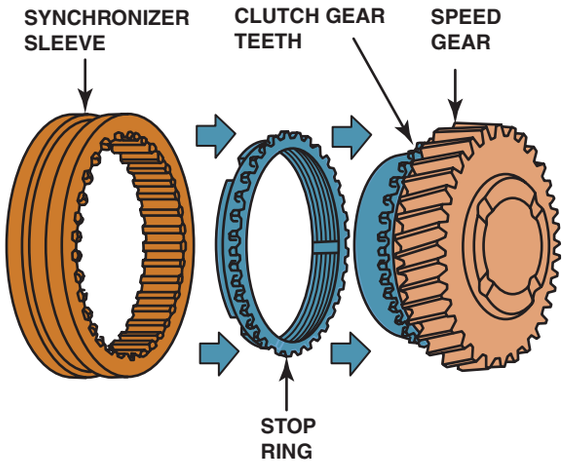


FIGURE 122–18 The shifter fork fits into the groove of the synchronizer sleeve. When a shift is made, the sleeve is moved toward the speed gear. The sleeve presses the stop ring (synchronizer ring) against the cone area of the speed gear. The friction between the stop ring and the speed gear causes the speed of the two to become equal, permitting the sleeve to engage the gear clutch teeth of the speed gear. When this engagement occurs, the shift is complete.



FIGURE 122–19 Typical synchronizer assembly.

or clutch teeth. The sleeve is splined to the hub, so it rotates with the output shaft.

- A **stop ring** sits between the speed gear and the sleeve. The coupling teeth on the stop ring match those on both the sleeve and the speed gear. The stop ring also has a tapered cone to match the cone machined on the speed gear.
- Small, spring-loaded detent keys, also called **synchronizer keys** or **struts,** ride in slots on the outer sleeve. The stop ring has slots to match these keys. This allows the stop ring to rotate slightly, relative to the sleeve, before the keys hit the sides of their slots and stop the stop ring. As the sleeve moves, the synchronizer keys move with it, which pushes the blocking ring onto the tapered cone of the speed gear.

SYNCHRONIZER OPERATION

When the outer sliding sleeve is centered on the hub, the synchronizer is in its neutral position—it does not contact either of the speed gears. ● **SEE FIGURE 122–19.** To shift into gear, the driver disengages the clutch and moves the shift linkage. The shift linkage, which is described later in this chapter, pushes the sleeve toward one of the speed gears. As the sleeve moves, the detent keys help guide the stop ring toward the speed gear. This causes the ring cone to slide onto the tapered cone of the speed gear.

The speed gear is turning because it is in constant mesh with a countershaft gear. However, the gear may not be turning at the same speed as the synchronizer assembly even though both are on the same shaft. When the clutch is disengaged, the engine is no longer driving the transmission, so there is no torque applied to the input shaft, and the countershaft, or cluster gear, simply freewheels. As the shift is made, the stop ring acts as a brake to slow down the gear so that its speed matches the speed of the synchronizer assembly. That is, it synchronizes the shift. This matched speed allows the internal hub splines to easily engage the coupling teeth on the stop ring and speed gear. When the clutch disengages, the crankshaft drives the input shaft, which drives the countershaft, which drives the output shaft through the selected gear.

The synchronizer goes through three stages during a shift:

1. As the shift is selected, the sliding sleeve moves towards the speed gear. If the speeds of the sliding sleeve (main shaft) and the speed gear (counter shaft) are not identical, the speed difference will cause the tapered cone to "mis-align" the teeth of the sleeve, the stop ring, and the speed gear. This "blocks" the shift. Now, the tapered teeth of the sliding sleeve push against the teeth of the stop ring, which in turn pushes the stop ring tapered surface up against the tapered surface of the speed gear. This causes the speed gear to either speed up or slow down based on the difference between the main shaft speed (hub) and the counter gear speed (speed gear). When the speeds are equal, the thrust is released on the tapered surface which now allows the "alignment" of the sliding sleeve teeth, the stop ring teeth and the speed gear teeth which allows the shift to be completed. ● **SEE FIGURE 122–20.**
2. The sleeve overcomes the force of the detent key springs as the shift linkage continues to move it toward the gear. This allows the stop ring to relax and move slightly so that the sleeve splines begin to engage the coupling teeth on the stop ring. At this point, the coupling teeth on the stop ring and the speed gear may not line up with each other. However, friction continues to build between the ring and the cone, so the gear continues to slow down.
3. Once the sleeve, stop ring, and gear are all turning at the same speed, it takes just a small movement between the stop ring and gear to align the coupling teeth and allow the sleeve to slip completely over both sets. The speed gear is now locked to the output shaft through the synchronizer stop ring and sleeve. ● **SEE FIGURE 122–21.**

Synchronizer stop rings are a simple type of clutch, called a cone clutch for the shape of the mating surfaces. Some manufacturers refer to the synchronizer action as "clutching."

Synchronizer sleeves and hubs are gear-quality steel. Stop rings are a softer metal—usually brass, copper, or a sintered metal—to absorb the friction of synchronizer operation. The tapered cone is relieved, that is grooves are machined into its contact surface. These grooves serve two purposes; they

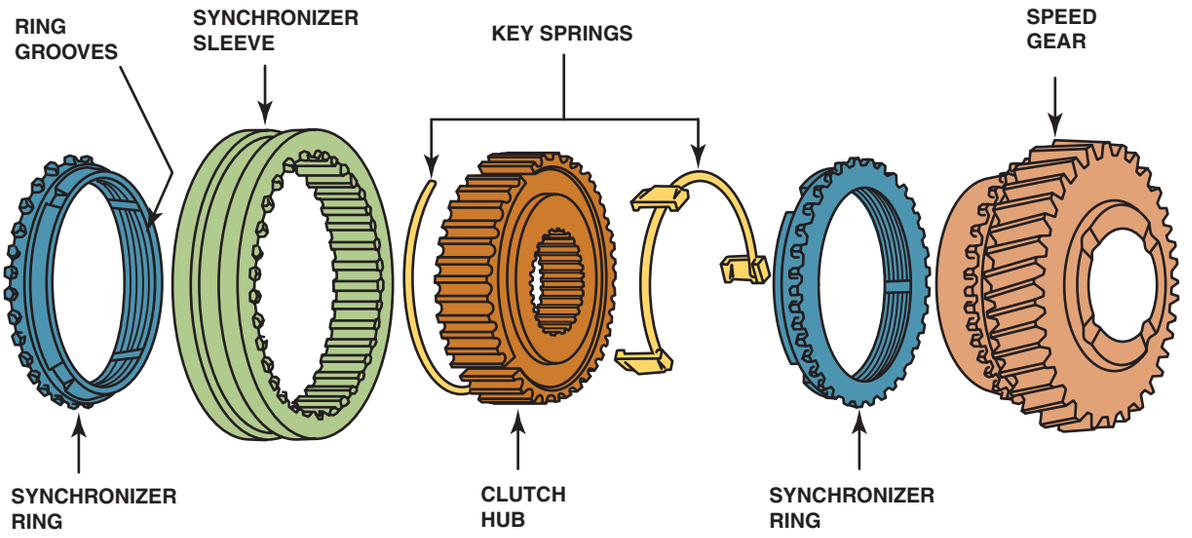


FIGURE 122–20 Synchronizer keys are attached to the clutch hub and push against the synchronizer ring when the sleeve is being moved during a shift. Notice the grooves on the synchronizer ring. These grooves prevent lubricating oil from becoming trapped between the ring and the cone surface of the speed gear. The grooves also help the ring release from the cone surface when a shift is made out of a gear.

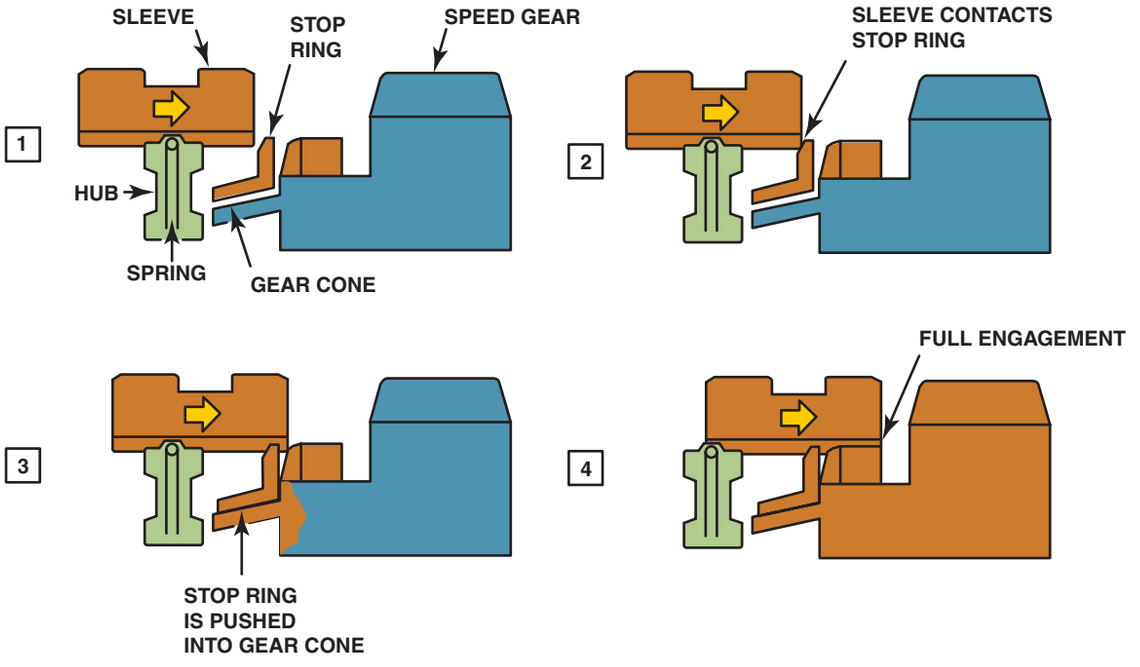


FIGURE 122–21 A shift sequence starts when the shift fork is moved by the driver, (1) applying a force on the sleeve that moves it toward the speed gear. (2) The sleeve and the inserts contact the stop ring (blocking ring). (3) The synchronizer ring (stop ring) engages the cone on the speed gear, causing both assemblies to reach the same speed. (4) The shift is completed when the internal teeth of the sleeve mesh with the gear clutch teeth of the speed gear.

FREQUENTLY ASKED QUESTION

What Do the Keys Do?

The keys are there to limit the amount of rotation of the ring from 1/2 tooth misaligned in the forward direction, to 1/2 tooth misaligned in the "coast" direction so that both upshifts and downshifts can be made. The detent key springs are designed to "push up" on the keys which have a "bump" on them that aligns with a notch in the inside center of the sliding sleeve. This upward pressure tends to keep the sliding sleeve in the neutral position and prevents unwanted movement toward another unwanted gear.

- Channel excess lubricant out from between the two pieces for better contact.
- Retain a small amount of lubricant. This decreases wear when the cone clutch must slip slightly during coupling tooth alignment.

The internal splines on the synchronizer sleeve and the coupling gear teeth on stop rings and speed gears have a special shape that works to hold the gear engaged once the driver releases the shift lever. The ends of the gear teeth are chamfered, giving them a triangular shape. These pointed ends allow easier sleeve-to-gear alignment as the angles tend to center the splines between the teeth.

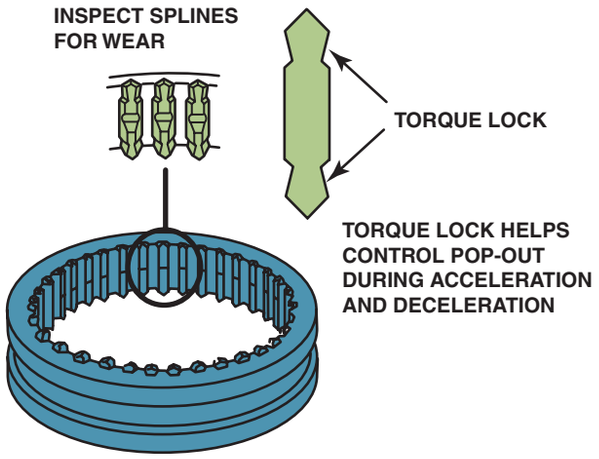


FIGURE 122–22 Before reassembling the transmission/transaxle, carefully inspect the splines on the synchronizer sleeves for wear. The shape of the splines helps prevent the transmission/transaxle from jumping out of gear during acceleration and deceleration.

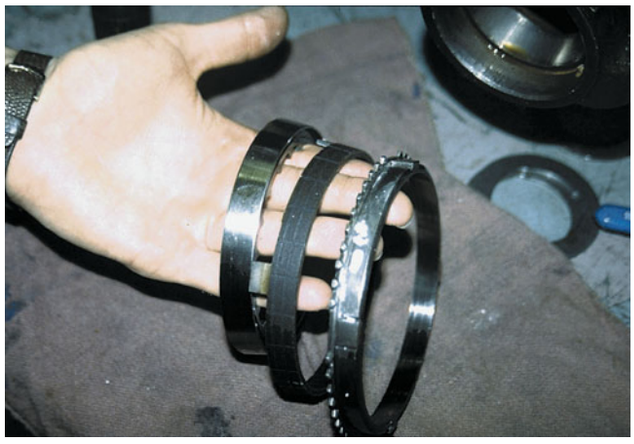


FIGURE 122–23 A three-piece synchronizer assembly. This type of synchronizer uses two cones, which helps achieve a smooth shift with less driver effort. Many newer transmissions/transaxles use a paper lining similar to that of the clutches in an automatic transmission. The transmissions/transaxles that have these paper linings must use automatic transmission fluid (ATF) for proper operation and long life.

Once aligned, a back taper machined behind the chamfered end of the teeth and splines tends to keep the sleeve in place until the linkage pushes the sleeve away for another shift. **Back taper** is an angle cut opposite to the chamfer so that spline or tooth narrows just behind the chamfered end. ● **SEE FIGURE 122–22.** The back taper creates resistance to motion to keep the splines from sliding off the coupling teeth. This is especially important when there is no torque load, such as coasting, to help keep the parts meshed. Worn back taper may cause the transmission to jump out of gear, usually when the throttle is released.

Some synchronizer stop rings have friction material on the cone surface. This paper friction material is the same as used on automatic transmission clutch plates, and provides a smoother synchronizing action than metal-to-metal contact. A manual transmission with paper stop rings must use automatic transmission fluid (ATF). Other lubricants damage the paper ring surface. ● **SEE FIGURE 122–23.**

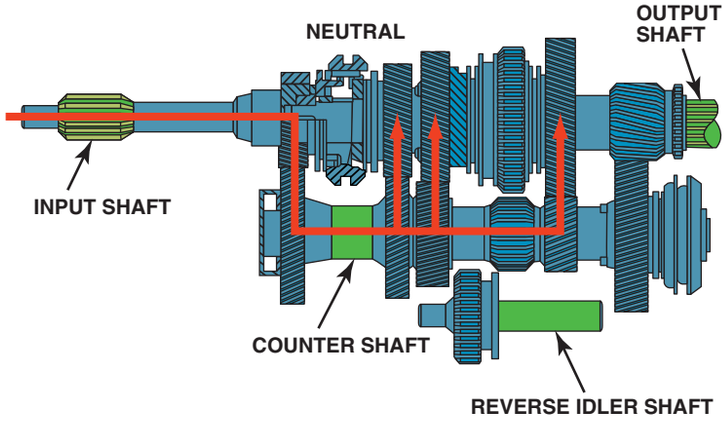


FIGURE 122–24 In neutral, the input shaft and the countershaft are rotating if the clutch is engaged (clutch pedal up), but no torque is being transmitted through the transmission.

FIVE-SPEED TRANSMISSION TORQUE FLOW

This section describes how power is transmitted through a typical five-speed transmission. Although minor differences exist among different designs, the basic pattern of torque flow, also called power flow, is similar for most gearboxes. The concept of torque flow, or torque transfer, is the same for any transmission, regardless of the number of gear ratios available. The differences are in how the parts assemble and where they are located in the transmission.

FIVE-SPEED TRANSMISSION A five-speed transmission has six gear sets that provide five forward speeds and one reverse speed. Either a sliding gear or constant-mesh gears may be used for reverse. All forward gears are the constant-mesh type. The Borg-Warner T5 manual transmission serves as an example of a contemporary five-speed design. In addition to reverse, the T5 provides three gear reduction ratios (first, second, and third), direct drive (fourth), and an overdriven ratio (fifth). A sliding idler gear is used to change output shaft direction and provide reverse.

NEUTRAL. In **neutral,** all of the synchronizer sleeves are centered on their hubs as shown in ● **FIGURE 122–24.** Note that in this and the following illustrations the reverse idler shaft and sliding gear have been repositioned for clarity. In actuality, the assembly is positioned so it meshes with the reverse gears of the countershaft and output shaft simultaneously.

With the clutch engaged, the drive gear of the input shaft turns the cluster gear, or countershaft. The speed gears are driven by the cluster gears, but rotate freely, on the output shaft. The output shaft may turn if the vehicle is moving or coasting, but no engine torque being transferred through the transmission.

FIRST GEAR. In **first gear,** the shift linkage slides the 1–2 synchronizer sleeve rearward toward the first speed gear. ● **SEE FIGURE 122–25.** The synchronizer assembly locks the speed gear to the output shaft.

With the clutch engaged, the input shaft drives the countershaft, delivering engine torque to the gearbox. Torque transfers from the first counter gear to the first speed gear, which drives the output shaft through the 1–2 synchronizer hub splines. Torque flows through the transmission in gear reduction at the first gear ratio.

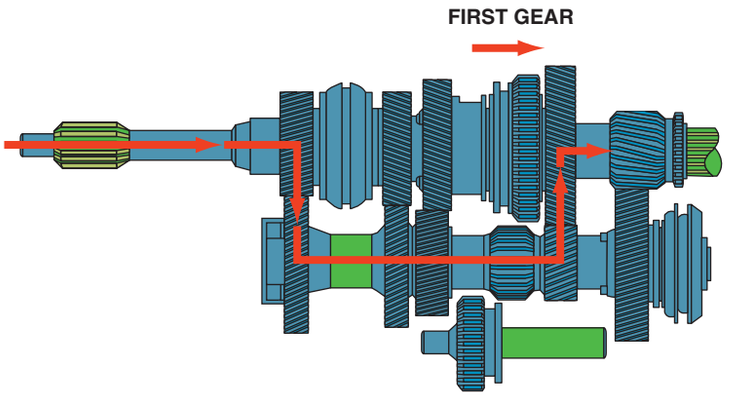


FIGURE 122–25 In first gear, the 1–2 synchronizer sleeve is moved rearward, locking the first speed gear to the output shaft. Torque is transmitted from the input shaft to the countershaft and then to the output shaft.

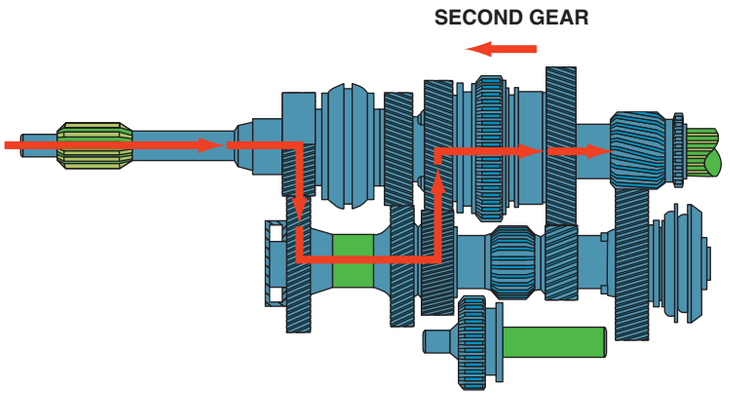


FIGURE 122–26 In second gear, the 1–2 synchronizer sleeve is moved forward, which locks the second speed gear to the output shaft.

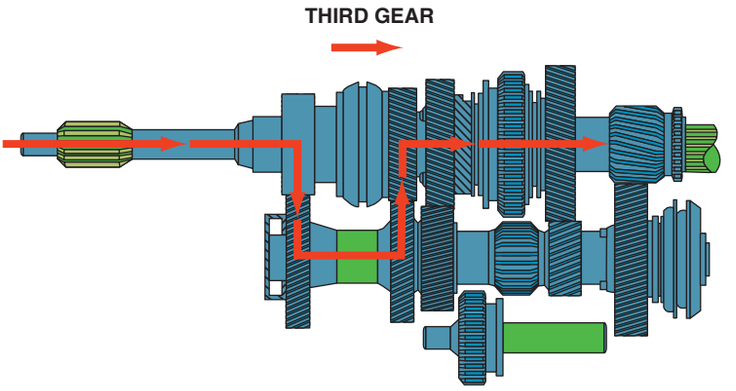


FIGURE 122–27 To achieve third gear, the shaft linkage first centers the 1–2 synchronizer sleeve and then moves the 3–4 synchronizer sleeve rearward, locking third speed gear to the output shaft.

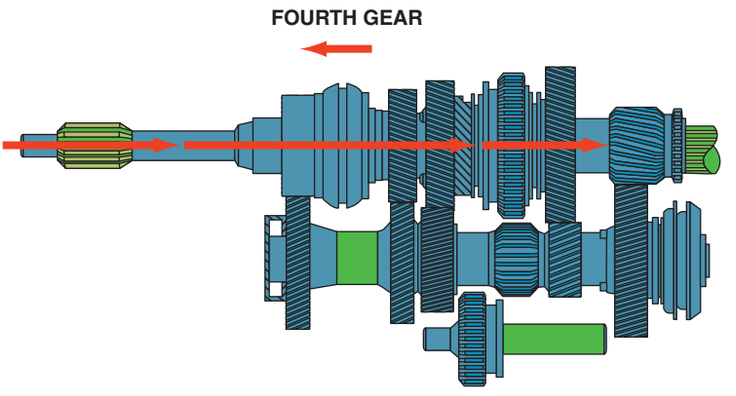


FIGURE 122–28 In fourth gear, the 3–4 synchronizer sleeve is moved forward, which locks the fourth speed gear to the output shaft.

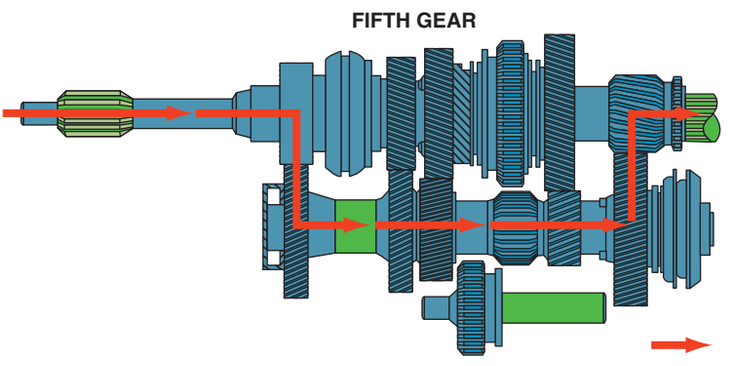


FIGURE 122–29 To achieve fifth gear, the shift linkage first centers the 3–4 synchronizer sleeve and then moves the fifth synchronizer sleeve toward the fifth speed gear, locking it to the output shaft.

SECOND GEAR. In **second gear,** the shift linkage slides the 1–2 synchronizer sleeve forward, away from the first speed gear and toward the second speed gear. ● **SEE FIGURE 122–26.** The synchronizer assembly releases first gear, then locks the second speed gear to the output shaft.

With the clutch engaged, the input shaft is driven at crankshaft speed and turns the countershaft. Engine torque transfers from the second counter gear to the second speed gear, which drives the output shaft through the 1–2 synchronizer hub splines. Torque flows through the transmission in gear reduction at the second gear ratio.

THIRD GEAR. In **third gear,** the shift linkage centers the 1–2 synchronizer sleeve and moves the 3–4 synchronizer sleeve back toward the third speed gear. ● **SEE FIGURE 122–27.** The synchronizer assembly locks the third speed gear to the output shaft.

With the clutch engaged and the input shaft driving the countershaft, the third counter gear transfers torque to the third speed gear. The speed gear drives the output shaft through the 3–4 synchronizer hub splines. Torque flows through the transmission in gear reduction at the third gear ratio.

FOURTH GEAR. In **fourth gear,** the shift linkage moves the 3–4 synchronizer sleeve forward, away from the third speed gear and toward the input shaft drive gear. ● **SEE FIGURE 122–28.** The synchronizer assembly locks the input shaft drive gear to the output shaft.

With the clutch engaged, the input shaft drives the output shaft through the 3–4 synchronizer hub splines and both shafts rotate at crankshaft speed. Torque flows straight through the transmission at a 1:1 ratio, delivering engine torque to the drive shaft. This is called direct drive because there is no gear reduction through the transmission. The counter gears also turn because they are in constant mesh, but they do not affect torque flow because all of the speed gears are freewheeling on the output shaft.

FIFTH GEAR. In **fifth gear,** the shift linkage centers the 3–4 synchronizer sleeve and moves the fifth synchronizer sleeve toward the fifth speed gear. ● **SEE FIGURE 122–29.** Note that on the T5 transmission

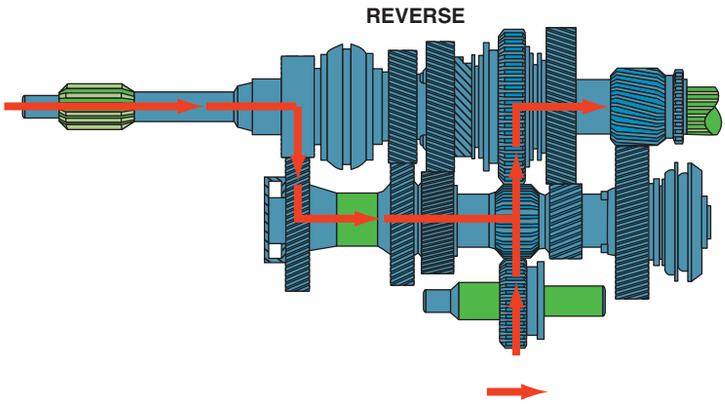


FIGURE 122–30 Torque flows through the transmission in reverse gear. Note that the idler gear drives the 1–2 synchronizer sleeve gear, which is splined to the output shaft.

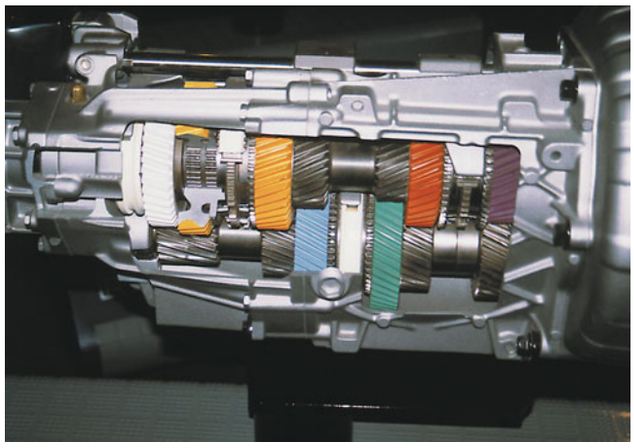


FIGURE 122–31 Cutaway of a T56 six-speed transmission showing all of its internal parts.

the synchronizer assembly locks the fifth speed gear to the countershaft. The speed gear drives a fixed gear on the output shaft.

With the clutch engaged, the input shaft drives the countershaft. The fifth synchronizer hub is splined to the countershaft, so it is driven and driving the fifth speed gear when fifth gear is engaged. This transfers engine torque to the output shaft through the fixed fifth gear. Note the countershaft gear is larger than the output shaft gear. Therefore, fifth gear is overdriven. Torque flows through the transmission at the fifth gear, or overdrive, ratio. Typical overdrive gear ratios are between 0.6:1 and 0.8:1. This lowers engine speed for economical highway cruising.

On some five-speed transmissions, the fifth speed gear is on the output shaft with the other speed gears. This type of arrangement is typically used with constant-mesh reverse gears. In these designs, fifth and reverse gears share a synchronizer assembly. The fixed countershaft gear drives the speed gear, which drives the output shaft through the hub splines when the sliding sleeve is engaged. Torque flow through the transmission is similar to any of the gear reduction forward speeds detailed above, but the fifth speed gear is generally overdriven.

REVERSE. There are two common **reverse** gear designs used on transmissions:

1. Sliding gear.
2. Constant-mesh gear.

With a **sliding reverse gear** design, such as on the Borg-Warner T5, the shift linkage slides the reverse idler gear on its shaft until it engages the reverse gears on the countershaft and output shaft gear. Both gears are fixed to their respective shafts. This design uses spur gears for reverse, not helical gears, because the gear teeth must move into and out of mesh. On some gearboxes, the sliding gear splines to the output shaft. The linkage moves the gear along the output shaft splines to engage the reverse idler gear.

An unusual feature of the Borg-Warner T5 is that it does not have a separate reverse output shaft gear. ● **SEE FIGURE 122–30.** Instead, spur teeth machined around the outside of the 1–2 synchronizer sleeve act as the reverse output gear. When the T5 is shifted into reverse, the linkage moves the reverse idler gear rearward so it simultaneously meshes with the countershaft reverse gear and the gear on the synchronizer sleeve.

When the clutch is engaged, the countershaft is driven and the reverse gear drives the idler gear, which rotates in the opposite direction of the countershaft. The idler gear drives the 1–2 synchronizer sleeve, so there is another directional change in rotation. Although the sleeve is not engaged to a speed gear, it remains splined to the output shaft, so the sleeve drives the output shaft when the idler gear is engaged. The output shaft rotates in the opposite direction of the input shaft because the idler gear is between them.

With **constant-mesh gears,** the shift linkage moves the 5-reverse synchronizer sleeve away from the fifth speed gear and toward the reverse speed gear when reverse is selected. Typically, no stop ring is used between the synchronizer sleeve and the reverse gear, so the output shaft must be stopped to engage reverse without grinding the sleeve splines against the coupling teeth of the reverse gear. The synchronizer assembly locks the reverse speed gear to the output shaft.

With the clutch engaged, the input shaft drives the countershaft. The reverse counter gear drives the reverse idler gear, which drives the reverse speed gear in the direction opposite normal rotation. The reverse speed gear drives the output shaft through the 5-reverse synchronizer hub splines. Torque flows through the transmission in gear reduction at the reverse gear ratio. The output shaft turns opposite its normal direction of rotation, so the vehicle moves to the rear. ● **SEE FIGURE 122–31.**

MANUAL TRANSAXLE CONSTRUCTION

A manually shifted transaxle includes an input shaft, an output shaft, and a differential assembly all in one case. The input shaft is attached to the clutch, which transfers engine torque from the engine flywheel to the input shaft when the clutch is engaged. Most transaxles use speed gears and synchronizers on both the input and output shafts, as shown in ● **FIGURE 122–32.** The differential assembly, also called a **final drive assembly,** attaches to the output shaft and splits the torque to both front drive axles. ● **SEE FIGURE 122–33.**

TRANSMISSION/ TRANSAXLE REMOVAL

Before removing the transmission/transaxle for service, double-check that the problem is not due to any malfunction of the clutch or shift linkage. To remove a transmission or transaxle, always follow

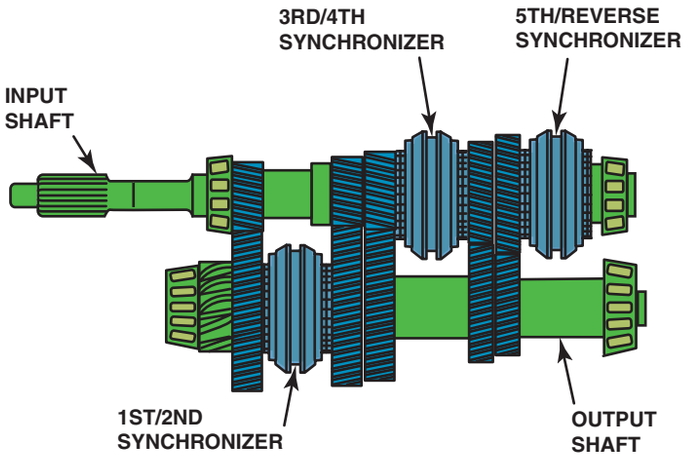


FIGURE 122–32 Notice that this five-speed transaxle from a Dodge/Plymouth Neon uses synchronizers on both the input and output shafts.

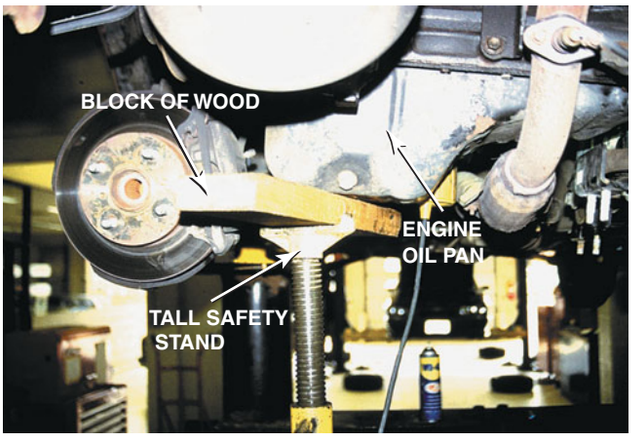


FIGURE 122–34 When the transmission/transaxle is removed from the vehicle, the engine must be supported. In this case, the engine oil pan is supported with a block of wood to spread the load across the entire oil pan to prevent damage. The block of wood is placed on top of a tall safety stand that allows room for the service technician to work while standing.

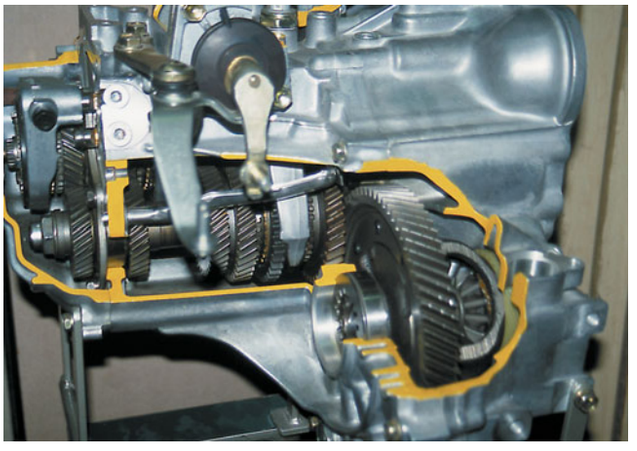


FIGURE 122–33 Cutaway of a typical manual transaxle showing all of its internal parts including the final drive assembly.

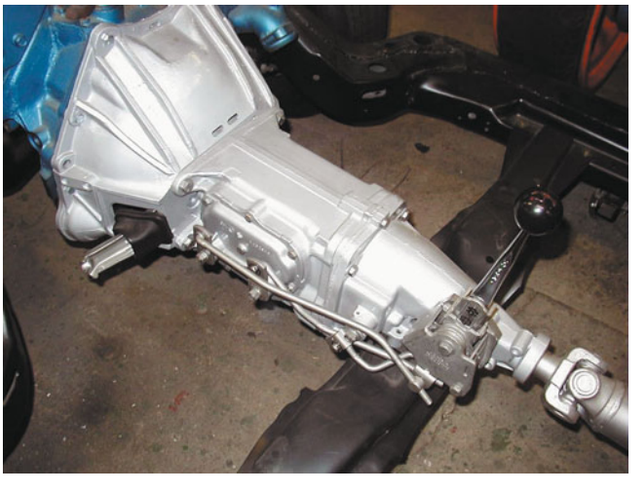


FIGURE 122–35 A transmission from a restored muscle car from the 1970s. Notice the use of external control rod shift linkage.

the procedure in the service manual to be assured of doing no harm to either the vehicle or to yourself. Steps typically involved in the removal and disassembly include

- Disconnecting the negative battery cable
- Safely hoisting and supporting the vehicle
- Supporting the engine with a holding fixture or other support (front-wheel-drive). ● **SEE FIGURE 122–34.**
- Removing the drive axle shafts or drive shaft (rear-wheel-drive)
- Removing the clutch linkage and shift linkage. ● **SEE FIGURES 122–35 AND 122–36.**
- Disconnecting the vehicle speed sensor and reverse (backup) light connectors
- Removing the attaching bolts/nuts from the engine and transmission/transaxle mounts and then removing the unit from the vehicle

Sometimes it is easier to remove the entire power train (engine and transaxle as an assembly) from the vehicle, as shown in ● **FIGURE 122–37.** When the entire assembly has been removed from the vehicle, often the transaxle can then be removed from the engine.

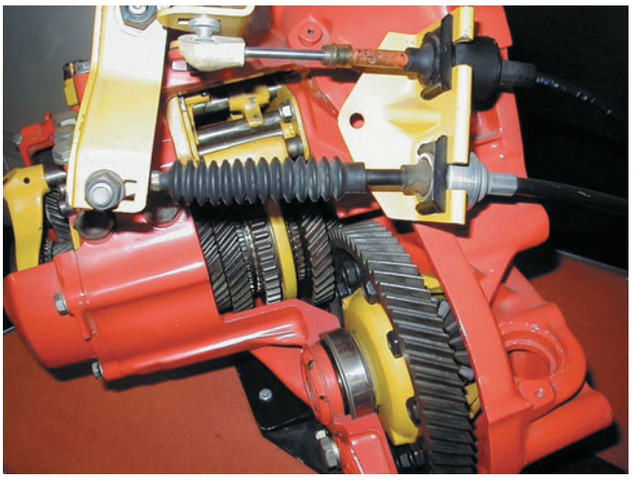
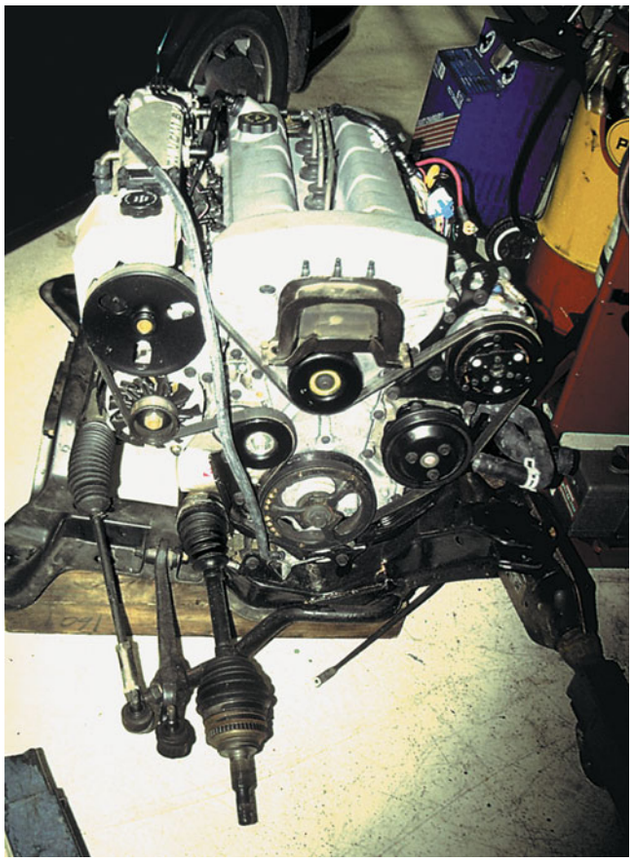
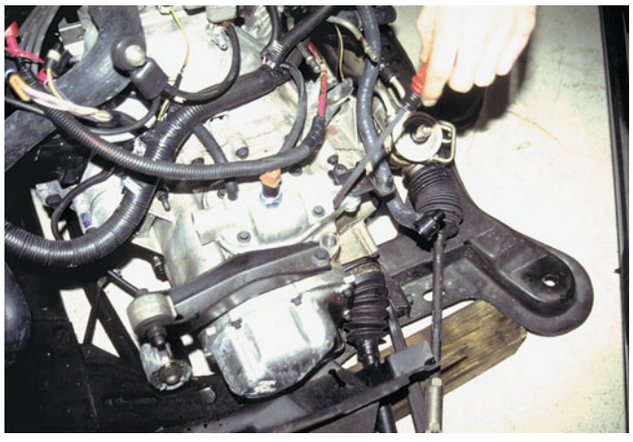


FIGURE 122–36 Typical cable-operated shift linkage used on a front-wheel-drive transaxle.



(a)



(b)

FIGURE 122–37 (a) Saturn drive train is removed as an assembly along with the cradle. (b) The transaxle can now be easily removed from the cradle and the engine.

TRANSMISSION/ TRANSAXLE DISASSEMBLY

Before disassembling the transmission/transaxle, drain any remaining gear lubricant from the unit and dispose of it properly.

CAUTION: Most extreme pressure (EP) lubricants contain sulfur compounds that can cause skin irritation. Either wear protective gloves or wash your hands thoroughly using soap and water after exposure to used gear lubricant.

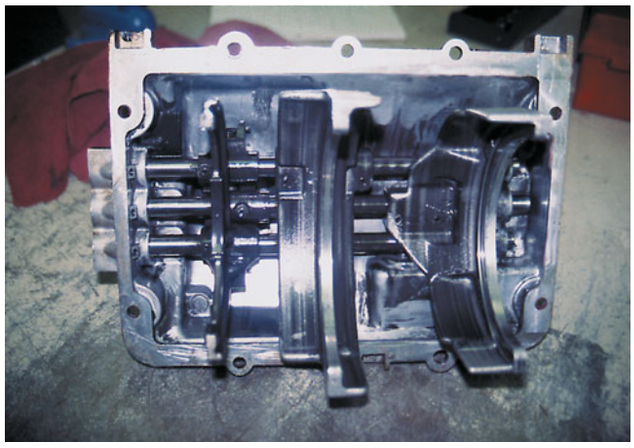


FIGURE 122–38 The shift forks should be inspected for wear.

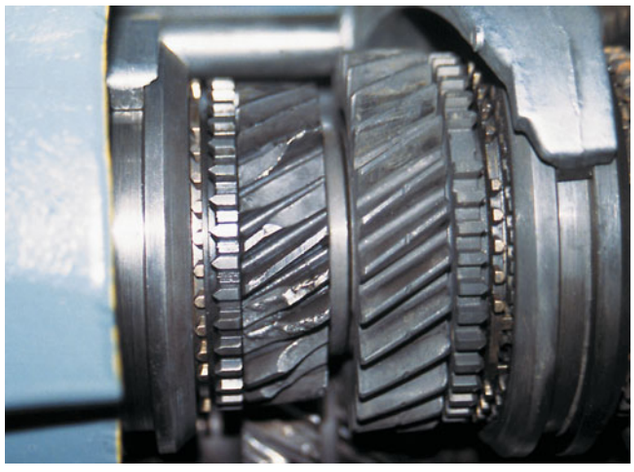


FIGURE 122–39 The cost to replace these gears may exceed the cost of a replacement transmission.

TECH TIP

Manual Transmission Service Tips

A wise technician once told a beginning technician to remember these items when working with transmissions:

- Always use a *brass* or *plastic* hammer when pounding on a steel or aluminum component.
- If using a steel hammer, always use a *brass* or *aluminum* punch or place wood between the steel components and the hammer.
- Many parts can be installed in either direction but usually only one way is correct.
- If you are exerting a lot of force, you are probably doing something wrong.
- Many drive train parts are pulled or pressed off and pressed or driven on.

Mount the transmission/transaxle on a holding fixture or place it on a large, clean work surface. Many vehicle manufacturers recommend removing the shift housing before further disassembly. The removal of the shifter housing allows the technician to see any obvious damage as well as providing the opportunity to check the shift forks, which are frequently worn in manually-shifted transmissions/transaxles. ● **SEE FIGURES 122–38 AND 122–39.**

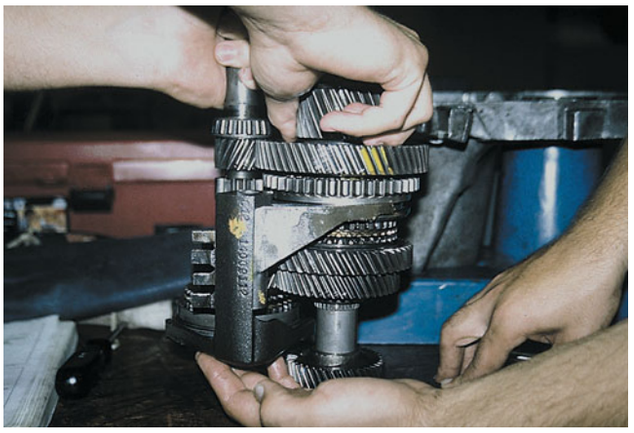


FIGURE 122–40 It often requires two people to assemble a transaxle because the shaft with the shifter forks needs to be placed into the case as an assembly, as on this unit.

The disassembly and reassembly of a manual transaxle is similar to that for a manual transmission except for the addition of the final drive unit. Some transaxles require two people for disassembly and reassembly because often the shift linkage has to be held in place while assembled components are placed into the case, as shown in ● **FIGURE 122–40.**

Check the service manual for the exact disassembly procedures to follow for the unit being serviced. Sometimes the main shaft is removed through the rear of the transmission and sometimes it is removed through the top of the case. Also look for hidden snap rings. ● **SEE FIGURES 122–41 AND 122–42.** Also see the Tech Tip titled "Manual Transmission Service Tips."

HARD-TO-SHIFT PROBLEM DIAGNOSIS

Several items that could be worn or defective can cause a manual transmission/transaxle to be difficult to shift, including

- **Clutch not fully disengaging.** If the clutch linkage is not properly adjusted or if there is a leak in the hydraulic clutch linkage, the clutch may not be fully disengaged. A shift is very difficult, if not impossible, if engine torque is being transferred through the transmission/transaxle as a shift is being attempted.
- **Worn synchronizer.** If the synchronizer rings are worn, the rings will be unable to properly match the speed gear speed, making the shift difficult and/or creating gear clash (noise) when shifting.
- **Worn, cracked, or loose shift forks.** If there is any problem with the shift forks, the synchronizer cannot be properly moved during a shift attempt, making shifting difficult, if not impossible. If only one fork is worn or defective, usually engaging two gears instead of one is likely.
- **Excessive input- or main-shaft end play.** Excessive end play in the input or main shaft will cause the gears to move away from the synchronizer assembly, resulting in grinding during shifts or shifts that are difficult or impossible to complete.



(a)



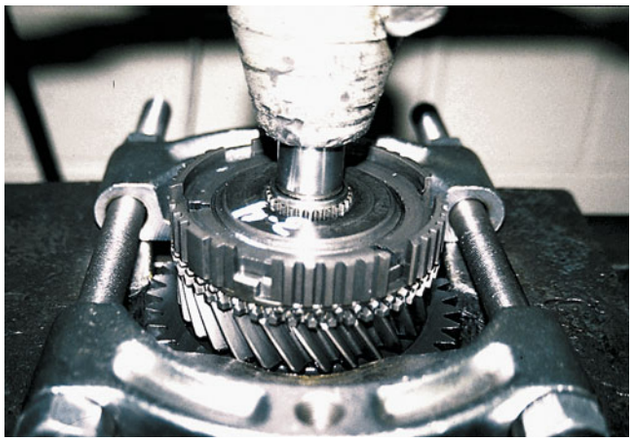
(b)



(c)

FIGURE 122–41 (a) During the disassembly of any manual transmission/transaxle, carefully check for the location of the snap rings. Often they are hidden. Consult the factory service manual or unit repair manual for information and procedures for the unit being serviced. (b) Using snap-ring pliers to remove a snap ring. Many snap rings have an "up" side. Be sure to reinstall any snap rings in the correct direction. (c) After the snap ring is removed, some components can be simply lifted off the main shaft, while other gears may require the use of a press.

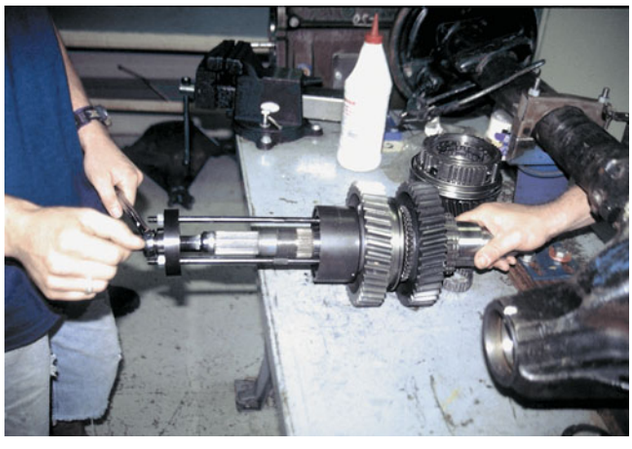
- **Improper lubrication.** Many of today's manual transmissions use synchronizer rings (blocking rings) that are lined with compounds, paper, or other friction material. All of these transmissions/transaxles must be filled with the proper fluid formulated for proper shifting.



(a)



(b)



(c)

FIGURE 122–42 (a) Many gears require that a hydraulic press be used to separate the gear(s) from the shaft. After double-checking that all snap ring retainers have been removed and after checking in the service manual to see which gear needs to be pressed off, carefully position the "bearing splitter" as far inward as possible to avoid damaging the teeth during the pressing operation. (b) For safety, place an old brake drum over the gear(s) being pressed off. If the gear were to shatter, the parts will be trapped inside the brake drum. (c) Some transmission disassembly and reassembly procedures require the use of special pullers, such as this tool being used on a NV 4500 transmission.

REAL WORLD FIX

The Worn Shift Fork Mystery

A vehicle equipped with a manual transmission had to be repaired several times for worn shift forks. Even though the vehicle warranty paid for the repair, both the customer and the service department personnel were concerned about the repeated failures. All technical service bulletins (TSBs) were checked to see if there was an updated, improved shift fork. No luck. Even the manufacturer's technical assistance personnel were unable to determine why the shift forks were wearing out. After the third repair, the service technician rode with the customer to see if the cause could be determined. As the woman driver got into the driver's seat, she placed the handle of her purse over the shifter on the floor and allowed the purse to hang from the shifter. The technician asked the owner if she always placed her purse on the shifter and when she said yes, the technician knew immediately the cause of the worn shift forks. The purse exerted a force on the shifter all the time. This force pushed the shift forks against the synchronizer sleeve. Because the sleeve rotates all the time the vehicle is in motion, the shift forks were quickly worn. The service technician should have determined the root cause of the problem after the *first* repair. The customer agreed to find another location for her purse so that the transmission problem would not reoccur.

NOTE: A worn synchronizer sleeve and/or blocking ring can cause the transmission/transaxle to pop out of gear while accelerating or decelerating.

MANUAL TRANSMISSION INSTALLATION

When installing a repaired or replacement transmission/transaxle, the clutch should be carefully inspected and replaced as necessary. The clutch friction disc must be held in position using an alignment tool (sometimes called a *dummy shaft*) that is secured in the pilot bearing. This holds the disc in position while the pressure plate is being installed. Finally, the engine bell housing is put on the engine, if it was not installed before. The alignment of this type of bell housing is then checked.

CAUTION: Perfectly round cylinders can be distorted whenever another part of the engine is bolted and torqued to the engine block. For example, it has been determined that after the cylinders are machined, the rear cylinder bore can be distorted as much as 0.006 inch (0.15 millimeter) out-of-round after the bell housing is bolted onto the block! To help prevent this distortion, always apply the specified torque to all fasteners going into the engine block and tighten in the recommended sequence.

The clutch release yoke should be checked for free movement. Usually, the clutch release bearing is replaced, ensuring that the new bearing is securely attached to the clutch release yoke. The transmission can then be installed.

The transmission clutch shaft must be guided straight into the clutch disc and pilot bearing. See the Tech Tip "The Headless Bolt Trick." The transmission clutch shaft is rotated, as required, to engage in the splines of the clutch disc. The assembly bolts are secured when the transmission fully mates with the bell housing.

CAUTION: Always adjust the clutch free play *before* starting the engine to help prevent thrust bearing damage.

Complete the installation by attaching the transmission/transaxle mount, driveshaft (drive axle shafts), vehicle speed sensor, and reverse (backup) light switch.

GEAR LUBRICATION

After the installation of the transmission/transaxle, the unit should be filled with the correct lubricant. The various lubricants, their general use, and their American Petroleum Institute (API) rating include

GL-1 Straight mineral oil

GL-2 Worm-type gear lubricant

GL-3 Mild-type EP lubricant (will not protect hypoid gears)

GL-4 EP-type lubricant (okay for manual transmissions/transaxles)

GL-5 EP-type okay for hypoid gears and for Mil-L2150B (military)



FIGURE 122–43 Some manual transmissions/transaxles require synchromesh transmission fluid.

Manual transmissions/transaxles require one of the following lubricants:

- SAE 80W-90 (GL-4) gear lube
- STF (synchromesh transmission fluid), but with friction characteristics designed for manual transmissions. ● **SEE FIGURE 122–43.**
- ATF (automatic transmission fluid)
- Engine oil (usually SAE 5W-30)

CAUTION: Failure to use the specified manual transmission/transaxle lubricant could cause hard shifting and possible severe transmission damage.

TECH TIP

The Headless Bolt Trick

Sometimes parts do not seem to line up correctly. Try this tip the next time. Cut the head off extra-long bolts that are of the same diameter and thread as those being used to retain the part, such as a transmission. ● **SEE FIGURE 122–44.** Use a hacksaw to cut a slot in the end of these guide bolts for a screwdriver slot. Install the guide bolts; then install the transmission. Use a straight-blade screwdriver to remove the guide bolts after securing the transmission with the retaining bolts.

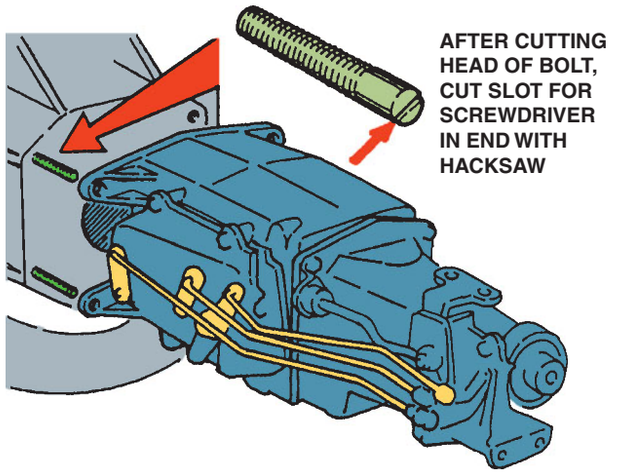
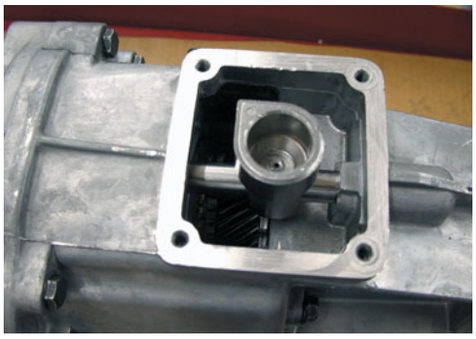


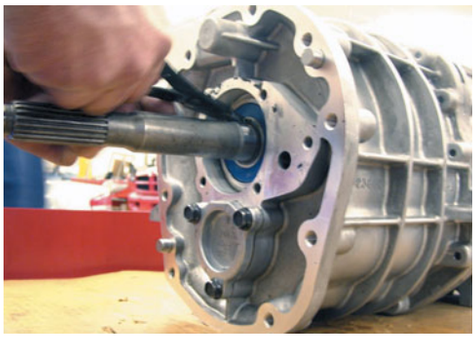
FIGURE 122–44 Headless, long bolts can be used to help install a transmission to the engine.



1 A NV-1500 five-speed manual transmission is used in two-wheel drive applications only.



2 The shifter assembly has been removed. Note the roll pin in the center of the shift lever socket.



3 Snap-ring pliers are being used to remove the snap ring retaining the input shaft bearing.



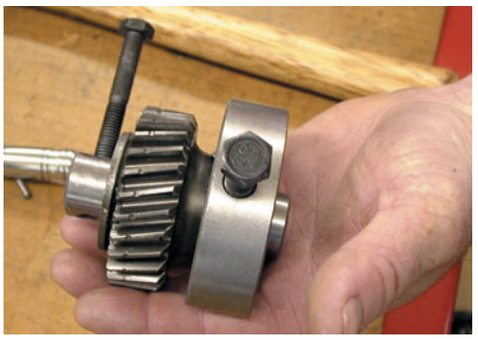
4 The upside down case is being separated showing the countershaft (top) and shift forks.



5 Before further disassembly can be accomplished, the shift lever socket roll pin must be driven out using a punch and a hammer.



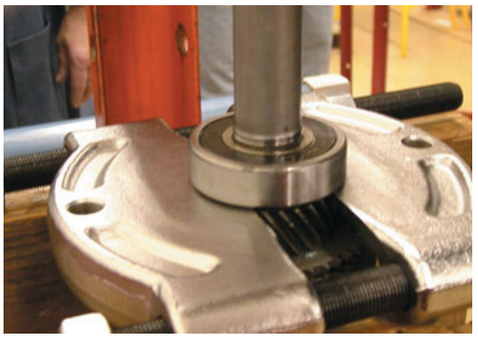
6 The shift shaft and forks can now be removed.



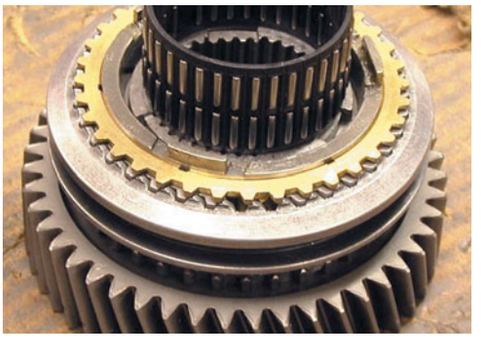
7 The reverse idle gear is unbolted from the case and removed.



8 The output shaft assembly fifth gear (far left) and the synchronizer assemblies.



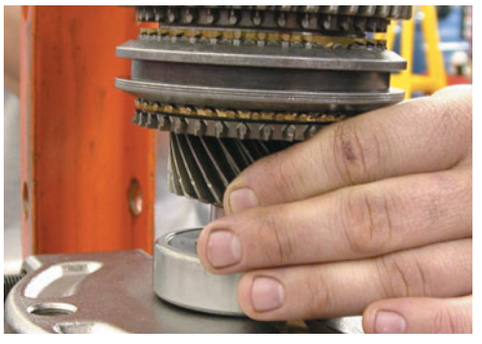
9 The bearing is being removed using a bearing splitter and a hydraulic press.



10 A speed gear (bottom) along with the double row needle bearing used between the shaft and the speed gear. The hub (center) is splined and rotates with the output shaft.



11 A synchronizer assembly being reassembled. It often takes several hands to hold the hub (center) and the sleeve (outer ring).

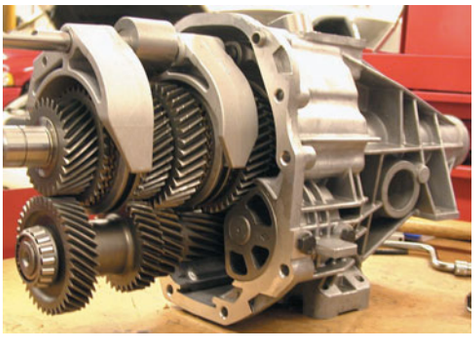


12 A hydraulic press is used to reassemble output shaft and bearing.

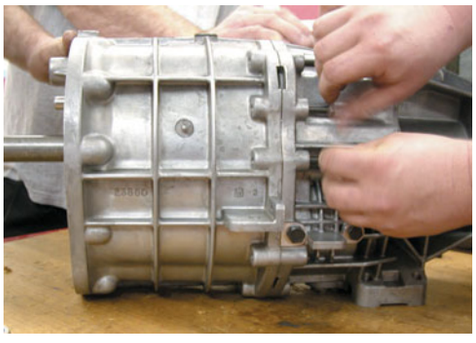
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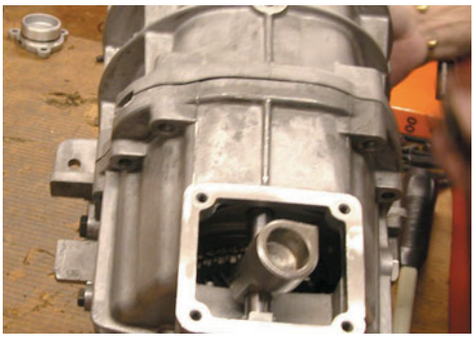
13 The assembled output shaft is held against the counter shaft to double check that all of the gears have been correctly assembled.



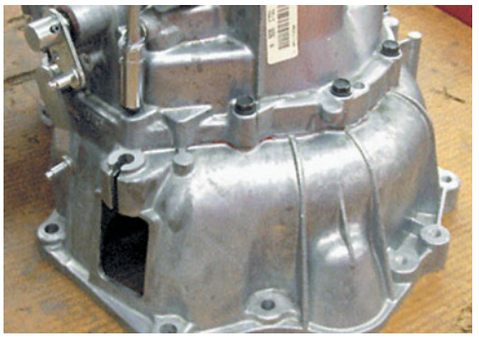
14 The assembled output shaft and counter shaft are being reinstalled in the transmission case.



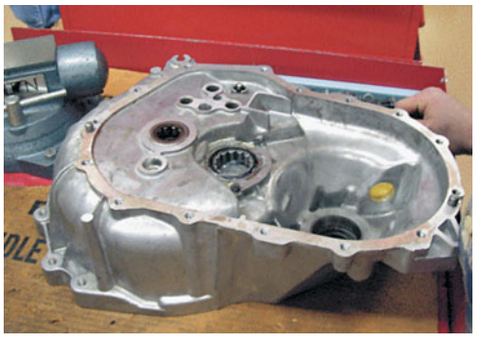
15 The case halves are bolted together.



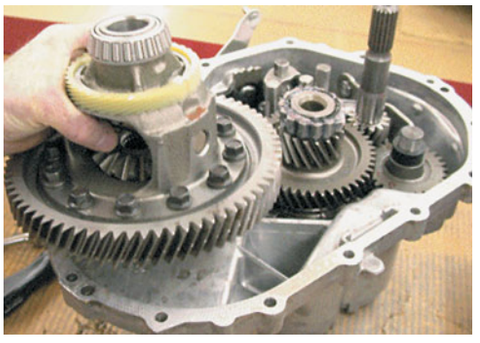
16 The last step is to assembly the shift lever and check for proper operation in all gear positions.



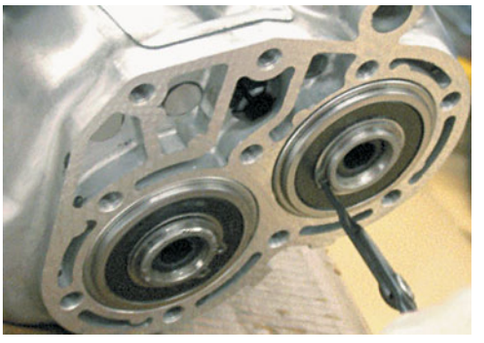
1 After the transaxle has been removed from the vehicle and the fluid drained, place the transaxle on a work surface.



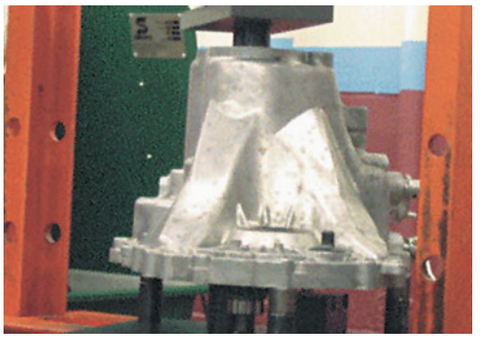
2 The bell housing case half containing the large output shaft front bearing (center) and the input shaft front bearing (smaller bearing on the left).



3 The differential assembly is simply lifted out of half of the case.



4 The input and output shafts are a press fit into the bearings and are also retained with a snap ring, which must be removed.



5 Using a special tool, the input and output shafts are pressed out of the housing using a hydraulic press.



6 The input shaft can be disassembled using a bearing splitter and a press, or two screwdrivers to pry the gears off the shaft.

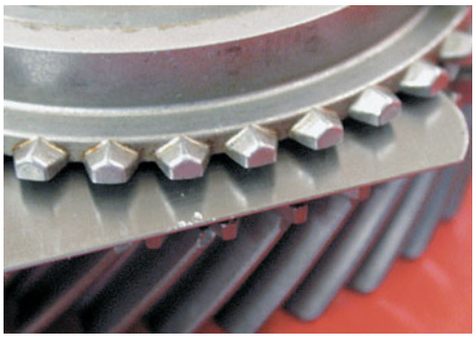
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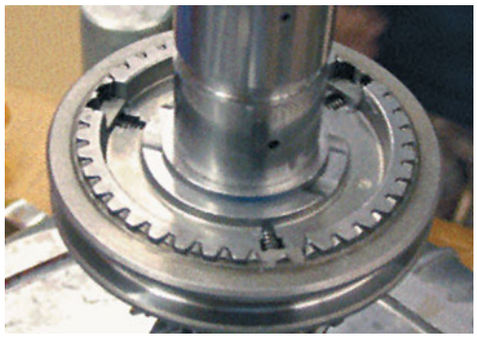
7 This transaxle uses both brass and powdered metal synchronizer rings with a fiber (paper) inner cone surface.



8 Synchronizer ring gaps are being measured using a feeler (thickness) gauge. The factory specifications are usually 0.040 in. to 0.069 in.



9 The gear clutch teeth should be inspected for wear.



10 An assembled synchronizer assembly containing a sleeve, keys, springs, and detent.



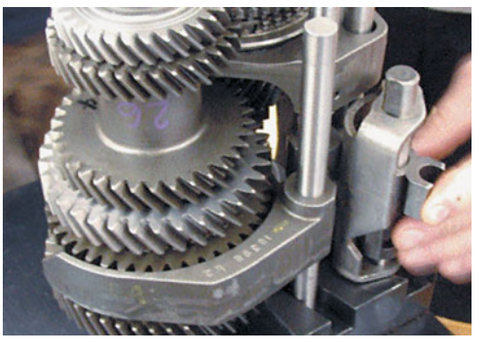
11 The input shaft (left) and the output shaft (right) are checked for proper assembly before being installed into the case.



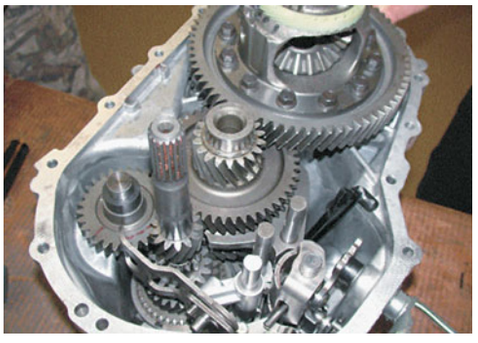
12 The differential bearing preload is determined by measuring for zero end play; then adding the thickness shim under the bearing cup.



13 The bearing cup is being installed using an installation tool and a hammer.



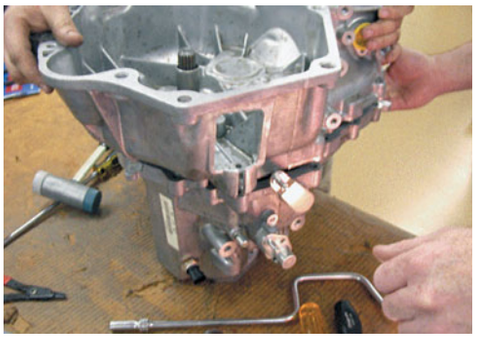
14 All of the shift forks and shift arms must be aligned properly before installing the components into the case.



15 All of the components, including the differential (right), the output shaft (center), and the input shaft (left), plus the shift linkage are installed and checked for proper positioning.



16 The case halves being reinstalled. The bearings (top) must be pressed back onto the input and output shafts using a press.



17 The bell housing case being reattached.



18 The completed assembly. Notice the bearing cover (top) has already been installed.

REVIEW QUESTIONS

1. Calculate the gear ratio if the driven gear has 36 teeth and the driving gear has 12 teeth.
2. Explain what is meant by an overdrive ratio.
3. List the parts of a manual transmission.
4. Explain how a synchronizer assembly is able to allow a clash-free shift.
5. List four possible causes for a manual transmission/transaxle being difficult to shift.
6. List the possible lubricants that a manual transmission/ transaxle may require.

CHAPTER QUIZ

1. Technician A says that the torque available at the output shaft is greater in second gear than when the transmission/transaxle is in third gear at the same engine speed. Technician B says that the output shaft is rotating faster when the transmission/ transaxle is in second gear compared to third gear when the engine is at the same speed. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
2. The driving gear has 15 teeth and the driven gear has 29 teeth. Technician A says that the output gear will be going faster than the input gear. Technician B says the ratio is 3.86:1. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
3. Which part is splined to the clutch disc?
   a. Main shaft **c.** Cluster shaft
   b. Countershaft (lay shaft) **d.** Main gear
4. Two technicians are discussing how torque is increased inside a manual transmission/transaxle. Technician A says that the gear ratio in first gear between the main shaft and the countershaft should be *multiplied* by the ratio of the corresponding countershaft gear and output shaft gear. Technician B says that the two ratios should be added together. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
5. Which component cannot be removed before removing the transmission/ transaxle from the vehicle?
   a. Vehicle speed sensor
   b. Reverse (backup) light connector
   c. Front bearing retainer (quill)
   d. Drive axle shaft(s)
6. Technician A says that snap-rings are used to hold many components of a manual transmission/transaxle. Technician B says that snap rings have a "right side" that should always face up so that the snap-ring pliers can be applied. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
7. A customer complained of hard shifting particularly into first gear and reverse. Technician A says that the blocking ring may be worn. Technician B says that the clutch may be defective or out of adjustment. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
8. Which part of a synchronizer is splined to a shaft?
   a. Synchronizer sleeve
   b. Hub
   c. Synchronizer ring (blocking ring)
   d. Speed gear
9. A manual transmission is difficult to shift but only when the outside temperature is below freezing (32°F or 0°C). Technician A says that the brass blocking ring could be defective. Technician B says that incorrect gear lubricant could be the cause. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
10. Which type of lubricant is usually *not* used in a manual transmission/ transaxle?
    a. Automatic transmission fluid (ATF)
    b. High-temperature chassis grease
    c. SAE 80W-90 gear lube
    d. Engine oil

chapter 123

DRIVE AXLE SHAFTS AND CV JOINTS

OBJECTIVES: After studying Chapter 123, the reader will be able to: • Prepare for ASE Suspension and Steering (A4) certification test content area "C" (Related Suspension and Steering Service). • Name driveshaft and U-joint parts, and describe their function and operation. • Describe how CV joints work. • Explain how the working angles of the U-joints are determined. • List the various types of CV joints and their applications. • Discuss the proper grease to use in CV joints.

KEY TERMS: Cardan joints 1497 • Center support bearing 1495 • CV joint boot 1501 • CV joints 1498 • Double-Cardan joints 1498 • Drive axle shaft 1500 • Driveshaft 1495 • Fixed joint 1499 • Half shaft 1500 • Plunge joint 1500 • Propeller shaft 1495 • Rzeppa joint 1498 • Spider 1496 • Trunnions 1496 • Universal joints 1496

INTRODUCTION

A drive axle shaft transmits engine torque from the transmission or transaxle (if front wheel drive) to the rear axle assembly or drive wheels. ● **SEE FIGURES 123–1 AND 123–2.**

Driveshaft is the term used by the Society of Automotive Engineers (SAE) to describe the shaft between the transmission and the rear axle assembly on a rear-wheel-drive vehicle. General Motors and some other manufacturers use the term **propeller shaft** or *prop shaft* to describe this same part. The SAE term will be used throughout this textbook.

A typical driveshaft is a hollow steel tube. A splined end yoke is welded onto one end that slips over the splines of the output shaft of the transmission. ● **SEE FIGURE 123–3.** An end yoke is welded onto the other end of the driveshaft. Some driveshafts use a center support bearing.

DRIVESHAFT DESIGN

Most driveshafts are constructed of hollow steel tubing. *The forces are transmitted through the surface of the driveshaft tubing.* The surface is therefore in tension, and cracks can develop on the outside surface of the driveshaft due to metal fatigue. Driveshaft tubing can bend and, if dented, can collapse. A dented driveshaft should be replaced and no attempt should be made to repair the dent. ● **SEE FIGURE 123–4.**

Most rear-wheel-drive cars and light trucks use a one- or two-piece driveshaft. A steel tube driveshaft has a maximum *length of about 65 in. (165 cm).* Beyond this critical length, a **center support bearing** must be used, as shown in ● **FIGURE 123–5.** A center support bearing is also called a steady bearing or hanger bearing.

Some vehicle manufacturers use aluminum driveshafts; these can be as long as 90 in. (230 cm) with no problem. Many extended-cab pickup trucks and certain vans use aluminum driveshafts to eliminate the need (and expense) of a center support bearing. Composite-material driveshafts are also used in some vehicles. These carbon-fiber-plastic driveshafts are very strong yet lightweight, and can be made in extended lengths without the need for a center support bearing.

To dampen driveshaft noise, it is common to line the inside of the hollow driveshaft with cardboard or rubber. This helps eliminate the tinny sound whenever shifting between drive and reverse in a vehicle equipped with an automatic transmission. ● **SEE FIGURE 123–6.**

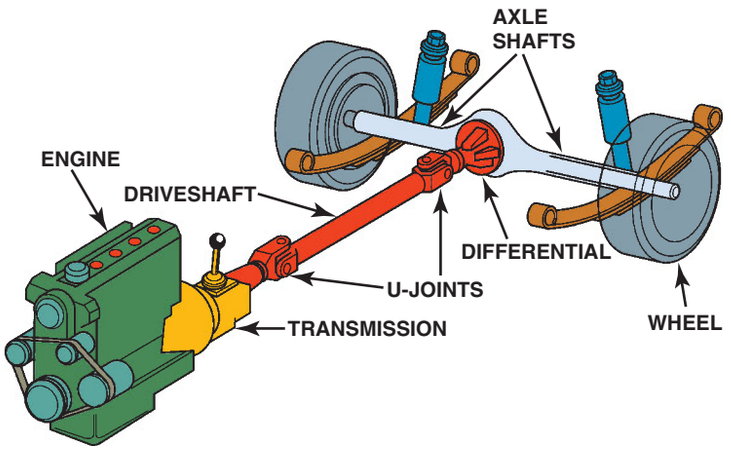


FIGURE 123–1 Typical rear-wheel-drive powertrain arrangement. The engine is mounted longitudinal (lengthwise).

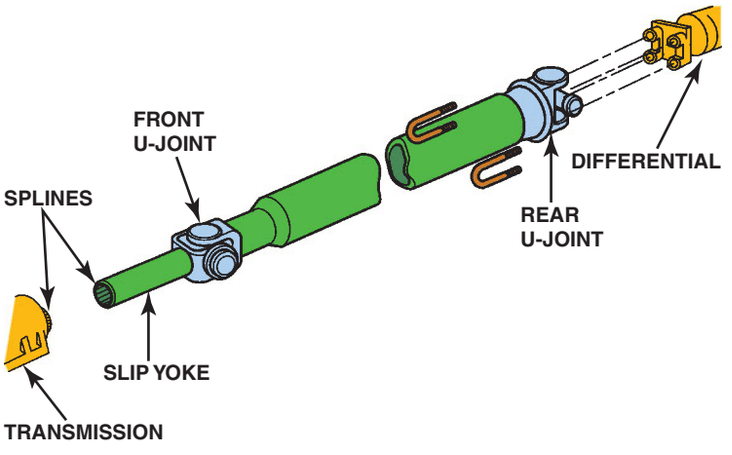


FIGURE 123–3 Typical driveshaft (also called a *propeller shaft*). The driveshaft transfers engine power from the transmission to the differential.

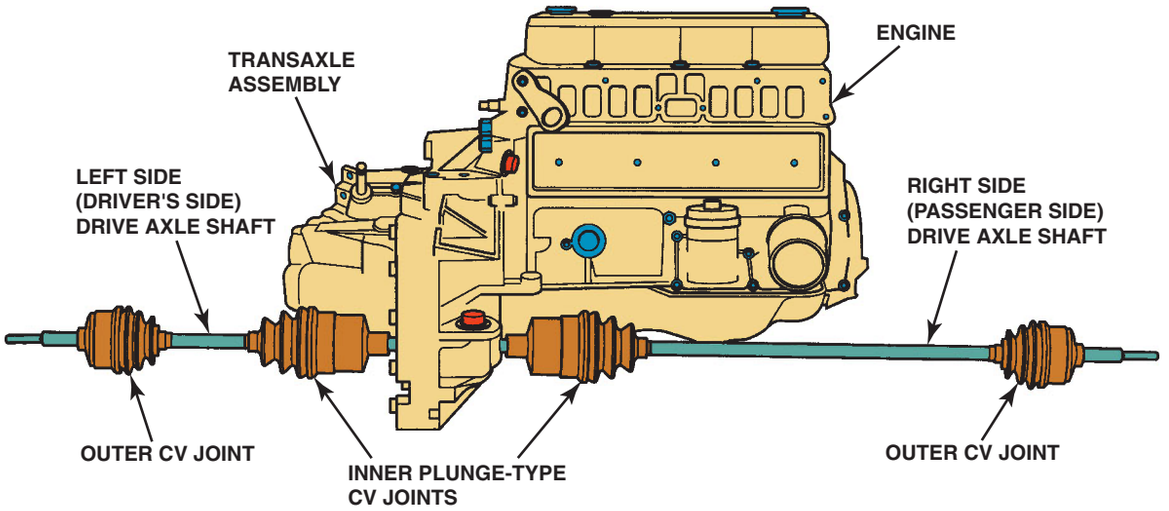


FIGURE 123–2 Typical front-wheel-drive powertrain arrangement. The engine is usually mounted transversely (sideways).

DRIVESHAFT BALANCE

All driveshafts are balanced. Generally, any driveshaft whose rotational speed is greater than 1,000 RPM must be balanced. Driveshaft balance should be within 0.5% of the driveshaft weight. (This is one of the biggest reasons why aluminum or composite driveshafts can be longer because of their light weight.)

Driveshafts are often not available by make, model, and year of the vehicle. There are too many variations at the factory, such as transmission type, differential, or U-joint type. To get a replacement driveshaft, it is usually necessary to know the series of U-joints (type or style of U-joint) and the center-to-center distance between the U-joints.

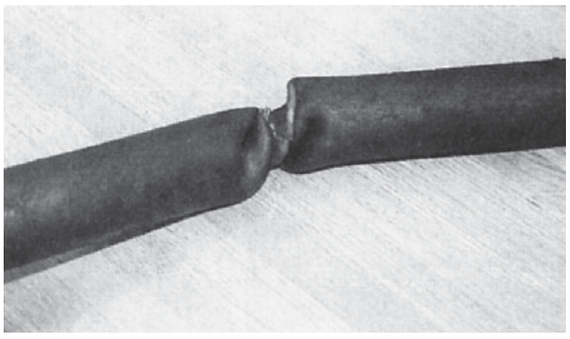


FIGURE 123–4 This driveshaft failed because it had a slight dent caused by a rock. When engine torque was applied, the driveshaft collapsed, twisted, and then broke.

U-JOINT DESIGN AND OPERATION

PARTS INVOLVED **Universal joints (U-joints)** are used at both ends of a driveshaft. U-joints allow the wheels and the rear axle to move up and down, remain flexible, and still transfer torque to the drive wheels. A simple universal joint can be made from two Y-shaped yokes connected by a crossmember called a cross or **spider.** The four arms of the cross are called **trunnions.** ● **SEE FIGURE 123–7** for a line drawing of a simple U-joint with all part names identified. A similar design is the common U-joint used with a socket wrench set.



FIGURE 123–6 Some driveshafts use rubber between an inner and outer housing to absorb vibrations and shocks to the driveline.

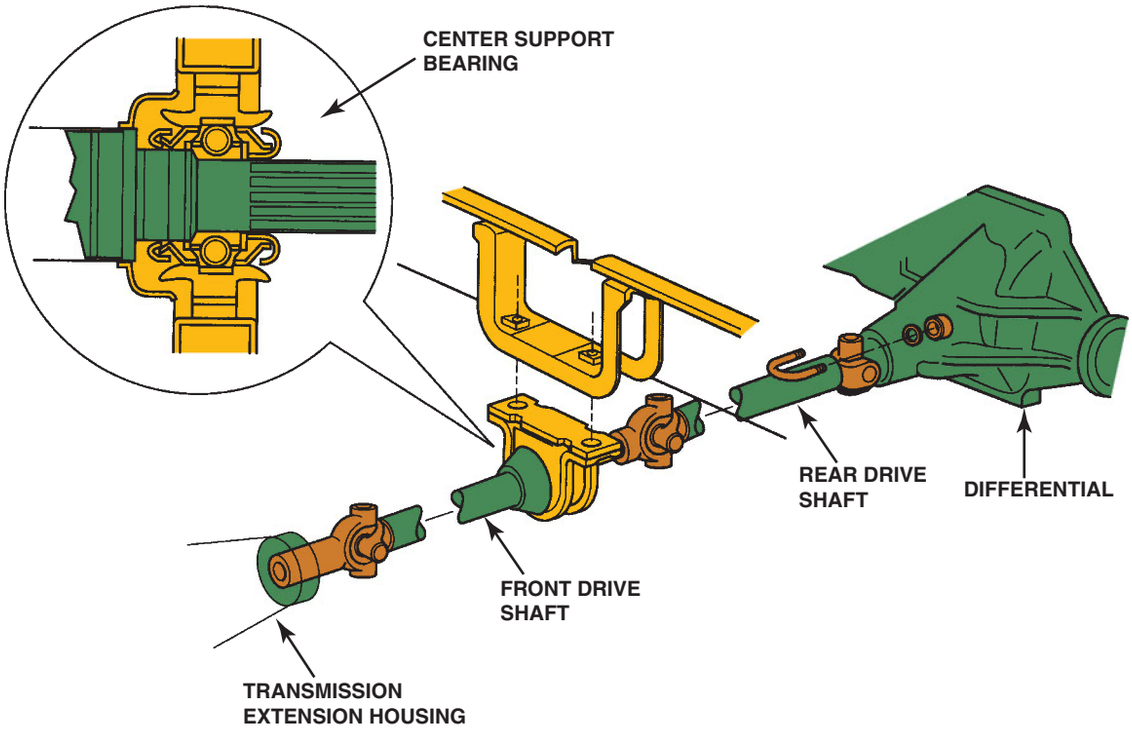


FIGURE 123–5 A center support bearing is used on many vehicles with long driveshafts such as long trucks.

Most U-joints are called cross-yoke joints or **Cardan joints.** *Cardan* is named for a sixteenth-century Italian mathematician who worked with objects that moved freely in any direction. Torque from the engine is transferred through the U-joint. The engine drives the U-joint at a constant speed, but the output speed of the U-joint changes because of the angle of the joint. The speed changes twice per revolution. *The greater the angle, the greater the change in speed (velocity).* ● **SEE FIGURE 123–8.**

U-JOINT OPERATION

If only one U-joint were used in a driveline, this change in speed of the driven side (output end) would generate vibrations in the driveline. To help reduce vibration, another U-joint is used at the other end of the driveshaft. If the angles of both joints are nearly equal, the acceleration and deceleration of one joint is offset by the alternate deceleration and acceleration of the second joint. *It is very important that both U-joints operate at about the same angle to prevent excessive driveline vibration.* ● **SEE FIGURE 123–9.**

ACCEPTABLE WORKING ANGLES

Universal joints used in a typical driveshaft should have a *working angle* of 1/2 to 3 degrees. ● **SEE FIGURE 123–10.** The working angle is the angle between the driving end and the driven end of the joint. If the driveshaft is perfectly straight (0-degree working angle), then the needle bearings inside the bearing cap are not revolving because there is no force (no difference in angles) to cause the rotation of the needle bearings.

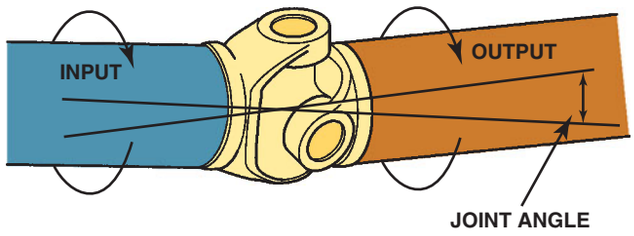


FIGURE 123–9 The joint angle is the difference between the angles of the joint. (*Courtesy of Dana Corporation*)

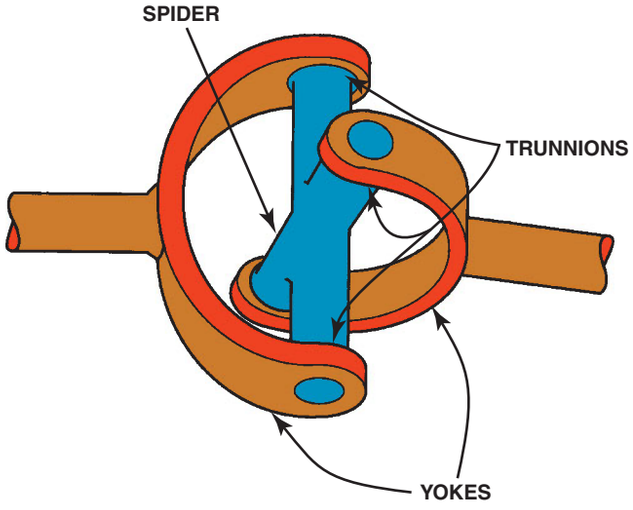


FIGURE 123–7 A simple universal joint (U-joint).



FIGURE 123–10 The angle of this rear Cardan U-joint is noticeable.

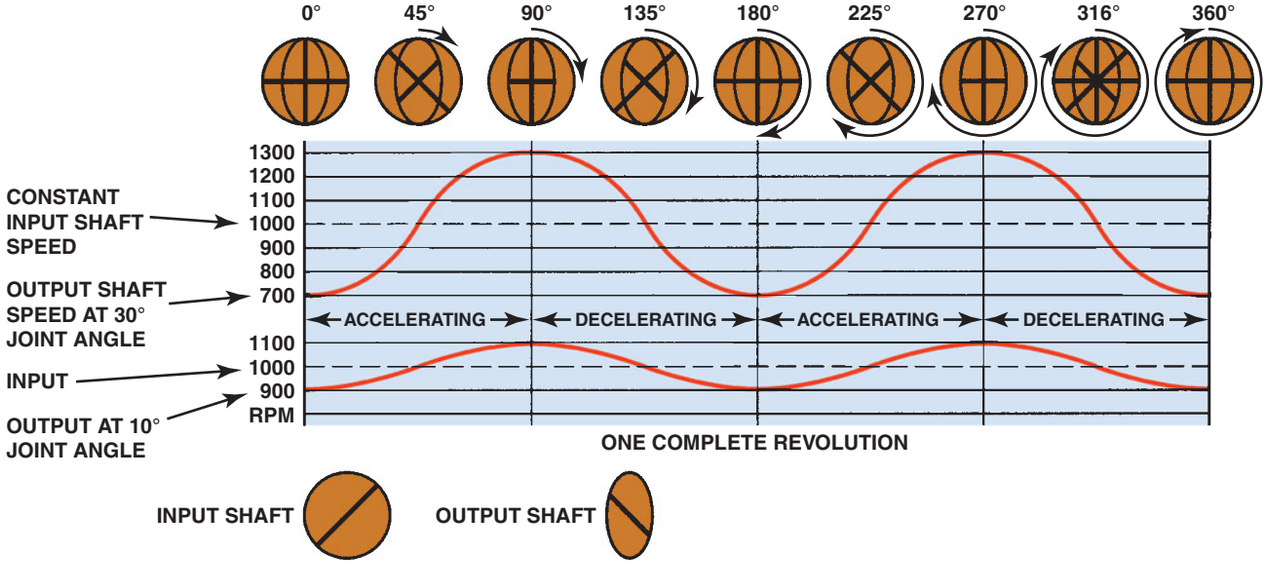


FIGURE 123–8 How the speed difference on the output of a typical U-joint varies with the speed and the angle of the U-joint. At the bottom of the chart, the input speed is a constant 1000 RPM, while the output speed varies from 900 RPM to 1100 RPM when the angle difference in the joint is only 10°. At the top part of the chart, the input speed is a constant 1000 RPM, yet the output speed varies from 700 to 1200 RPM when the angle difference in the joint is changed to 30°. (*Courtesy of Dana Corporation*)

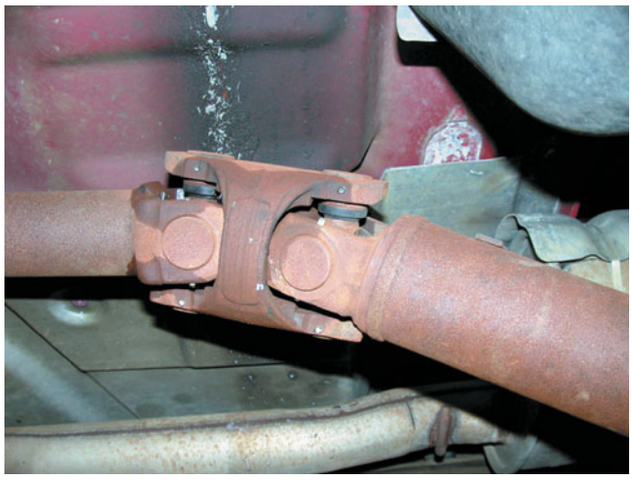


FIGURE 123–11 A double-Cardan U-joint.

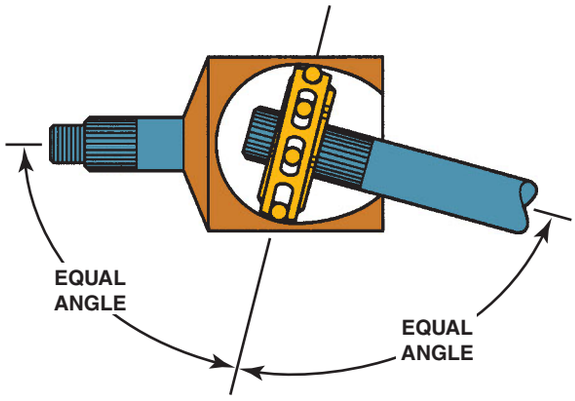


FIGURE 123–12 A constant velocity (CV) joint can operate at high angles without a change in velocity (speed) because the joint design results in equal angles between input and output.

If the needle bearings do not rotate, they can exert a constant pressure in one place and damage the bearing journal. If a two-piece driveshaft is used, one U-joint (usually the front) runs at a small working angle of about 1/2 degree, just enough to keep the needle bearings rotating. The other two U-joints (from the center support bearing and rear U-joint at the differential) operate at typical working angles of a single-piece driveshaft.

If the U-joint working angles differ by more than a 1/2 degree between the front and the rear joint, a vibration is usually produced that is *torque sensitive.* As the vehicle is first accelerated from a stop, engine torque can create unequal driveshaft angles by causing the differential to rotate on its suspension support arms. This vibration is most noticeable when the vehicle is heavily loaded and being accelerated at lower speeds. The vibration usually diminishes at higher speeds due to decrease in the torque being transmitted. If the driveshaft angles are excessive (over 3 degrees), a vibration is usually produced that increases as the speed of the vehicle (and driveshaft) increases.

FREQUENTLY ASKED QUESTION

What Is a 1350-Series U-Joint?

Most universal joints are available in sizes to best match the torque that they transmit. The larger the U-joint, the higher the amount of torque. Most U-joints are sized and rated by series numbers. See the accompanying chart for series numbers and sizes.

Series Number	Cap Diameter (inches)	Overall Length (inches)	Trunnion Diameter (inches)
1000	15/16	2 5/64	1/2
1100	15/16	2 13/64	1/2
1260/1270	1 1/16	2 31/32	19/32
1280	1 1/16	2 31/32	39/64
1310	1 1/16	2 31/32	21/32
1330	1 1/16	3 3/8	21/32
1350	1 3/16	3 3/8	49/64
1410	1 3/16	3 15/16	49/64
1480	1 3/8	3 7/8	57/64

CONSTANT VELOCITY JOINTS

PURPOSE AND FUNCTION Constant velocity joints, commonly called **CV joints,** are designed to rotate without changing speed. Regular U-joints are usually designed to work up to 12 degrees of angularity. If two Cardan-style U-joints are joined together, the angle at which this **double-Cardan joint** can function is about 18 to 20 degrees. ● **SEE FIGURE 123–11.**

Double-Cardan U-joints were first used on large rear-wheel-drive vehicles to help reduce drive-line-induced vibrations, especially when the rear of the vehicle was fully loaded and driveshaft angles were at their greatest. As long as a U-joint (either single or double Cardan) operates in a straight line, the driven shaft will rotate at the same constant speed (velocity) as the driving shaft. As the angle increases, the driven shaft speed or velocity varies during each revolution. This produces pulsations and a noticeable vibration or surge. The higher the shaft speed and the greater the angle of the joint, the greater the pulsations.

NOTE: Many four-wheel-drive light trucks use standard Cardan-style U-joints in the front drive axles. If the front wheels are turned sharply and then accelerated, the entire truck often shakes due to the pulsations created by the speed variations through the U-joints. This vibration is normal and cannot be corrected. It is characteristic of this type of design and is usually not noticeable in normal driving.

The first constant velocity joint was designed by Alfred H. Rzeppa (pronounced shep'pa) in the mid-1920s. The **Rzeppa joint** transfers torque through six round balls that are held in position midway between the two shafts. This design causes the angle between the shafts to be equally split regardless of the angle. ● **SEE FIGURE 123–12.** Because the angle is always split equally, torque is transferred equally without the change in speed (velocity) that occurs in Cardan-style U-joints. This style of joint results in a constant velocity between driving and driven shafts. It can also function at angles greater than simple U-joints can, up to 40 degrees.

NOTE: CV joints are also called LOBRö joints, the brand name of an original equipment manufacturer.

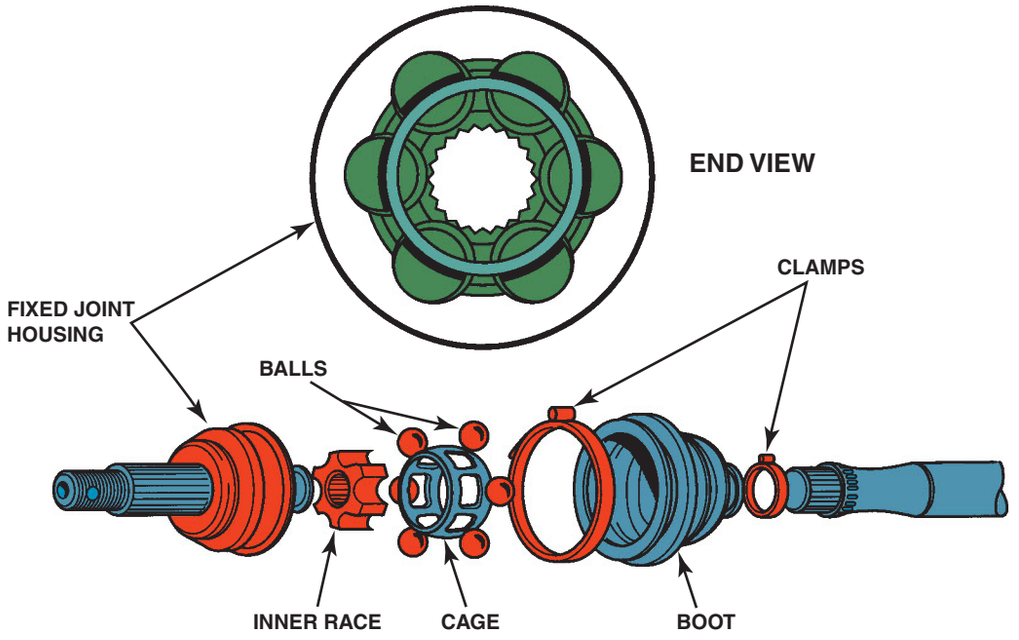


FIGURE 123–13 A Rzeppa fixed joint on a front-wheel-drive vehicle. This type of CV joint is commonly used at the wheel side of the drive axle shaft on a front-wheel-drive vehicle. This joint can operate at high angles to compensate for suspension travel and steering angle changes. (*Courtesy of Dana Corporation*)

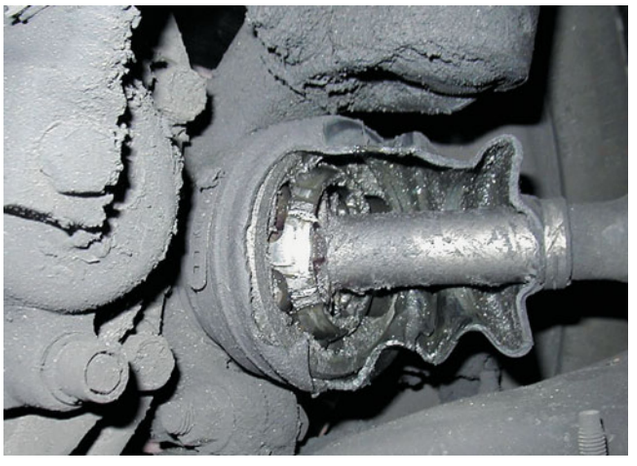


FIGURE 123–14 The protective CV joint boot has been torn away on this vehicle and all of the grease has been thrown outward onto the brake and suspension parts. The driver of this vehicle noticed a "clicking" noise, especially when turning.

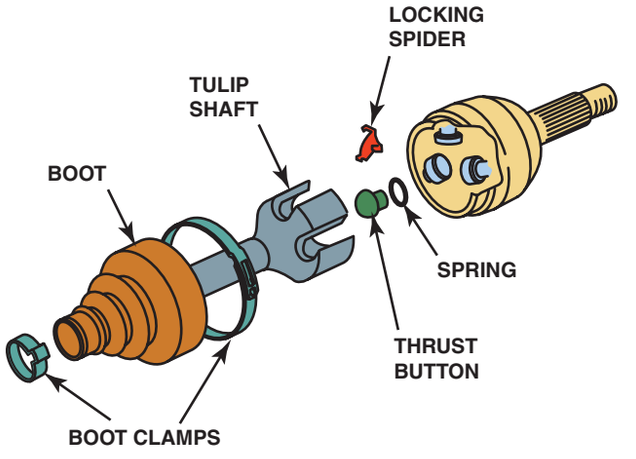


FIGURE 123–15 A tripod fixed joint. This type of joint is found on some Japanese vehicles. If the joint wears out, it is to be replaced with an entire drive axle shaft assembly.

While commonly used today in all front-wheel-drive vehicles and many four-wheel-drive vehicles, its first use was on the front-wheel-drive 1929 Cord. Built in Auburn, Indiana, the Cord was the first front-wheel-drive car to use a CV-type drive axle joint.

OUTER CV JOINTS The Rzeppa-type CV joint is most commonly used as an outer joint on most front-wheel-drive vehicles. ● **SEE FIGURE 123–13.** The outer joint must do the following:

1. Allow up to 40 degrees or more of movement to allow the front wheels to turn
2. Allow the front wheels to move up and down through normal suspension travel in order to provide a smooth ride over rough surfaces
3. Be able to transmit engine torque to drive the front wheels

Outer CV joints are called **fixed joints.** The outer joints are also attached to the front wheels. They are more likely to suffer from road hazards that often can cut through the protective outer flexible boot. ● **SEE FIGURE 123–14.** Once this boot has been split open, the special high-quality grease is thrown out and contaminants such as dirt and water can enter. Some joints cannot be replaced individually if worn. ● **SEE FIGURE 123–15.**

NOTE: Research has shown that in as few as eight hours of driving time, a CV joint can be destroyed by dirt, moisture, and a lack of lubrication if the boot is torn. The technician should warn the owner as to the possible cost involved in replacing the CV joint itself whenever a torn CV boot is found.

INNER CV JOINTS Inner CV joints attach the output of the transaxle to the drive axle shaft. Inner CV joints are

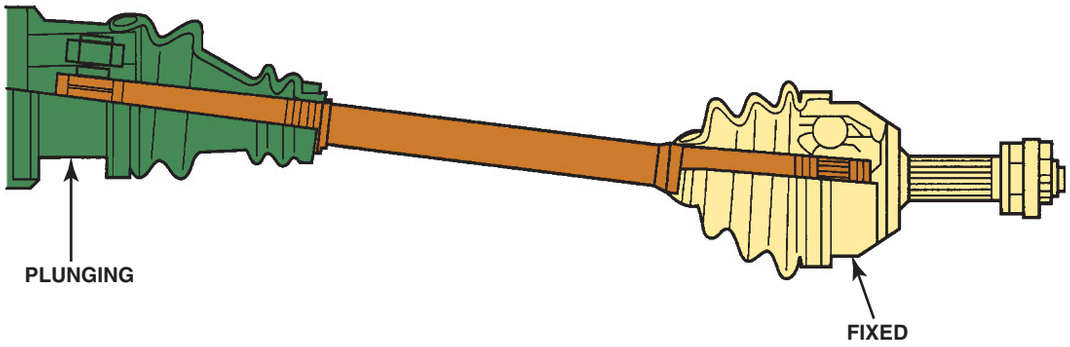
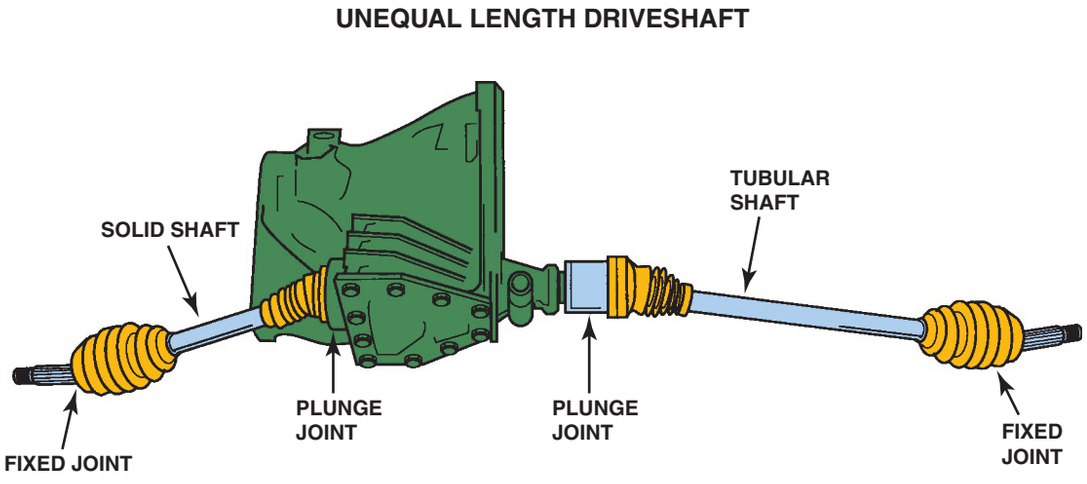


FIGURE 123–16 The fixed outer joint is required to move in all directions because the wheels must turn for steering as well as move up and down during suspension movement. The inner joint has to be able to not only move up and down but also plunge in and out as the suspension moves up and down. (*Courtesy of Dana Corporation*)



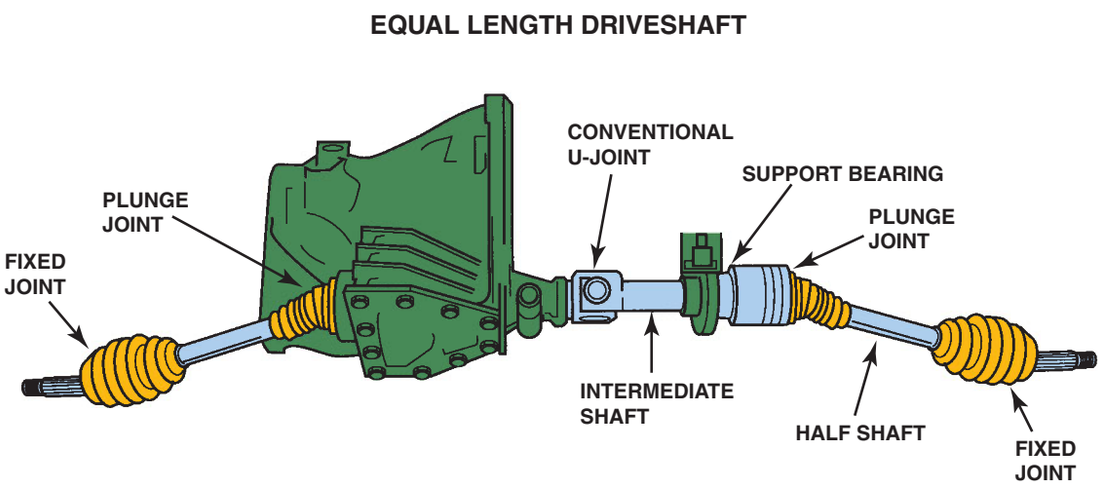


FIGURE 123–17 Unequal-length driveshafts result in unequal drive axle shaft angles to the front drive wheels. This unequal angle side-to-side often results in a steering of the vehicle during acceleration called torque steer. By using an intermediate shaft, both drive axles are the same angle and the torque steer effect is reduced. (*Courtesy of Dana Corporation*)

therefore inboard, or toward the center of the vehicle. ● **SEE FIGURE 123–16.**

Inner CV joints have to be able to perform two very important movements:

1. Allow the drive axle shaft to move up and down as the wheels travel over bumps.
2. Allow the drive axle shaft to change length as required during vehicle suspension travel movements (lengthening and shortening as the vehicle moves up and down; same as the slip yoke on a conventional RWD driveshaft). CV joints are also called **plunge joints.**

DRIVE AXLE SHAFTS Unequal-length **drive axle shafts** (also called **half shafts**) result in unequal drive axle shaft angles to the front drive wheels. ● **SEE FIGURE 123–17.** This unequal angle often results in a pull on the steering wheel during acceleration. This

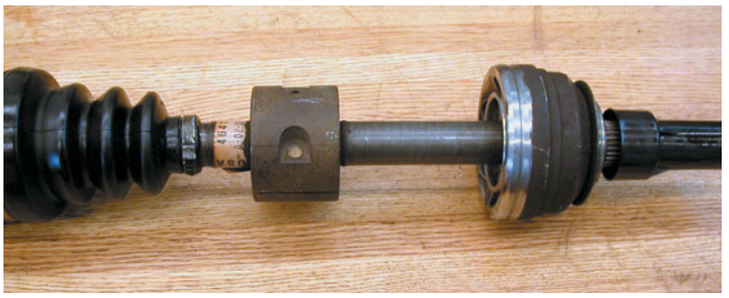


FIGURE 123–18 A typical drive axle shaft with dampener weight.

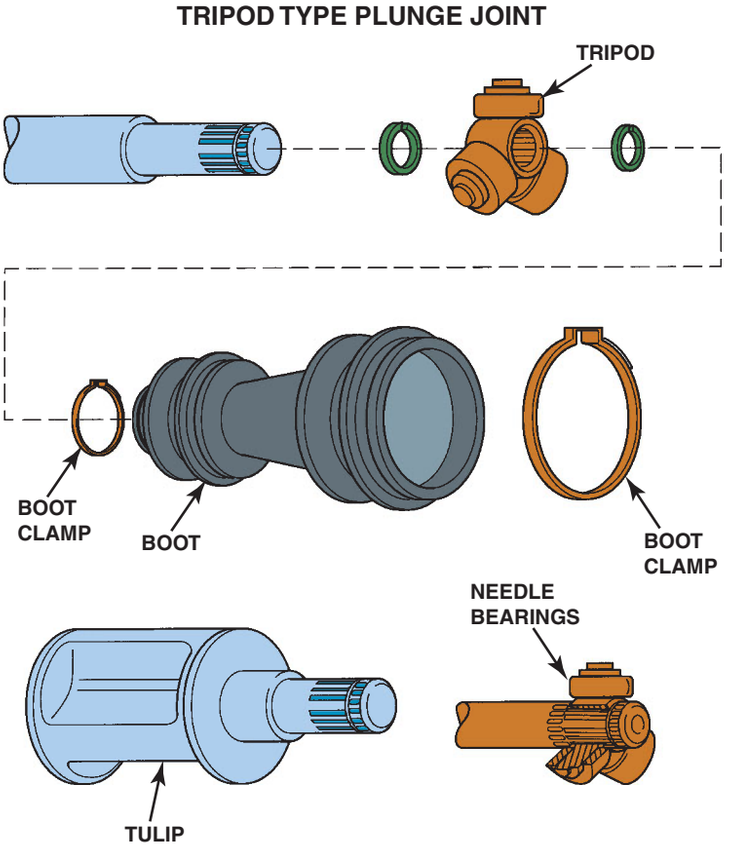


FIGURE 123–19 A tripod joint is also called a tripot, tripode, or tulip design. (*Courtesy of Dana Corporation*)

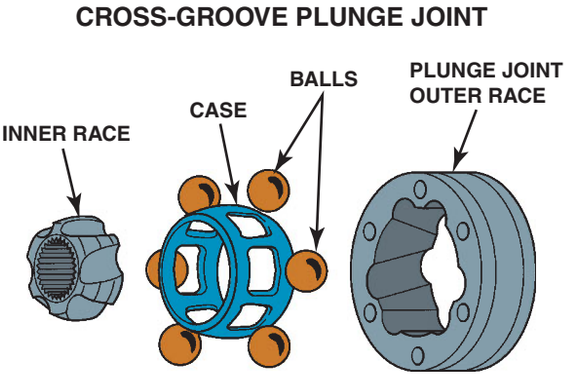


FIGURE 123–20 A cross-groove plunge joint is used on many German front-wheel-drive vehicles and as both inner and outer joints on the rear of vehicles that use an independent-type rear suspension. (*Courtesy of Dana Corporation*)

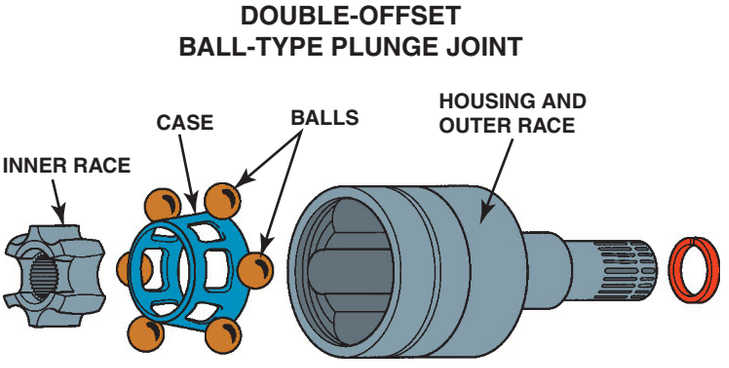


FIGURE 123–21 Double-offset ball-type plunge joint. (*Courtesy of Dana Corporation*)

pulling to one side during acceleration due to unequal engine torque being applied to the front drive wheels is called torque steer. To help reduce the effect of torque steer, some vehicles are manufactured with an intermediate shaft that results in equal drive axle shaft angles. Both designs use fixed outer CV joints with plunge-type inner joints.

Typical types of inner CV joints that are designed to move axially, or *plunge,* include the following:

1. Tripod. ● **SEE FIGURE 123–19.**
2. Cross groove. ● **SEE FIGURE 123–20.**
3. Double offset. ● **SEE FIGURE 123–21.**

CV joints are also used in rear-wheel-drive vehicles and in many four-wheel-drive vehicles.

CV JOINT BOOT MATERIALS The pliable boot surrounding the CV joint, or **CV joint boot,** must be able to remain flexible under all weather conditions and still be strong enough to avoid being punctured by road debris. There are four basic types of boot materials used over CV joints:

1. *Natural rubber* (black) uses a bridge-type stainless steel clamp to retain.
2. *Silicone rubber* (gray) is a high-temperature-resistant material that is usually only used in places that need heat protection, such as the inner CV joint of a front-wheel-drive vehicle.

? FREQUENTLY ASKED QUESTION

What Is That Weight for on the Drive Axle Shaft?

Some drive axle shafts are equipped with what looks like a balance weight. ● **SEE FIGURE 123–18.** It is actually a dampener weight used to dampen out certain drive line vibrations. The weight is not used on all vehicles and may or may not appear on the same vehicle depending on engine, transmission, and other options. The service technician should always try to replace a defective or worn drive axle shaft with the exact replacement. When replacing an entire drive axle shaft, the technician should always follow the manufacturer's instructions regarding either transferring or not transferring the weight to the new shaft.

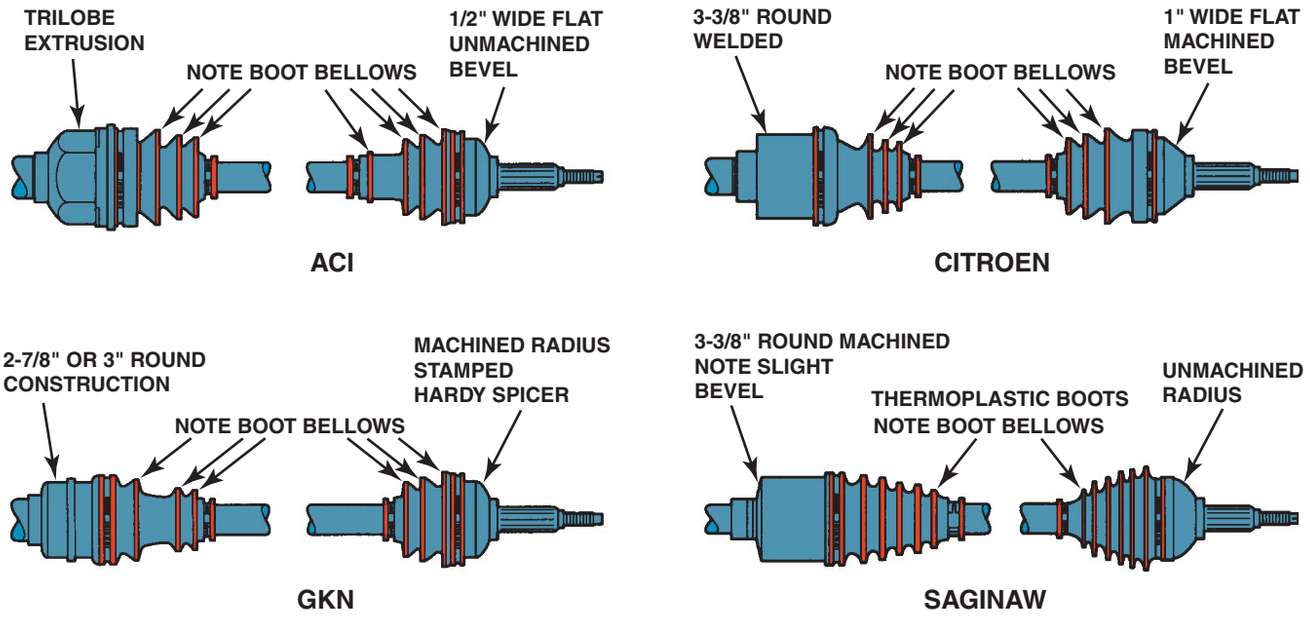


FIGURE 123–22 Getting the correct boot kit or parts from the parts store is more difficult on many Chrysler front-wheel-drive vehicles because Chrysler has used four different manufacturers for its axle shaft assemblies. (*Courtesy of Dana Corporation*)

3. *Hard thermoplastic* (black) is a hard plastic material requiring heavy-duty clamps and a lot of torque to tighten (about 100 lb-ft!).
4. *Urethane* (usually blue) is a type of boot material usually found in an aftermarket part. ● **SEE FIGURE 123–22** for examples of various types of CV joint boots depending on the manufacturer of the CV joints and shafts.

NOTE: Some aftermarket companies offer a split-style replacement CV joint boot. Being split means that the boot can be replaced without having to remove the drive axle shaft. Vehicle manufacturers usually do *not* recommend this type of replacement boot because the joint cannot be disassembled and properly cleaned with the drive axle still in the vehicle. The split boots must also be kept perfectly clean (a hard job to do with all the grease in the joint) in order to properly seal the seam on the split boot.

It is important that boot seals be inspected regularly and replaced if damaged. The inboard (plunging joint) can often pump water into the joint around the seals or through small holes in the boot material itself because the joint moves in and out. Seal retainers are used to provide a leakproof connection between the boot seal and the housing or axle shaft.

CV JOINT GREASE CV joints require special greases. Grease is an oil with thickening agents. Greases are named for the thickening agents used.

Most CV joint grease is molybdenum-disulfide-type grease, commonly referred to as *moly* grease. The exact composition of grease can vary depending on the CV joint manufacturer. *The grease supplied with a replacement CV joint or boot kit should be the only grease used.*

The exact mix of chemicals, viscosity (thickness), wear, and corrosion-resistant properties varies from one CV joint application to another. Some technicians mistakenly think that the *color* of the grease determines in which CV joint it is used. The color—such as black, blue, red, or tan—is used to identify the grease during manufacturing and packaging as well as to give the grease a consistent, even color (due to blending of various ingredients in the grease).

The exact grease to use depends on many factors, including the following:

1. The type (style) of CV joint. For example, outer (fixed) and inner (plunging) joints have different lubricating needs.
2. The location of the joint on the vehicle. For example, inner CV joints are usually exposed to the greatest amount of heat.
3. The type of boot. The grease has to be compatible with the boot material.

REVIEW QUESTIONS

1. Explain why Cardan-type U-joints on a driveshaft must be within 1/2-degree working angles.
2. What makes a constant velocity joint able to transmit engine torque through an angle at a constant velocity?
3. What type of grease must be used in CV joints?

CHAPTER QUIZ

1. The name most often used to describe the universal joints on a conventional rear-wheel-drive vehicle driveshaft is _____.
   a. Trunnion **c.** CV
   b. Cardan **d.** Spider
2. A rear-wheel-drive vehicle shudders or vibrates when first accelerating from a stop. The vibration is less noticeable at higher speeds. The most likely cause is _____.
   a. Driveshaft unbalance
   b. Excessive U-joint working angles
   c. Unequal U-joint working angles
   d. Brinelling of the U-joint
3. All driveshafts are balanced.
   a. True **b.** False
4. The maximum difference between the front and rear working angle of a driveshaft is _____.
   a. 1/4 degree **c.** 1 degree
   b. 1/2 degree **d.** 3 degrees
5. Which series U-joint has the greatest torque capacity?
   a. 1260 **c.** 1350
   b. 1310 **d.** 1480
6. Two technicians are discussing torque steer on a front-wheel-drive vehicle. Technician A says that equal length drive axle shafts help reduce torque steer. Technician B says that equal drive axle shaft angles help reduce torque steer. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. The outer CV joints used on front-wheel-drive vehicles are _____.
   a. Fixed type
   b. Plunge type
8. The proper grease to use with a CV joint is _____.
   a. Black chassis grease
   b. Dark blue EP grease
   c. Red moly grease
   d. The grease that is supplied with the boot kit
9. Drive axle shafts are also called _____.
   a. Double-Cardan shafts **c.** Driveshafts
   b. Half shafts **d.** Propeller shafts
10. Two technicians are discussing a dented driveshaft. Technician A says that it should be repaired. Technician B says it should be replaced. Which technician is correct?
    a. Technician A only **c.** Both Technicians A and B
    b. Technician B only **d.** Neither Technician A nor B

chapter 124 DRIVE AXLE SHAFT AND CV JOINT SERVICE

OBJECTIVES: **After studying Chapter 124, the reader will be able to:** • Prepare for ASE Suspension and Steering (A4) certification test content area "C" (Related Suspension and Steering Service). • Explain how to perform a U-joint inspection. • List the steps necessary to replace a U-joint. • Explain how to perform a measurement of the working angles of a U-joint. • Describe the service procedures for replacing CV joints and boots. • Describe the routine maintenance service procedures required for drive axle shafts and universal CV joints. • How to properly grease a u-joint • Describe the symptoms of a defective universal joint

KEY TERMS: Inclinometer 1508 • Pinch bolt 1510 • Plastic (Nylon) retainers 1507 • Spline bind 1506 • Torque prevailing nut 1510 • U-joints 1504

U-JOINT FAULT SYMPTOMS

The driveshaft of a typical rear-wheel-drive (RWD) vehicle rotates about three times faster than the wheels. This is due to the gear reduction that occurs in the differential. The differential not only provides gear reduction but also allows for a difference in the speed of the rear wheels that is necessary whenever turning a corner.

The driveshaft rotates at the same speed as the engine if the transmission ratio is 1 to 1 (1:1). The engine speed, in revolutions per minute (RPM), is transmitted through the transmission at the same speed. In lower gears, the engine speed is many times faster than the output of the transmission. Most transmissions today, both manual and automatic, have an overdrive gear. This means that at highway speeds, the driveshaft is rotating faster than the engine (the engine speed is decreased or overdriven to help reduce engine speed and improve fuel economy).



FIGURE 124–1 Notice how the needle bearings have worn grooves into the bearing surface of the U-joint.

REAL WORLD FIX

The Squeaking Pickup Truck

The owner of a pickup truck complained that a squeaking noise occurred while driving in reverse. The "eeeee-eeeee-eeee" sound increased in frequency as the truck increased in speed, yet the noise did not occur when driving forward.

Because there was no apparent looseness in the U-joints, the service technician at first thought that the problem was inside either the transmission or the rear end. When the driveshaft was removed to further investigate the problem, it became obvious where the noise was coming from. The U-joint needle bearing had worn the cross-shaft bearing surface of the U-joint. ● **SEE FIGURE 124–1.** The noise occurred only in reverse because the wear had occurred in the forward direction, and therefore only when the torque was applied in the opposite direction did the needle bearing become bound up and start to make noise. A replacement U-joint solved the squeaking noise in reverse.

The driveshaft must travel up and down as the vehicle moves over bumps and dips in the road while rotating and transmitting engine power to the drive wheels. The driveshaft and universal joints should be carefully inspected whenever any of the following problems or symptoms occur:

1. Vibration or harshness at highway speed
2. A clicking sound whenever the vehicle is moving either forward or in reverse
3. A clunking sound whenever changing gears, such as moving from Drive to Reverse

NOTE: A click-click-click sound while moving in reverse is usually the first indication of a defective U-joint. This clicking occurs in reverse because the needle bearings are being forced to rotate in a direction opposite the usual.

DRIVESHAFT AND U-JOINT INSPECTION

VISUAL INSPECTION

The driveshaft should be inspected for the following:

1. Any dents or creases caused by incorrect hoisting of the vehicle or by road debris.

   CAUTION: A dented or creased driveshaft can collapse, especially when the vehicle is under load. This collapse of the driveshaft can cause severe damage to the vehicle and may cause an accident.

2. Undercoating, grease, or dirt buildup on the driveshaft can cause a vibration.
3. Undercoating should be removed using a suitable solvent and a rag. Always dispose of used rags properly.

LUBRICATION

The **U-joints** should be inspected every time the vehicle chassis is lubricated, or four times a year. Original equipment (OE) U-joints are permanently lubricated and have no provision for greasing. If there is a grease fitting, the U-joint should be lubricated by applying grease with a grease gun. ● **SEE FIGURES 124–2 AND 124–3.**

In addition to periodic lubrication, the driveshaft should be grabbed and moved to see if there is any movement of the U-joints. If *any* movement is noticed when the driveshaft is moved, the U-joint is worn and must be replaced.

NOTE: U-joints are not serviceable items and cannot be repaired. If worn or defective, they must be replaced.

PREPARATION FOR REMOVAL

U-joints can be defective and still not show noticeable free movement. *A proper U-joint inspection can be performed only by removing the driveshaft from the vehicle.*

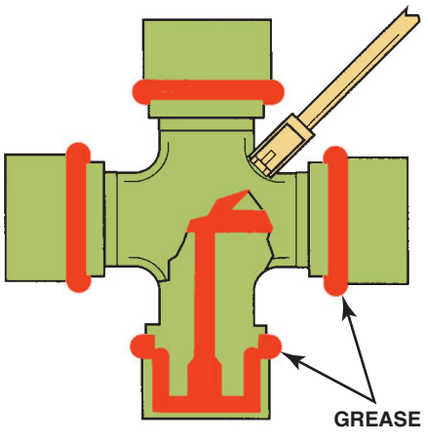
Before removing the driveshaft, always mark the position of all mating parts to ensure proper reassembly. White correction fluid, also known as "White Out" or "Liquid Paper," is an easy and fast-drying marking material. ● **SEE FIGURE 124–4.**

To remove the driveshaft from a rear-wheel-drive vehicle, remove the four fasteners at the rear U-joint at the differential. ● **SEE FIGURE 124–5.**

Push the driveshaft forward toward the transmission and then down and toward the rear of the vehicle. The driveshaft should slip out of the transmission spline and can be removed from underneath the vehicle.

NOTE: With the driveshaft removed, transmission lubricant can leak out of the rear extension housing. To prevent a mess, use an old spline the same size as the one being removed or place a plastic bag over the extension housing to hold any escaping lubricant. A rubber band can be used to hold the bag onto the extension housing.

To inspect U-joints, move each joint through its full travel, making sure it can move (articulate) freely and equally in all directions. ● **SEE FIGURE 124–6.**



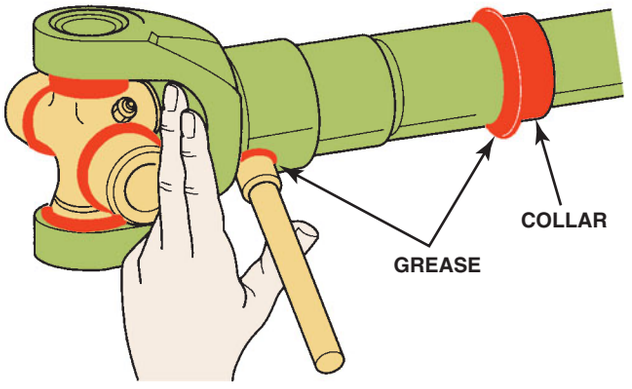
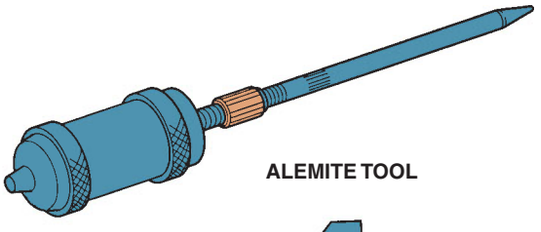


FIGURE 124–2 All U-joints and spline collars equipped with a grease fitting should be greased four times a year as part of a regular lubrication service. (*Courtesy of Dana Corporation*)



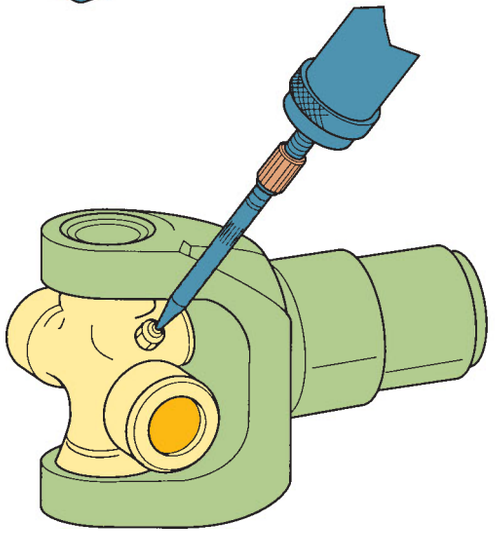


FIGURE 124–3 Many U-joints require a special grease gun tool to reach the grease fittings. Alemite is a manufacturer of lubrication equipment so many parts and tools use the Alemite name. (*Courtesy of Dana Corporation*)



FIGURE 124–4 Always mark the original location of U-joints before disassembly.

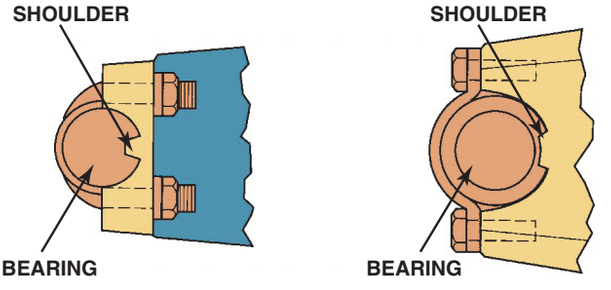


FIGURE 124–5 Two types of retaining methods that are commonly used at the rear U-joint at the differential. (*Courtesy of Dana Corporation*)

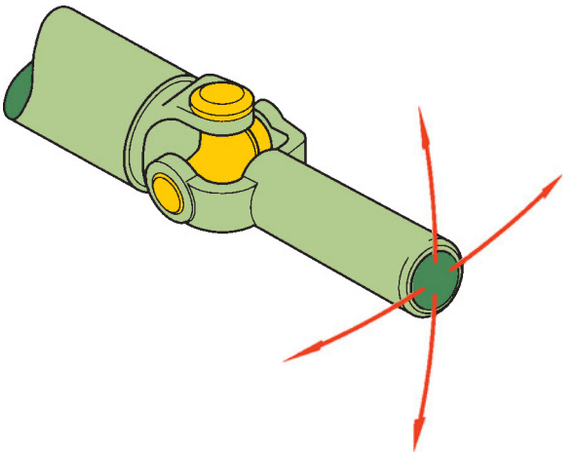


FIGURE 124–6 The best way to check any U-joint is to remove the driveshaft from the vehicle and move each joint in all directions. A good U-joint should be free to move without binding. (*Courtesy of Dana Corporation*)

U-JOINT REPLACEMENT

REMOVAL All movement in a U-joint should occur between the trunnions and the needle bearings in the end caps. The end caps are press-fit to the yokes, which are welded to the driveshaft. Three types of retainers are used to keep the bearing caps on the U-joints: the outside snap ring (● **SEE FIGURE 124–7**), the inside retaining ring, and injected synthetic (usually nylon).

DISASSEMBLY After removing the retainer, (● **SEE FIGURE 124–8**) use a press or a vise to separate the U-joint from the yoke. ● **SEE FIGURE 124–9.**

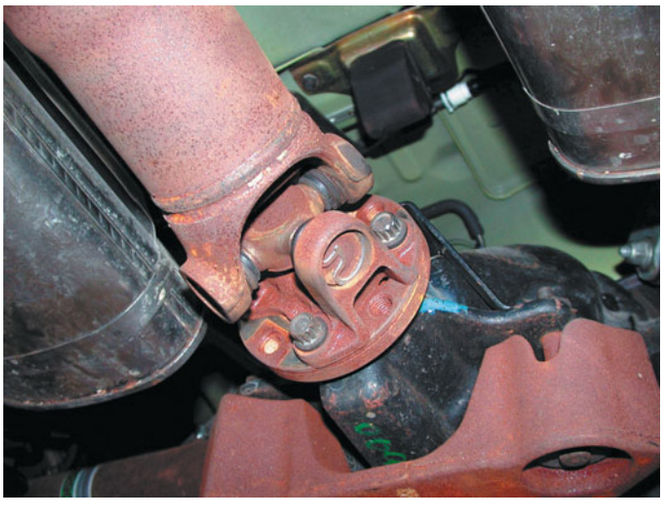


FIGURE 124–7 Typical U-joint that uses an outside snap ring. This style of joint bolts directly to the companion flange that is attached to the pinion gear in the differential.



FIGURE 124–8 A U-joint that is held together by nylon and usually requires that heat be applied to remove from the yoke.

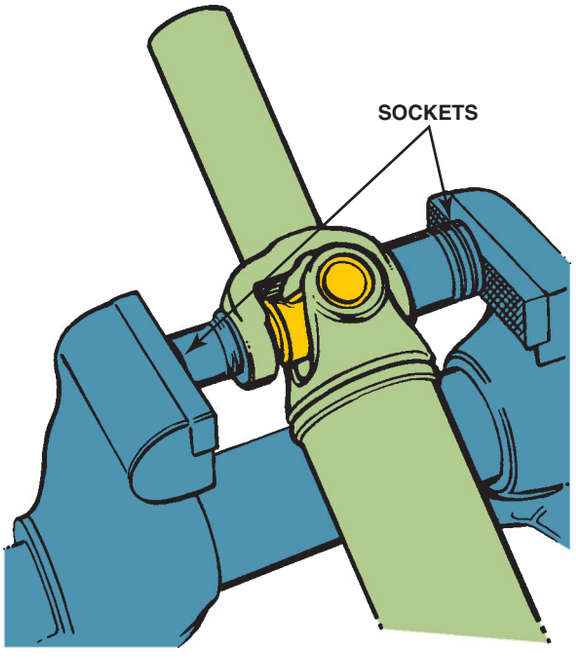


FIGURE 124–9 Use a vise and two sockets to replace a U-joint. One socket fits over the bearing cup and one fits on the bearing to press fit the cups from the crosspiece.

TECH TIP

Spline Bind Cure

Driveline "clunk" often occurs in rear-wheel-drive vehicles when shifting between drive and reverse or when accelerating from a stop. Often the cause of this noise is excessive clearance between the teeth of the ring and pinion in the differential. Another cause is called **spline bind,** where the changing rear pinion angle creates a binding in the spline when the rear springs change in height. For example, when a pickup truck stops, the weight transfers toward the front and unloads the rear springs. The front of the differential noses downward and forward as the rear springs unload. When the driver accelerates forward, the rear of the truck squats downward, causing the drive shaft to be pulled rearward when the front of the differential rotates upward. This upward movement on the spline often causes the spline to bind and make a loud clunk when the bind is finally released.

The method recommended by vehicle manufacturers to eliminate this noise is to follow these steps:

1. Remove the driveshaft.
2. Clean the splines on both the driveshaft yoke and the transmission output shaft.
3. Remove any burrs on the splines with a small metal file (remove all filings).
4. Apply a high-temperature grease to the spline teeth of the yoke. Apply grease to each spline, but do not fill the splines. Synthetic chassis grease is preferred because of its high temperature resistance.
5. Reinstall the driveshaft.

TECH TIP

Use Tape to Be Safe

When removing a driveshaft, use tape to prevent the rear U-joint caps from falling off. If the caps fall off the U-joint, all of the needle bearings will fall out and scatter over the floor. ● **SEE FIGURE 124–10.**



FIGURE 124–10 Taping the U-joint to prevent the caps from coming off.

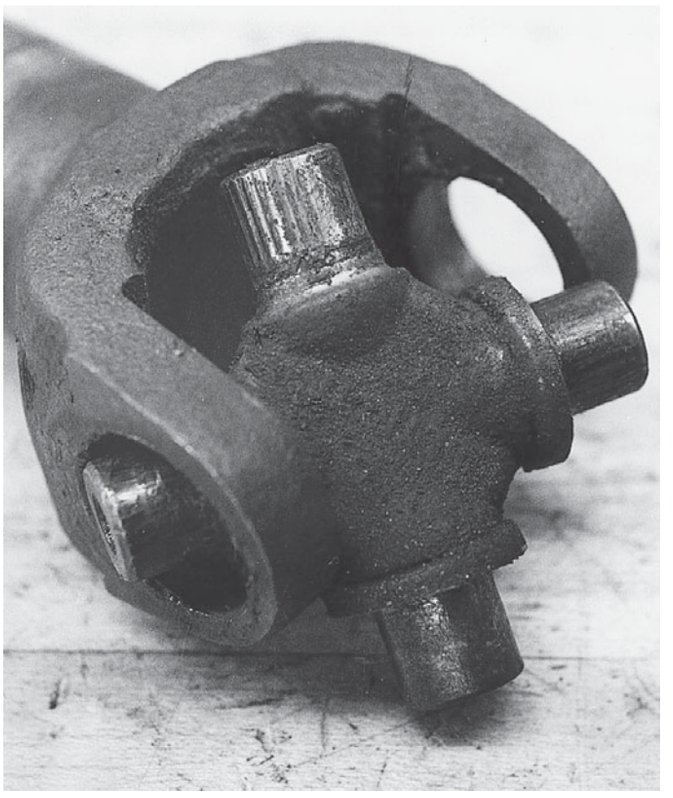
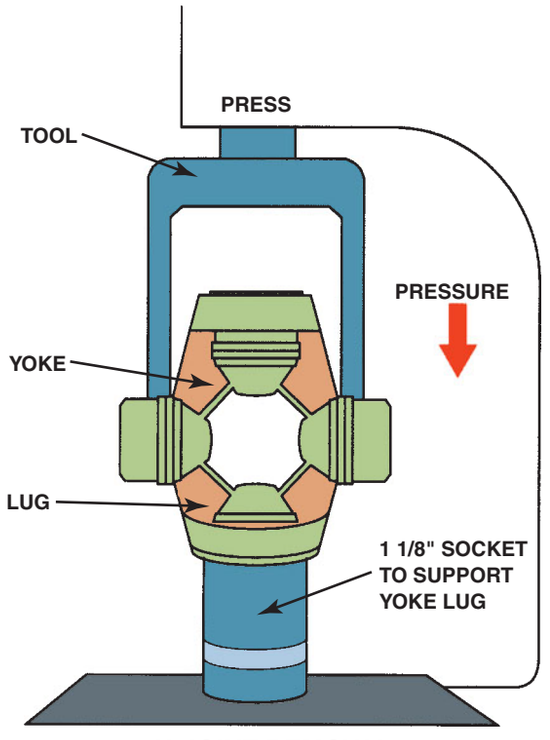


FIGURE 124–12 Removing the worn cross from the yoke.



U-JOINT REMOVAL
PLASTIC (NYLON) RETAINERS

FIGURE 124–11 A special tool being used to press apart a U-joint that is retained by injected plastic. Heat from a propane torch may be necessary to soften the plastic to avoid exerting too much force on the U-joint.

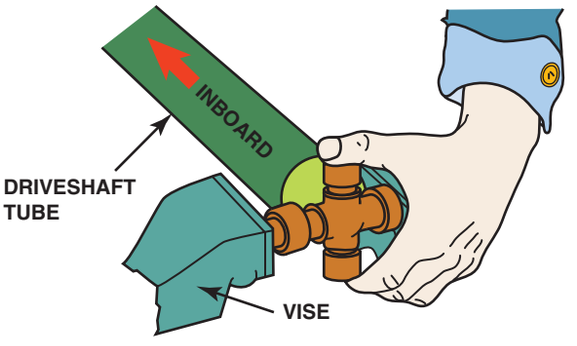


FIGURE 124–13 When installing a new U-joint, position the grease fitting on the inboard side (toward the driveshaft tube) and in alignment with the grease fitting of the U-joint at the other end.

U-joints that use **Plastic (Nylon) retainers** must be separated using a press and a special tool to press onto both sides of the joint in order to shear the plastic retainer, as shown in ● **FIGURE 124–11.**

REPLACEMENT Replacement U-joints use spring clips instead of injected plastic. Remove the old U-joint from the yoke, as shown in ● **FIGURE 124–12,** and replace with a new U-joint. Replacement U-joints should be *forged* (never cast) and use up to 32 needle bearings (also called *pin bushings*) instead of just 24 needle bearings, as used in lower-quality U-joints. Replacement U-joints usually have a grease fitting so that the new replacement U-joint can be properly lubricated. ● **SEE FIGURE 124–13.**

After removing any dirt or burrs from the yoke, press in a new U-joint. Rotate the new joint after installation to make sure it moves freely, without binding or stiffness. If a U-joint is stiff, it can cause a vibration.

NOTE: If a U-joint is slightly stiff after being installed, strike the U-joint using a brass punch and a light hammer. This often frees a stiff joint and is often called "relieving the joint." The shock aligns the needle bearings in the end caps.

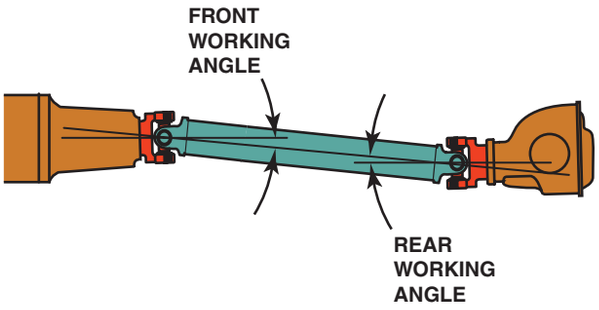


FIGURE 124–14 The working angle of most U-joints should be at least 1/2 degree (to permit the needle bearing to rotate in the U-joints) and should not exceed 3 degrees or a vibration can occur in the driveshaft, especially at higher speeds. The difference between the front and rear working angles should be within 1/2 degree of each other.



FIGURE 124–15 An inclinometer with a magnetic base is being used to measure the angle of the driveshaft at the rear U-joint.

U-JOINT WORKING ANGLES

POSSIBLE CAUSES OF INCORRECT U-JOINT ANGLES

Unequal or incorrect U-joint working angles can cause severe vibrations. Driveshaft and U-joint angles may change from the original factory setting due to one or more of the following:

1. Defective or collapsed engine or transmission mounts
2. Defective or sagging springs, especially the rear springs due to overloading or other causes
3. Accident damage or other changes to the chassis of the vehicle
4. Vehicle modification that raises or lowers the ride height

Replace any engine or transmission mount that is cracked or collapsed. When a mount collapses, the engine drops from its original location. The collapsed mount causes a change in the driveshaft angles are changed and a vibration may be felt.

Rear springs often sag after many years of service or after being overloaded. This is especially true of pickup trucks. Many people carry as much as the cargo bed can hold, often exceeding the factory-recommended carry capacity or gross vehicle weight (GVW) of the vehicle.

To measure U-joint and driveshaft angles, the vehicle must be hoisted using an axle contact or drive-on-type lift so as to maintain the same driveshaft angles as the vehicle has while being driven.

MEASURING THE WORKING ANGLES

The working angles of the two U-joints on a driveshaft should be within 1/2 degree of each other in order to cancel out speed changes. ● **SEE FIGURE 124–14.**

To measure the working angle of a U-joint, follow these steps:

STEP 1 Place an **inclinometer** (a tool used to measure angles) on the rear U-joint bearing cap. Level the bubble and read the angle. ● **SEE FIGURE 124–15**; the pictured reading is 19.5 degrees.

STEP 2 Rotate the driveshaft 90 degrees and read the angle of the rear yoke. For example, this reading is 17 degrees.

STEP 3 Subtract the smaller reading from the larger reading to obtain the working angle of the joint. In this example, it is 2.5 degrees (19.5 degrees − 17 degrees = 2.5 degrees).

Repeat the same procedure for the front U-joint. The front and rear working angles should be within 0.5 degrees. If the two working angles are not within 0.5 degrees, shims can be added to bring the two angles closer together. The angle of the rear joint is changed by installing a tapered shim between the leaf spring and the axle, as shown in ● **FIGURE 124–16.**

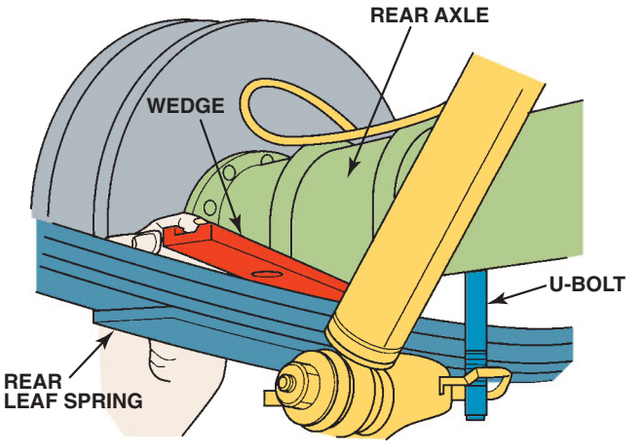


FIGURE 124–16 Placing a tapered metal wedge between the rear leaf spring and the rear axle pedestal to correct rear U-joint working angles.

CAUTION: Use caution whenever using wedges between the differential and the rear leaf spring to restore the correct U-joint working angle. Even though wedges are made to raise the front of the differential, the tilt often prevents rear-end lubricant from reaching the pinion bearing, resulting in pinion bearing noise and eventual failure.

The angle of the front joint is changed by adding or removing shims from the mount under the transmission. ● **SEE FIGURE 124–17.**

CV JOINT DIAGNOSIS

When a CV joint wears or fails, the most common symptom is noise while driving. An outer fixed CV joint will most likely be heard when turning sharply and accelerating at the same time. This noise is usually a clicking sound. While inner joint failure is less common, a defective inner CV joint often creates a loud clunk while accelerating from rest. To help verify a defective joint, drive the vehicle in reverse while turning and accelerating. This almost always will reveal a defective outer joint.

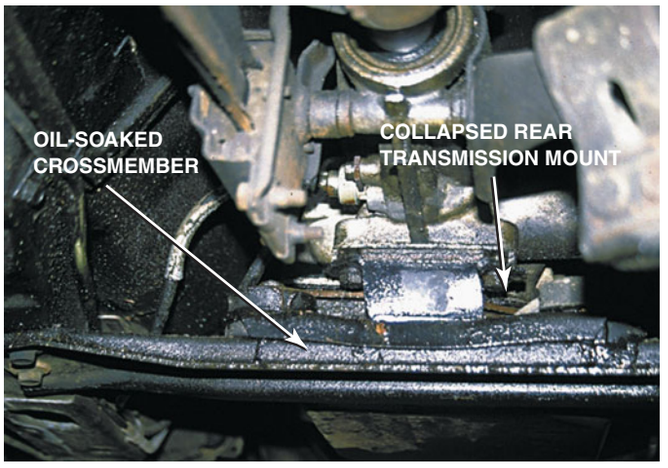


FIGURE 124–17 A transmission oil pan gasket leak allowed automatic transmission fluid (ATF) to saturate the rear transmission mount rubber, causing it to collapse. After replacing the defective mount, proper driveshaft angles were restored and the driveline vibration was corrected.

TECH TIP

Quick and Easy Backlash Test

Whenever a driveline clunk is being diagnosed, one possible cause is excessive backlash (clearance) between the ring gear teeth and differential pinion teeth in the differential. Another common cause of excessive differential backlash is too much clearance between differential carrier pinion teeth and side gear teeth. A quick test to check backlash involves three easy steps:

STEP 1 Hoist the vehicle on a frame contact lift, allowing the drive wheels to be rotated.

STEP 2 Have an assistant hold one drive wheel and the driveshaft to keep them from turning.

STEP 3 Move the other drive wheel, observing how far the tire can rotate. This is the amount of backlash in the differential; it should be less than 1 in. (25 mm) of movement measured *at the tire.*

If the tire can move more than 1 in. (25 mm), then the differential should be inspected for wear and parts should be replaced as necessary. If the tire moves *less* than 1 in. (25 mm), then the backlash between the ring gear and pinion is probably *not* the cause of the noise.

REPLACEMENT SHAFT ASSEMBLIES

Front-wheel-drive vehicles were widely used in Europe and Japan long before they became popular in North America. The standard repair procedure used in these countries is the replacement of the entire drive assembly if there is a CV joint failure. Replacement boot kits are rarely seen in Europe because it is felt that even a slight amount of dirt or water inside a CV joint is unacceptable. Vehicle owners simply wait until the joint wear causes severe noise, and then the entire assembly is replaced.

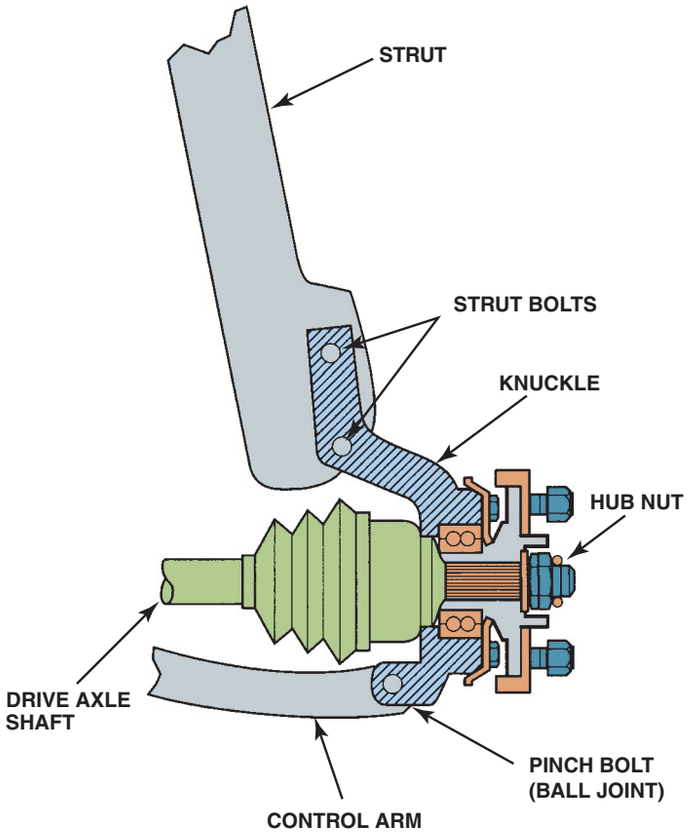


FIGURE 124–18 The hub nut must be removed before the hub bearing assembly or drive axle shaft can be removed from the vehicle.

The entire drive axle shaft assembly can easily be replaced and the defective unit can be sent to a company for remanufacturing. Even though cost to the customer is higher, the parts and repair shop does not have to inventory every type, size, and style of boot kit and CV joint. Service procedures and practices therefore vary according to location and the availability of parts. For example, some service technicians use replacement drive axle assemblies from salvage yards with good success.

NOTE: Some drive axle shafts have a weight attached between the inner and outer CV joints. This is a dampener weight. It is not a balance weight, and it need not be transferred to the replacement drive axle shaft (half shaft) unless instructed to do so in the directions that accompany the replacement shaft assembly.

CV JOINT SERVICE

The hub nut must be removed whenever servicing a CV joint or shaft assembly on a front-wheel-drive vehicle. Since these nuts are usually torqued to almost 200 lb-ft (260 N-m), keep the vehicle on the ground until the hub nut is loosened and then follow these steps (● **SEE FIGURE 124–18**):

STEP 1 Remove the front wheel and hub nut.

NOTE: Most manufacturers warn against using an air impact wrench to remove the hub nut. The impacting force can damage the hub bearing.

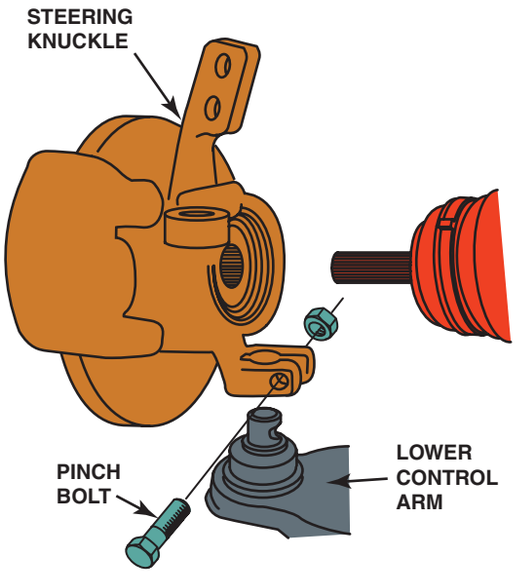
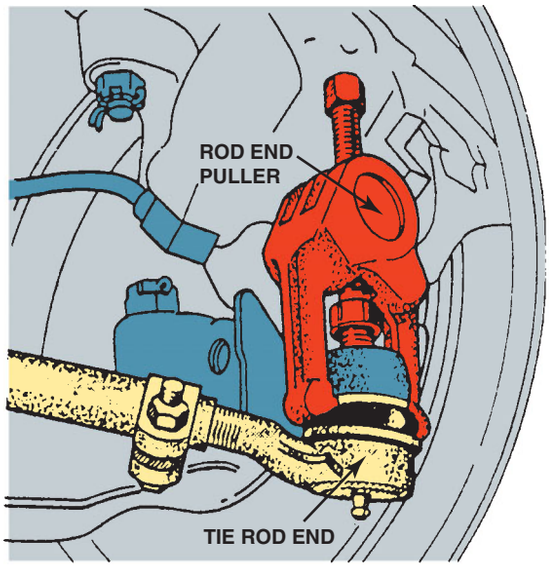


FIGURE 124–19 Many knuckles are attached to the ball joint on the lower control arm by a pinch bolt.



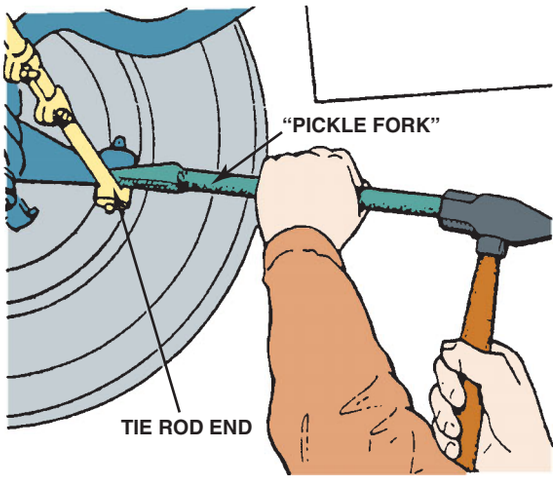


FIGURE 124–20 The preferred method for separating the tie rod end from the steering knuckle is to use a puller such as the one shown. A "pickle-fork"-type tool should be used only if the tie rod is going to be replaced. A pickle-fork-type tool can damage or tear the rubber grease boot. Striking the tie rod end with a hammer while holding another hammer behind the joint to shock and break the taper from the steering knuckle can also be used.

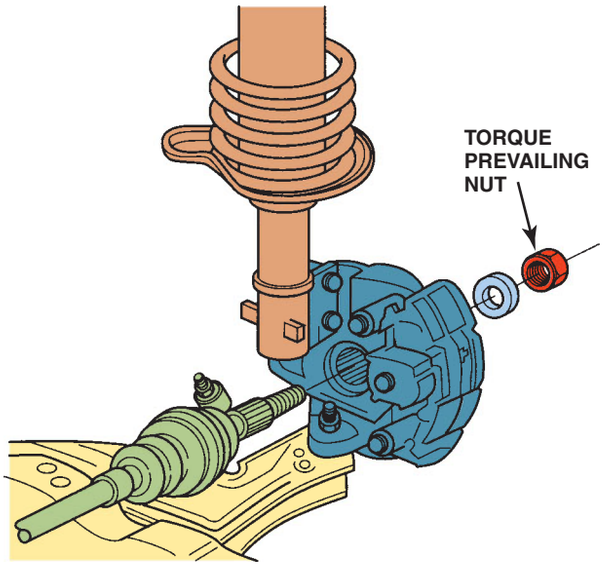


FIGURE 124–21 Many drive axles are retained by **torque prevailing nuts** that must not be reused. Torque prevailing nuts are slightly deformed or contain a plastic insert that holds the nut tight (retains the torque) to the shaft without loosening.

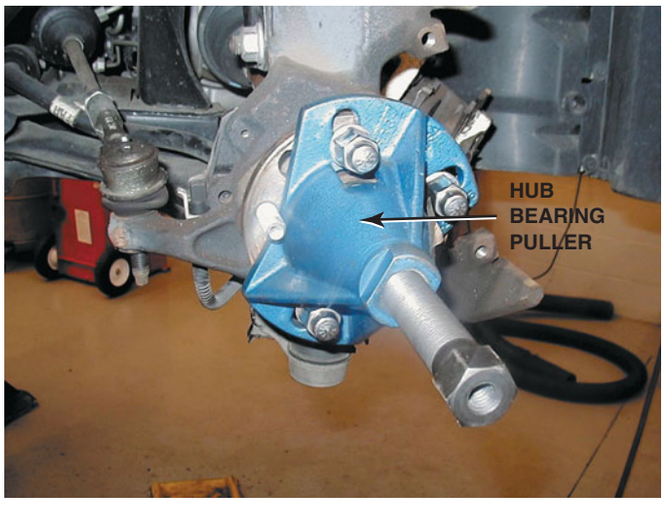


FIGURE 124–22 A special General Motors tool is being used to separate the drive axle shaft from the wheel hub bearing.

STEP 2 To allow the knuckle room to move outward enough to remove the drive axle shaft, some or all of the following will have to be disconnected:

- **a.** Lower ball joint or **pinch bolt** (● **SEE FIGURE 124–19**).
- **b.** Tie rod end (● **SEE FIGURE 124–20**).
- **c.** Stabilizer bar link.
- **d.** Front disc brake caliper.

STEP 3 Remove the splined end of the axle from the hub bearing. Sometimes a special puller may be necessary, but in most cases the shaft can be tapped inward through the hub bearing with a light hammer and a brass punch can be used. To protect the threads of the drive axle shaft, install the hub nut temporarily. ● **SEE FIGURES 124–21 AND 124–22**.

STEP 4 Use a prybar or special tool with a slide hammer, as shown in ● **FIGURE 124–23**, and remove the inner joint from the transaxle.

STEP 5 Disassemble, clean, and inspect all components. ● **SEE FIGURES 124–24 THROUGH 124–30**.

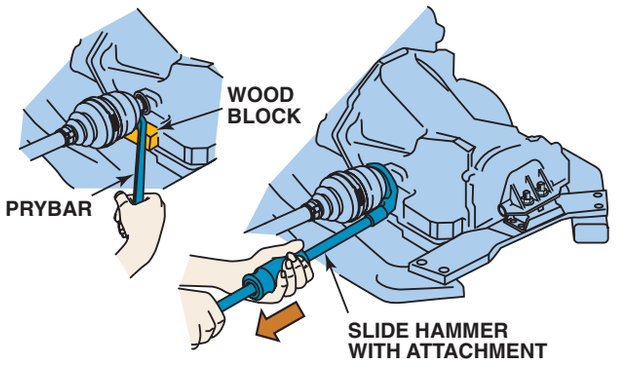


FIGURE 124–23 Most inner CV joints can be separated from the transaxle with a prybar.



FIGURE 124–24 When removing a drive axle shaft assembly, use care to avoid pulling the plunge joint apart.



FIGURE 124–25 If other service work requires that just one end of the drive axle shaft be disconnected from the vehicle, be sure that the free end is supported to prevent damage to the protective boots or allowing the joint to separate.

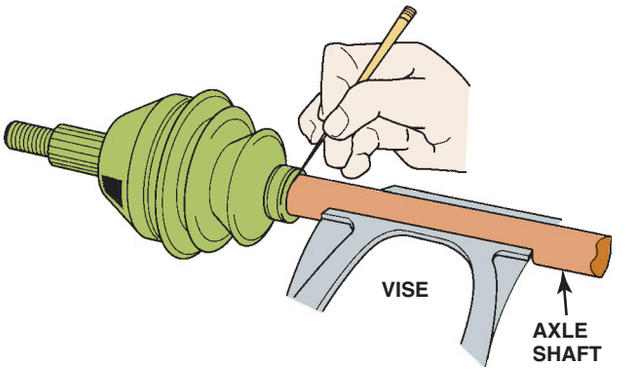


FIGURE 124–26 With a scribe, mark the location of the boots before removal. The replacement boots must be in the same location.

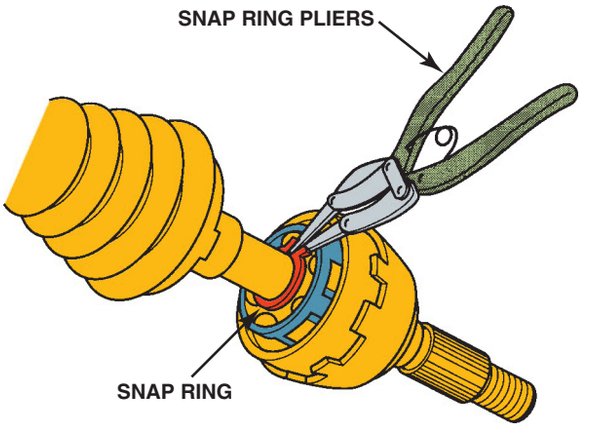


FIGURE 124–27 Most CV joints use a snap ring to retain the joint on the drive axle shaft.

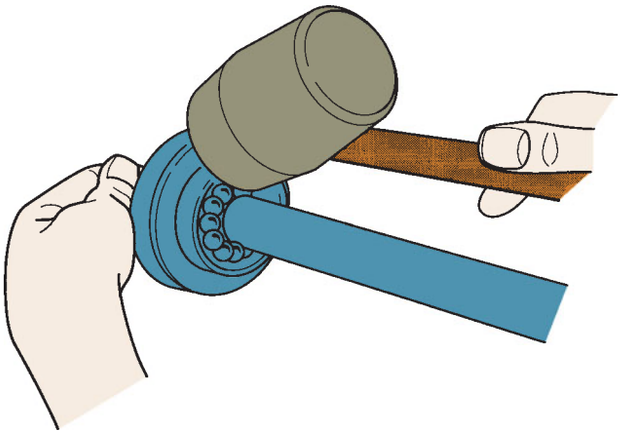


FIGURE 124–28 After releasing the snap ring, most CV joints can be tapped off the shaft using a brass or shot-filled plastic (dead-blow) hammer.

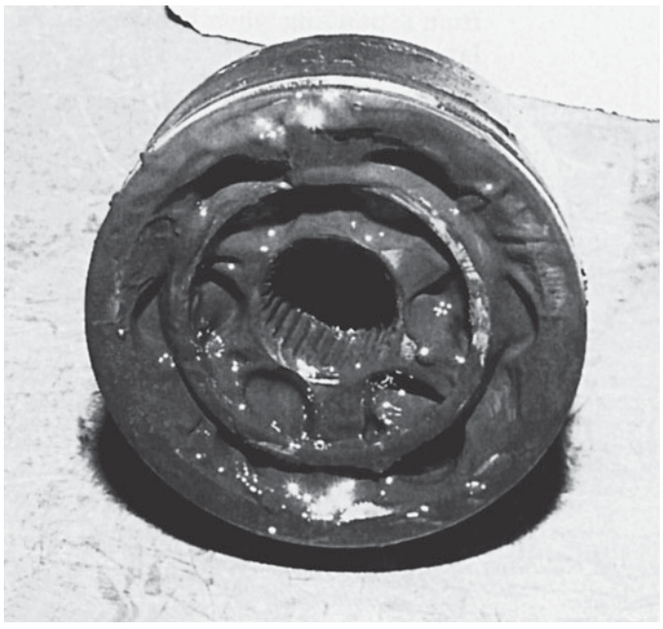


FIGURE 124–29 Typical outer CV joint after removing the boot and the joint from the drive axle shaft. This joint was removed from the vehicle because a torn boot was found. After disassembly and cleaning, this joint was found to be OK and was put back into service. Even though the grease looks terrible, there was enough grease in the joint to provide enough lubrication to prevent any wear from occurring.

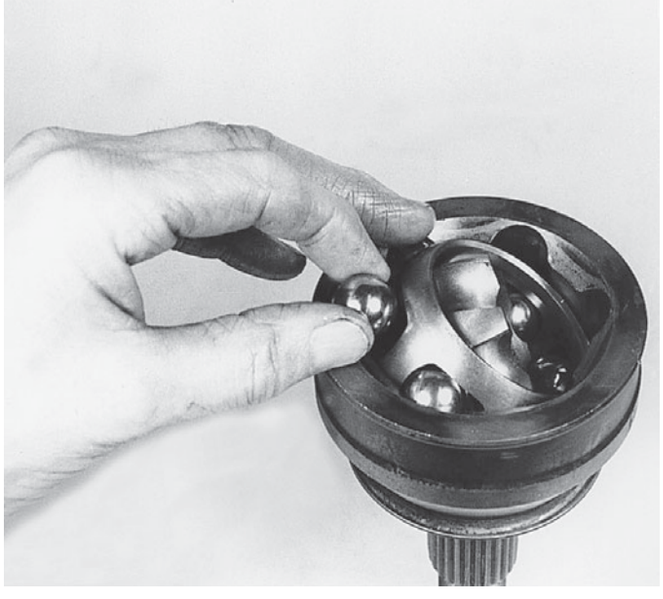


FIGURE 124–30 The cage of this Rzeppa-type CV joint is rotated so that one ball at a time can be removed. Some joints require that the technician use a brass punch and a hammer to move the cage.

STEP 6 Replace the entire joint if there are *any* worn parts. Pack *all* the grease that is supplied into the assembly or joint. ● **SEE FIGURE 124–31**. Assemble the joint and position the boot in the same location as marked. Before clamping the last seal on the boot, be sure to release trapped air to prevent the boot from expanding when heated and collapsing when cold. This is sometimes called *burping the boot.* Clamp the boot according to the manufacturer's specifications.

STEP 7 Reinstall the drive axle shaft in the reverse order of removal, and torque the drive axle nut to factory specifications. ● **SEE FIGURE 124–32**.

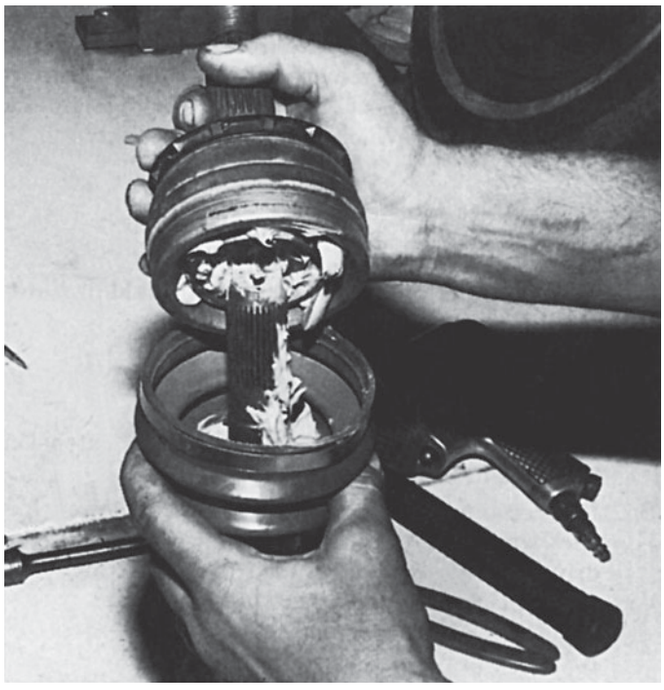


FIGURE 124–31 Be sure to use *all* of the grease supplied with the replacement joint or boot kit. Use only the grease supplied and do not use substitute grease.



FIGURE 124–32 A screwdriver is shown, but a punch would be better, to keep the rotor from rotating while removing or installing the drive axle shaft spindle nut.



FIGURE 124–33 The engine had to be raised higher to get the new (noncollapsed) engine mount installed.



REAL WORLD FIX

The Vibrating Buick

The owner of a front-wheel-drive Buick complained that it vibrated during acceleration only. The vehicle would also pull toward one side during acceleration. An inspection discovered a worn (cracked) engine mount. After replacing the mount, the CV joint angles were restored and both the vibration and the pulling to one side during acceleration were solved. ● **SEE FIGURE 124–33.**

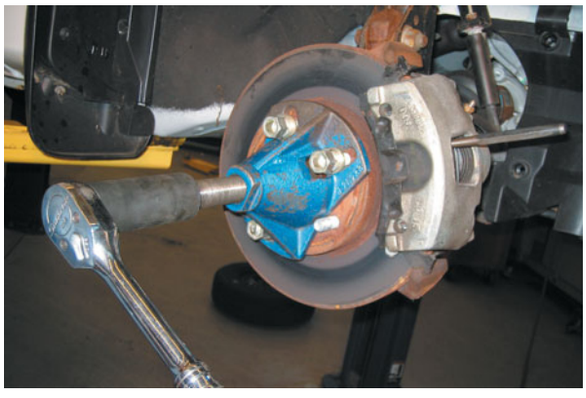
DRIVE AXLE SHAFT REPLACEMENT



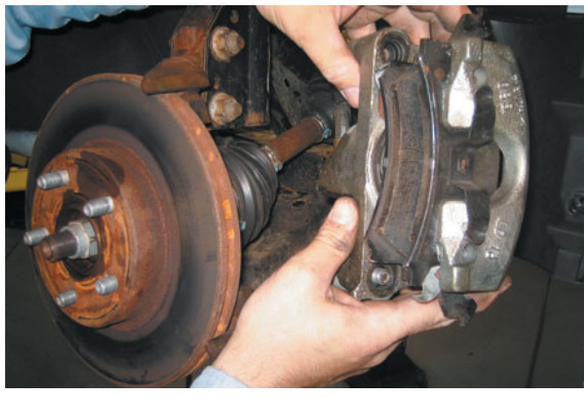
1 Tools needed to replace a drive axle shaft on a General Motors vehicle include a punch, sockets, plus a prybar bearing/axle shaft special tool.



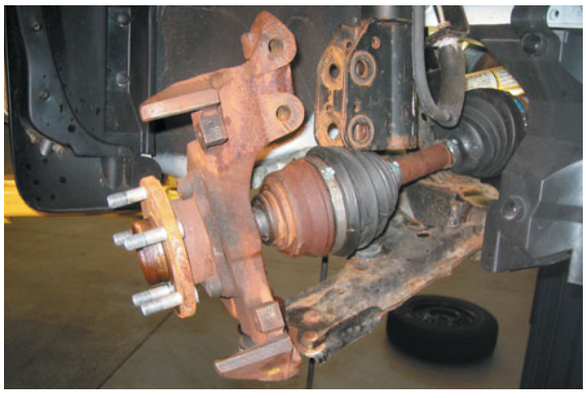
2 The drive axle shaft retaining nut can be loosened with the tire on the ground, or use a drift inserted into the rotor cooling fins before removing the nut.



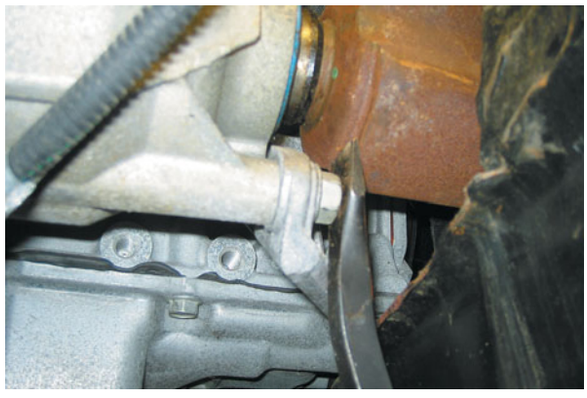
3 Using a special tool to push the drive axle splines from the bearing assembly.



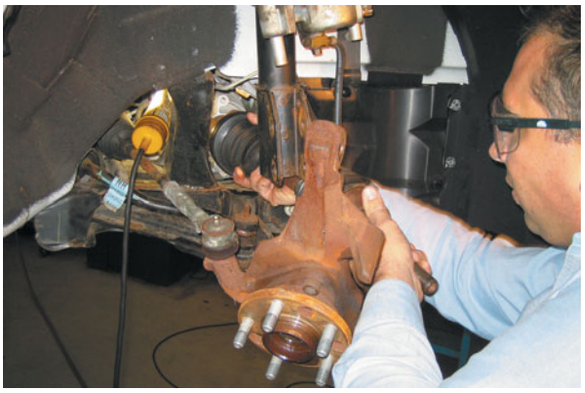
4 Remove the disc brake caliper and support it out of the way. Then, remove the disc brake rotor.



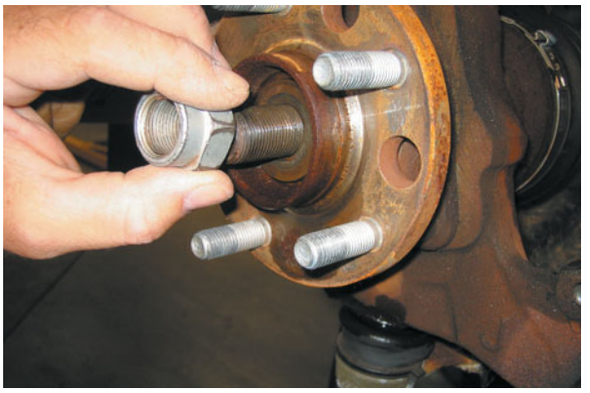
5 To allow for the removal of the drive axle shaft, the strut is removed from the steering knuckle assembly.



6 A prybar is used to separate the inner drive axle shaft joint from the transaxle.



7 After the inner joint splines have been released from the transaxle, carefully remove the drive axle shaft assembly from the vehicle.



8 To install, reverse the disassembly procedure and be sure to install the washer under the retainer-nut, and always use a new prevailing torque nut.



9 Reinstall the disc brake rotor and caliper and then torque the drive axle shaft retaining nut to factory specifications.

REVIEW QUESTIONS

1. List two items that should be checked when inspecting a driveshaft.
2. List the steps necessary to measure driveshaft U-joint working angles.
3. Describe how to replace a Cardan-type U-joint.
4. Explain the proper steps to perform when replacing a CV joint.

CHAPTER QUIZ

1. Two technicians are discussing U-joints. Technician A says that a defective U-joint could cause a loud clunk when the transmission is shifted between Drive and Reverse. Technician B says a worn U-joint can cause a clicking sound often when driving the vehicle in reverse. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. Incorrect or unequal U-joint working angles are most likely to be caused by _____.
   a. A bent driveshaft
   b. A collapsed engine or transmission mount
   c. A dry output shaft spline
   d. Defective or damaged U-joints
3. A defective outer CV joint will usually make a _____.
   a. Rumbling noise
   b. Growling noise
   c. Clicking noise
   d. Clunking noise
4. The last step after installing a replacement CV boot is to _____.
   a. "Burp the boot"
   b. Lubricate the CV joint with chassis grease
   c. Mark the location of the boot on the drive axle shaft
   d. Separate the CV joint before installation
5. A Cardan-type U-joint may require what tool(s) to replace? _____
   a. A special tool
   b. A torch
   c. A press or a vise
   d. May require any of the above
6. What needs to be removed to replace a drive axle shaft from a front-wheel-drive vehicle?
   a. Tie rod end
   b. Lower control arm or ball joint
   c. Hub nut
   d. All of the above
7. The splines of the driveshaft yoke should be lubricated to prevent _____.
   a. A vibration
   b. Spline bind
   c. Rust
   d. Transmission fluid leaking from the extension housing
8. It is recommended by many experts that an air impact wrench *not* be used to remove or install the drive axle shaft nut because the impacting force can damage the hub bearing.
   a. True
   b. False
9. Front and rear driveshaft U-joint working angles should be within _____ degrees of each other.
   a. 0.5
   b. 1.0
   c. 3.0
   d. 4.0
10. A defective (collapsed) engine mount on a front-wheel-drive vehicle can cause a vibration.
    a. True
    b. False

chapter 125 DIFFERENTIALS

OBJECTIVES: **After studying Chapter 125, the reader will be able to:** • Prepare for ASE Manual Drive Train and Axles (A3) certification test content area "E" (Rear Axle Diagnosis and Repair). • Describe how the differential allows engine torque to be applied to both drive wheels and still allow a difference in the speed of the drive wheels during cornering. • Discuss differential seals and bearings. • Explain how a limited slip-type differential works. • Determine the rear axle ratio. • Perform a tooth contact pattern check and determine corrective action. • Describe how to determine proper drive pinion gear depth. • Explain how to achieve proper drive pinion bearing preload. • Describe how to adjust the ring gear position to provide the proper backlash.

KEY TERMS: Axle ratio 1519 • Coast (or concave) side 1518 • Companion flange 1521 • Crown 1518 • Diff 1517 • Differential case 1517 • Drive (or convex) side 1518 • Drive pinion gear 1517 • Floating position 1518 • Heel 1518 • Hunting gear sets 1519 • Hypoid gear set 1517 • Lap 1519 • Nonhunting gear sets 1519 • Partially nonhunting gear sets 1519 • Pinion gear 1517 • Pinion shaft 1517 • Preloaded clutch 1520 • Rear end 1517 • Ring gear 1517 • Ring gear runout 1525 • Root 1518 • Side gears 1517 • Spider gears 1517 • Straddle-mounted pinion 1522 • Toe 1518 • Turning torque 1529 • Viscous coupling 1521

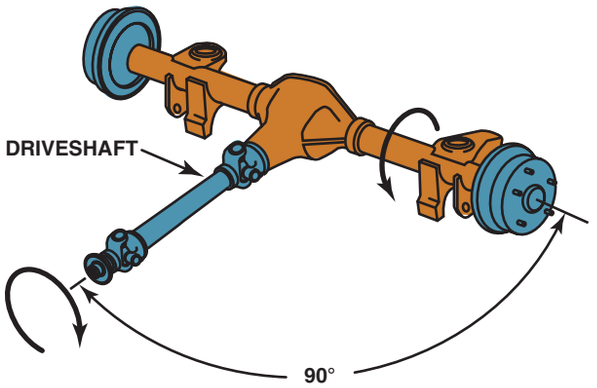


FIGURE 125–1 The differential assembly changes the direction of engine torque and increases the torque to the drive wheels.

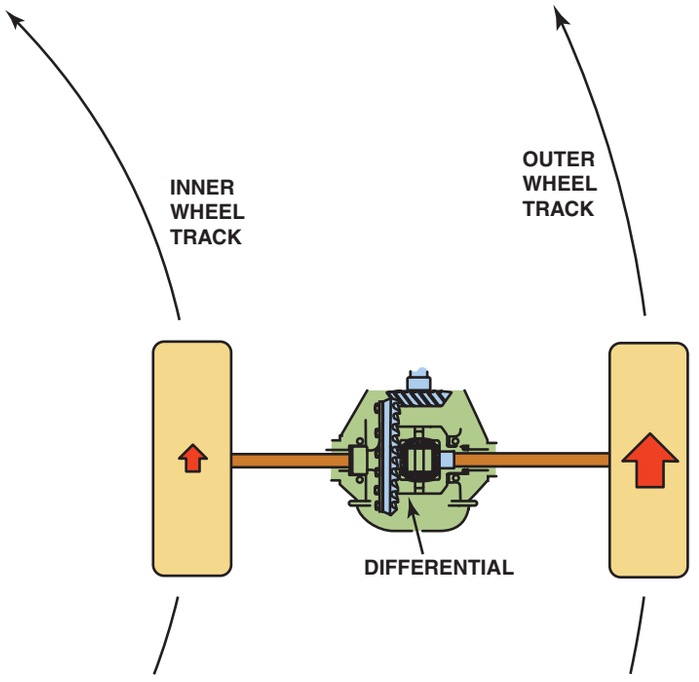


FIGURE 125–2 The difference between the travel distance of the drive wheels is controlled by the differential.

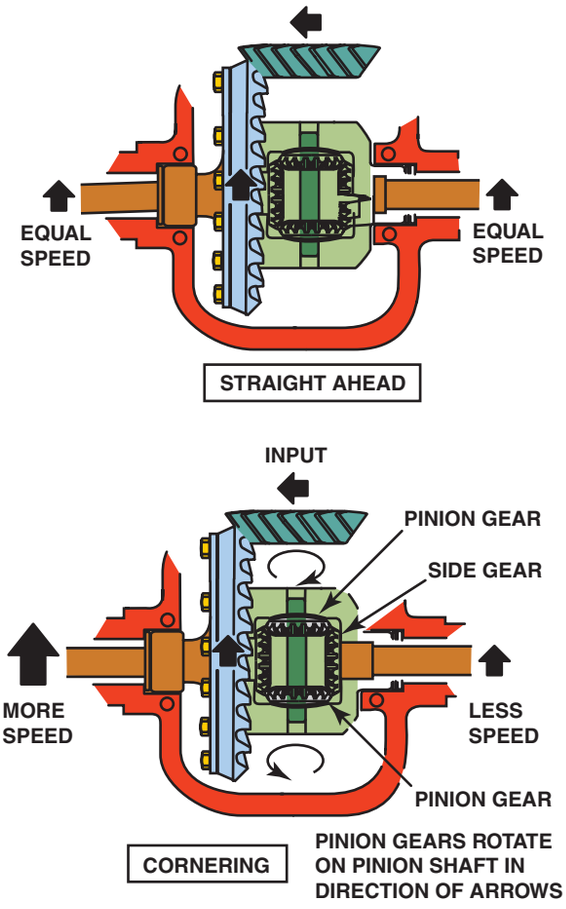


FIGURE 125–3 When the vehicle turns a corner, the inner wheel slows and the outer wheel increases in speed to compensate. This difference in rotational speed causes the pinion gears to "walk" around the slower side gear.

NOTE: The differential used in most front-wheel-drive vehicles is incorporated into the transaxle assembly and is called the final drive assembly. The purpose and function of this final drive assembly is similar to the differential assembly used in rear-wheel-drive vehicles.

DIFFERENTIALS

The differential allows engine torque to be applied to both drive axles, which rotate at varying speeds during cornering and while traveling over bumps and dips in the road. The differential also changes the direction of engine torque 90° from the rotation of the driveshaft lengthwise with the vehicle. These two purposes of a differential can be summarized as follows:

- To change the direction of engine torque (● **SEE FIGURE 125–1**).
- To allow the drive wheels to rotate at different speeds (● **SEE FIGURE 125–2**).

A differential is a mechanical addition and subtraction assembly. By splitting the engine torque to the drive wheels when the vehicle is turning a corner, the torque forces cause the side gear and pinion gears to subtract torque from one side and add torque to the opposite side. ● **SEE FIGURE 125–3.**

PARTS OF A DIFFERENTIAL

A differential is also called a **rear end** or abbreviated simply as a **diff.** Whenever any vehicle makes a turn, the outside wheel must travel a greater distance than the inside wheel. The driveshaft applies torque to the **drive pinion gear** that meshes below the center line of a **ring gear** as shown in ● **FIGURE 125–4.** This type of gear set is called a **hypoid gear set** and requires gear lubrication specifically designed for this type of service. The ring gear is attached to a **differential case** that also contains small beveled **spider gears** or **pinion gears.** A **pinion shaft** passes through the two pinion gears in the case. In mesh with the pinion gears are two **side gears** that are splined to the inner ends of the axles. ● **SEE FIGURE 125–5.**

THE PINION AND RING GEARS DURING OPERATION

During operation, the position of the drive pinion gear on the ring gear changes. The ring gear mounts onto the differential case as shown in ● **FIGURE 125–6** on page 1518. Each slanted ring gear tooth has

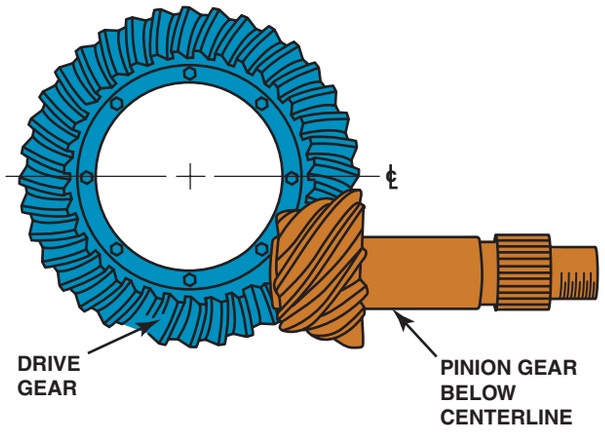


FIGURE 125–4 A hypoid gear set uses a drive pinion that meshes with the ring gear below the center line of the ring gear.

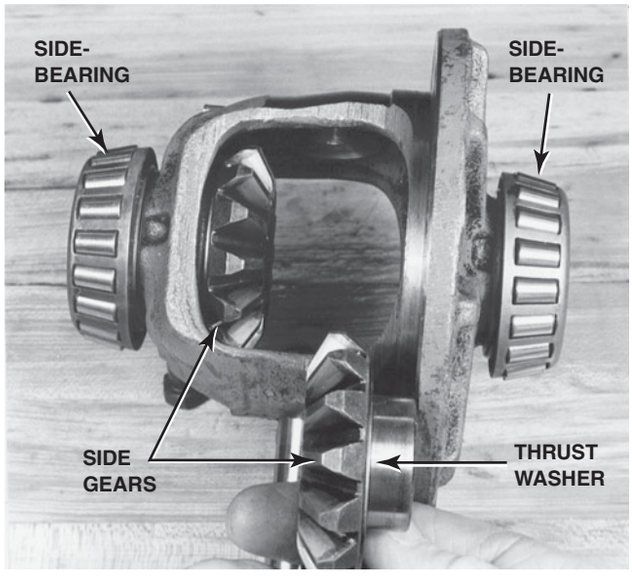


FIGURE 125–5 The differential case provides the support for the ring gear, side bearings, and side gears.

two ends. Its **toe** is closest to the ring gear center; its **heel,** closest to the outside circumference. The tooth **root** is the depression lying between two teeth, and the **crown** is the very top of each tooth.

While a vehicle accelerates, the drive pinion contacts the ring teeth on its **drive,** or **convex side.** While decelerating, the drive pinion contacts the ring teeth on its **coast,** or **concave side.** ● **SEE FIGURE 125–7.** The intermediate position between drive and coast, when neither the ring gear nor the pinion is driving each other, is called the **"floating" position.**

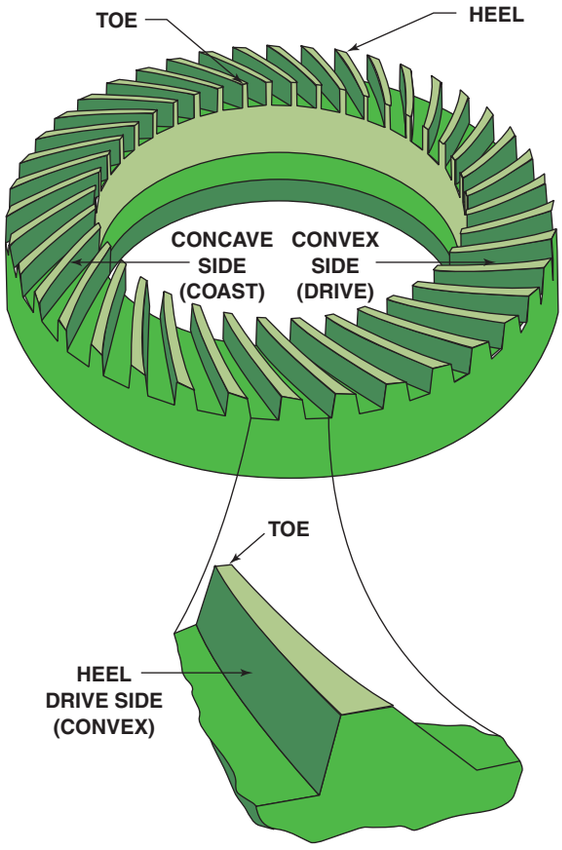


FIGURE 125–7 The drive side is the convex side of the ring gear except for some front axles used in four-wheel vehicles, and they often use the concave side on the drive side.

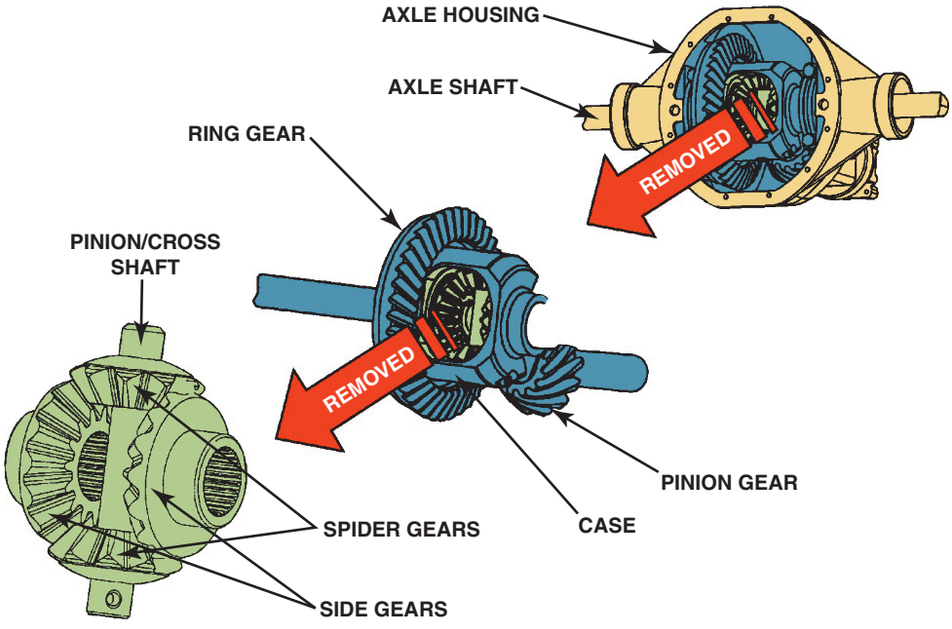


FIGURE 125–6 The relationship among the ring gear and drive pinion as well as the side and spider gears.

DIFFERENTIAL GEAR RATIOS

The final gear reduction in the drive train occurs in the differential assembly. The amount of torque a gear set delivers depends on the gear ratio between the drive pinion gear and the driven ring gear. The gear ratio of the final drive (differential) is called the **axle ratio.** To determine the axle ratio, divide the number of teeth of the ring gear (driven gear) by the number of teeth of the drive pinion gear (driving gear):

$$\frac{\text{Ring gear (41 teeth)}}{\text{Pinion gear (10 teeth)}} = 4.10 \text{ (Axle ratio)}$$

The higher the axle ratio number, the faster the engine rotates for each rotation of the drive wheels. See the High-Performance Tip "Change the Axle Ratio."

RING AND PINION GEAR SET TYPES The final drive gear ratio determines how many times a drive pinion tooth will make contact with a particular ring gear tooth during one revolution. This affects final drive gear set manufacture and service.

Final drive gear sets may be divided into three types, depending on the final drive gear ratio.

1. **Hunting gear sets** are gear sets with final drive ratios expressible in a fraction that cannot be reduced to any lower terms. An example of a hunting gear set is one that has 41 teeth on the ring gear and 11 teeth on the drive pinion. This combination creates a 3.73:1 axle ratio. This type of gear set requires no timing marks or alignment during assembly. As the pinion gear drives the ring gear, each pinion tooth will hunt for, or seek, contact with every ring gear tooth.
2. **Nonhunting gear sets** are gear sets with final drive ratios expressible as a whole number. An example of a nonhunting gearset is a differential that uses 39 teeth on the ring gear and 13 teeth on the pinion gear which gives a 3.00:1 gear ratio. Nonhunting gear sets require timing marks. As the pinion gear drives the ring gear, each pinion tooth contacts only a few ring gear teeth during each revolution.
3. **Partially nonhunting gear sets** are gear sets with final drive ratios expressible as a reducible fraction not equaling a whole number. An example of a partial nonhunting gearset is an axle ratio of 3.50:1.

Partially nonhunting gear sets also require timing marks. During final drive operation, each pinion tooth contacts only some of the ring pinion teeth. For the pinion teeth to make contact with the highest number of ring gear teeth, the pinion gear must drive the ring gear more than one revolution.

On nonhunting and partially nonhunting gears, manufacturers **lap** the contacting gear teeth to decrease wear. For this reason, these gear sets are marked to ensure proper alignment during assembly procedures. To preserve the wear patterns, the gear sets should be reassembled using the same alignment. This prolongs the life of the gear set and decreases operational noise.

DIFFERENTIALS

PURPOSE AND FUNCTION While a vehicle travels straight ahead, the speed of each driven wheel must be allowed to vary slightly as they go over bumps, potholes, railroad tracks, and other road surface irregularities. While cornering, the wheels must be able to turn at much greater differences in speed. Without some mechanism to allow for a difference in speed between the wheels, the left wheel would skid through the turn.

Inside the differential gear housing four to six bevel gears help drive the axles. In most differentials, there are two bevel gears called pinions that are constantly meshed with a beveled axle side gear on each axle. The pinion and axle side gears are contained in a housing called the carrier or case.

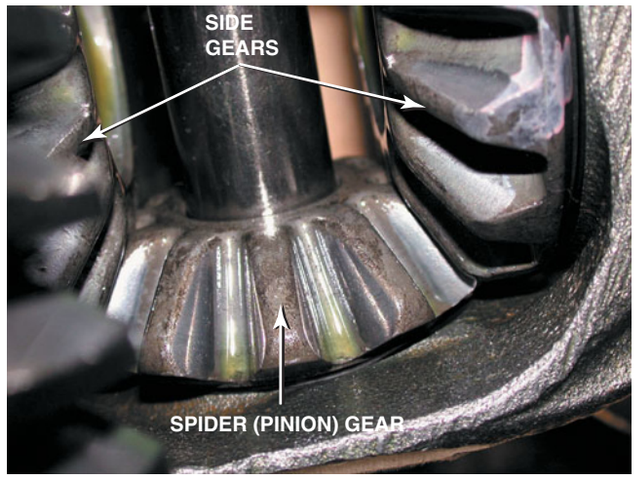


FIGURE 125–8 A close-up view of the side gears and spider (pinion) gear. Note the ridges on the gear teeth. These ridges are manufactured into the gear teeth to help retain lubricant so that no metal-to-metal contact occurs.

HIGH PERFORMANCE TIP **Change the Axle Ratio**

To increase vehicle performance, replace a high ratio (lower number) rear axle ratio with a lower ratio (higher number) rear axle. For example,

Stock rear end = 3.23:1 (drive pinion has 13 teeth and the ring gear has 42 teeth)

Replacement rear end = 3.73:1 (drive pinion has 11 teeth and the ring gear has 41 teeth)

The high-performance axle ratio (3.73:1) allows the engine to rotate faster than the stock 3.23:1 ratio. Because most engines produce greater torque with increasing RPM (up to a point), this allows more torque to be applied to the drive wheels. Not only is the engine producing more torque, but the higher-number gear ratio also multiplies the available torque times 3.73 instead of the original 3.23. However, there are several disadvantages associated with changing the rear end ratio:

- Decreased fuel economy
- Incorrect speedometer and odometer readings that can affect the shifting of the automatic transmission unless changes are made to the computer or vehicle speed sensors
- Increased engine noise due to the higher engine speed
- Increased engine wear, again due to the increased engine speed

If you can live with these disadvantages, a change in the rear end ratio generates a real performance gain.

TORQUE FLOW THROUGH A STANDARD OPEN DIFFERENTIAL Open differentials deliver equal torque to both wheels at all times. As the case rotates (driven by the engine through the ring and pinion gears), the cross-shaft applies a drive force to the spider gears. The two side gears apply reaction forces that counter this drive force. ● **SEE FIGURE 125–8.** Because the spider

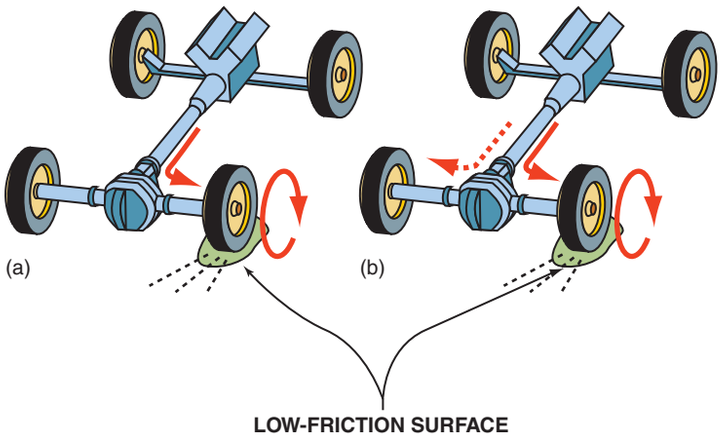


FIGURE 125–9 (a) A two-wheel-drive vehicle equipped with an open differential. (b) A two-wheel-drive vehicle equipped with a limited-slip differential.

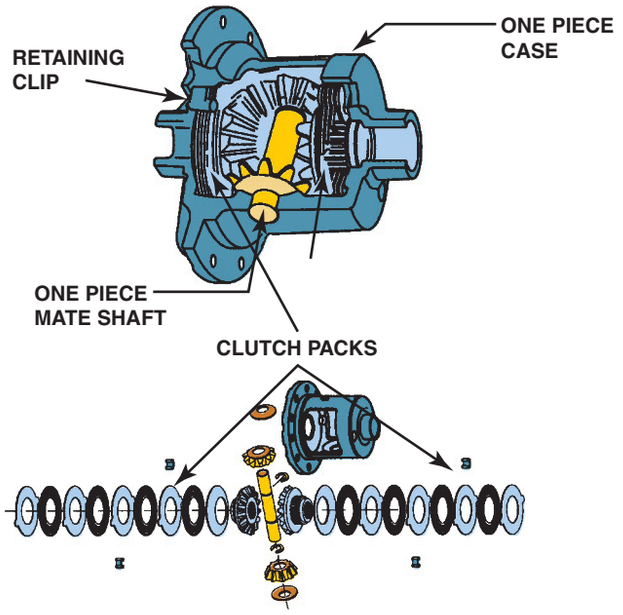


FIGURE 125–10 Trac-loc limited-slip differential. This type of limited-slip differential uses the preload force from a spring and the torque generated by the side gears as the two axles rotate at different rates to apply the clutches and limit the amount of difference in the speed of two axles.

gear is free to rotate about the cross-shaft, the two reaction forces are equal. As the side gear applies a force to the spider gear, the spider gear applies an equal and opposite force to the side gear. It is this force, on the side gear, that supplies the torque to the axle that drives the wheel. Because the force on each side gear is equal, the torque supplied to each wheel is also equal. This is true regardless of whether one wheel is rotating faster than the other or at the same speed.

TRAVELING STRAIGHT-AHEAD. Assuming that a vehicle has equal traction at both wheels, differential action does not occur. In other words, when traveling straight on smooth road surfaces the ring gear, carrier, and the drive axles are traveling at the same speed; they rotate as a unit and the spider gears are not rotating on the cross shaft.

TRAVELING AROUND CORNERS. The ability of the differential pinion gears to spin on their shafts allows each axle to rotate at a different speed.

Case speed is always equal to the average speed of the two side gears. Since the ring gear rotates with the case and each side gear rotates with its axle; when a vehicle corners, the outside wheel gains the same number of RPMs that the wheel on the inside loses, while ring gear RPM remains constant.

LIMITED SLIP DIFFERENTIALS

PURPOSE AND FUNCTION When a vehicle equipped with a standard differential spins a tire, the opposite wheel does not receive enough torque to move the vehicle. To solve this problem, most manufacturers use differentials that direct more power to the side gear attached to the spinning axle. Many differentials do this by forcing the side gear against the revolving case. This bypasses differential action, allowing the case to drive the side gear directly.

A limited-slip differential distributes torque to both wheels equally or unequally, allowing the wheels to turn at the same or at different speeds. ● **SEE FIGURE 125–9.**

The only means of having the standard differential apply different amounts of torque to each axle is to have the case drive the side gear directly, bypassing the pinion gears. One means of accomplishing this is to literally "push" the side gear out of mesh with the pinion gears against the rotating case.

PARTS AND OPERATION **Preloaded clutches** use two mechanisms to accomplish this action. First, a coil, Belleville, or leaf spring applies a force against the two side gears. ● **SEE FIGURE 125–10.** Second, a multidisc clutch pack or cones lie behind one or both of the side gears. Vehicle manufacturers refer to these differentials using various brand names, such as Positive Traction, Sure-Grip, Anti-Spin, and Traction-Lok.

When forces inside the differential push the side gear against the case, the clutch pack allows the gear to lock smoothly without jerking. The pack, lying between at least one of the backs of the side gears and the case, consists of two types of alternatively stacked steel discs with holes through their middle sections. The first is coated with friction material and the second is not. The interior splines of the friction disc holes mesh with the splines on the center hub protruding from the backside of the side gear. The holes of the steel discs are not splined. Instead, they have two or three tabs along their outside diameter that fit into slots machined into the differential case.

As the side gear is pushed farther against the case, each friction plate rubs against the steel plate in front of and behind it, gradually slowing the side gear's rotation until it smoothly locks against the case.

1. The rotating differential pinions apply pressure against the side gear. The amount of pressure depends on the traction beneath the tire connected to the side gear.
2. The spring applies the second force that allows the preloaded clutch to work. This spring, whether a coil, leaf, or Belleville, preloads the clutch discs, narrowing the clearances between them. Tighter springs cause the differential to lock up sooner than looser springs.

To vary the amount of traction a tire must have before its axle's side gear locks up, many differentials use adjustment shims. Available in different thicknesses, manufacturers install them between the rear of the clutch packs and the differential case. The thicker the shims, the sooner the differential locks up. Some differentials rely on the preload spring alone to determine when the side gear locks up. They use no shims.

During operation, the clutch discs slide against each other every time the vehicle turns and corners. This action creates friction, making it important to add the manufacturer-recommended lubricant that contains a friction modifier. This lubricant may already be included in the gear oil or may be a special additive. Using improper lubricants may cause the discs to wear prematurely and vibrate during turns.

CONE-TYPE The second type of preloading clutch differential uses two tapered cones instead of multidisc clutch packs. Positioned between the side gears and the case, the cone's tapered end fits inside a dished receptacle machined into the case. The same forces that push the side gears against the case in the clutch pack differential push the side gears against the case in the tapered-cone differential. When these forces press the cones into their dished receptacles, they come to a stop smoothly, locking the side gears to the case.

VISCOUS COUPLED LIMITED-SLIP UNITS Differentials can be designed to work on the principle of a **viscous coupling.** This design uses a series of closely positioned plates, which do not physically touch one another. Half of the plates are splined to the case, and the other half are alternately splined to each side gear. The plates are housed in a sealed chamber, which is filled with a thick and viscous silicone-based fluid. The silicone allows normal speed differences between two shafts, resisting high-speed differences associated with wheel spin on one shaft.

This type of viscous-coupled differential is used in the front differentials of some Japanese front-wheel-drive vehicles and in four-wheel-drive vehicles. See Chapter 99 for details.

THE EATON "LOCKER" DIFFERENTIAL The Eaton Locker's sturdier design makes it more efficient in transferring torque from the driveline to the axles while in the locked position than the clutch-type multidisc differential.

When a vehicle spins a rear wheel, both the preloaded multidisc differential and the Eaton "locker" compress their clutch packs lying between the side gears and the case. This allows the case to directly drive the axles, bypassing the effect of the rotating differential pinions.

The Eaton and preloaded multidisc differentials differ in how they compress their clutch packs. The preloaded multidisc uses either a coil, leaf, or Belleville spring to apply initial pressure against the side gears and the clutch pack. As the rotating pinion gears push against a slower moving side gear, it is forced against the case, thereby compressing the discs in the clutch pack together.

The Eaton differential, on the other hand, uses a unique mechanism to collapse the clutch packs. ● **SEE FIGURE 125–11.** It has four parts:

- A governor with two flyweights
- A cam plate and cam side gear on the left side
- A latching bracket
- A thrust block

These parts allow the Eaton to momentarily shift into the locked mode when side gear and case rotational speeds differ by more than 100 RPM.

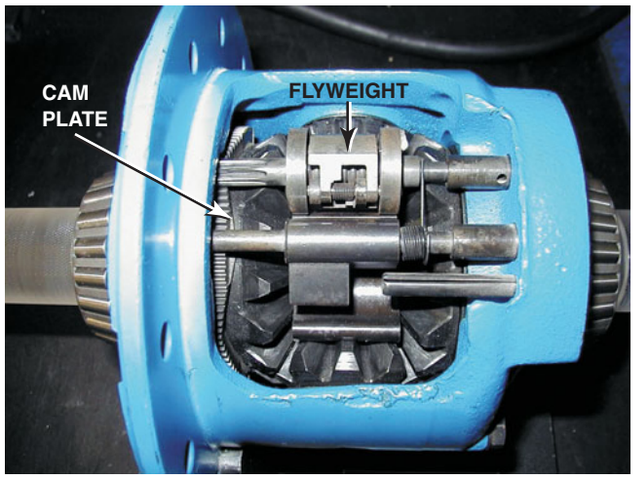


FIGURE 125–11 An Eaton locker differential.

REAL WORLD FIX

I Used to Have a Limited-Slip Differential

An owner of a Chevrolet S-10 pickup truck equipped with a V-6 and five-speed manual transmission complained that he used to be able to spin both rear tires on dry pavement, but lately only one tire spins. The service technician assigned to the repair order was very familiar with what might have occurred. Many General Motors pickup trucks are equipped with an Eaton locking differential that uses a torque limiting disc. The teeth of this disc are designed to shear to prevent the possibility of breaking an axle. ● **SEE FIGURE 125–12.**

The service procedure to correct the customer's concern is to replace the left-hand clutch plates. Usually, the shearing of the torque-linking teeth is associated with a loud bang in the rear axle. The differential will continue to operate normally as a standard (open) differential.

TORSEN DIFFERENTIALS The Torsen differential is a torque sensing, locking design that uses a set of worm side gears in mesh with individual worm wheel pinions that are supported by the differential case. ● **SEE FIGURE 125–13.** The pinions have spur gear sections machined on them at each end, which form the connection between left and right side pinions. Because of the worm and worm wheel configurations, the side gears can turn the pinions, but the pinions cannot turn the side gears. The result is a complex operation, which meets all drive requirements without excessive wheel slip.

This unit has been available as original equipment on several vehicles as well as for many aftermarket applications.

DIFFERENTIAL COMPONENTS

DRIVE PINIONS The drive pinion gear of the differential is driven by a flange often called a **companion flange.** The heavy bulk of the companion flange helps dampen vibrations and absorb

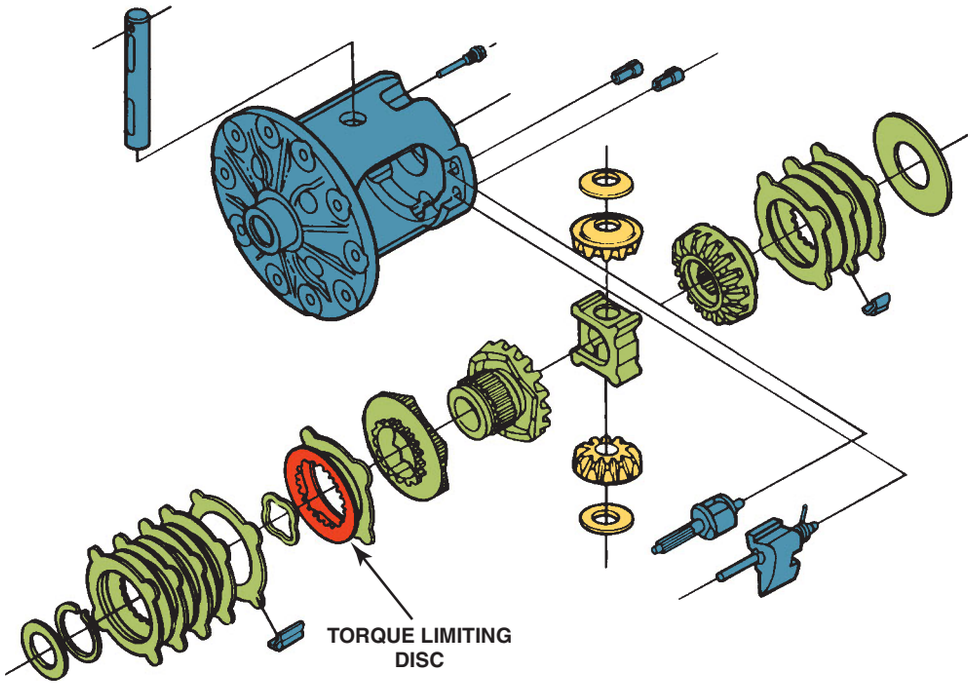


FIGURE 125–12 This Eaton design differential uses a torque-limiting disc to prevent the possibility of breaking an axle in the event of a high-torque demand. When the disc tangs shear, the differential will continue to function but as an open rather than as a limited-slip differential.

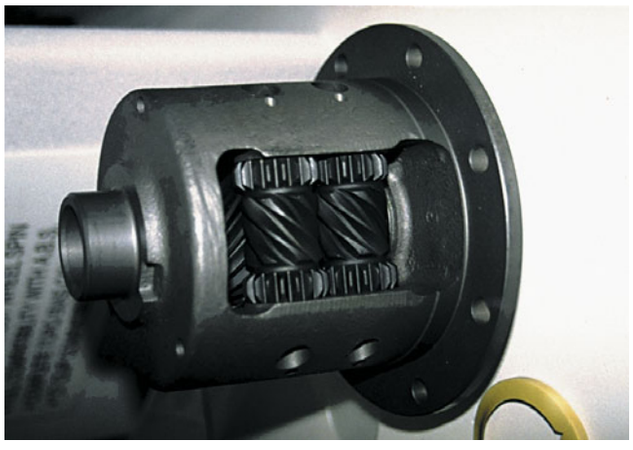


FIGURE 125–13 A Torsen differential. This type of differential provides torque to both drive wheels even if one tire is on ice. The complex system of gears allows this smooth transfer of torque without the use of clutches.

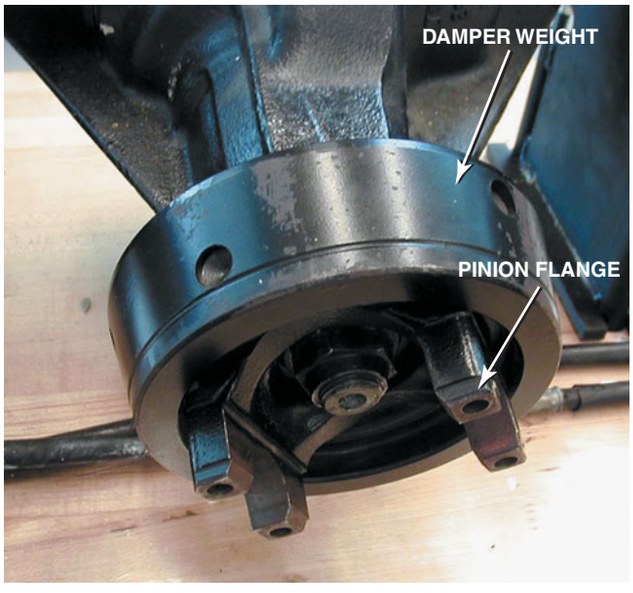


FIGURE 125–14 This pinion flange is equipped with a damper weight to help dampen driveline vibrations.

shocks in the driveline. ● **SEE FIGURE 125–14.** The final drive pinion shaft may be supported by bearings using one of two methods.

1. The first method and most common, uses two opposed taper roller bearings, with a collapsible (compressible) spacer separating the two inner races to support an overhung pinion. ● **SEE FIGURE 125–15.** The term "overhung" means all of the bearings supporting the pinion shaft lie on one side of the pinion gear. The bearings are preloaded, a state that minimizes wobble and endwise movement while the drive pinion shaft rotates.
2. The second method uses two opposed taper roller bearings to support a **straddle-mounted pinion,** but the distance between them is smaller than in the overhung design. Most noticeably, a third smaller bearing attaches to a stemlike machined pilot protruding from the gear-end of the drive pinion shaft. This third bearing, usually a straight roller type, fits into a bore

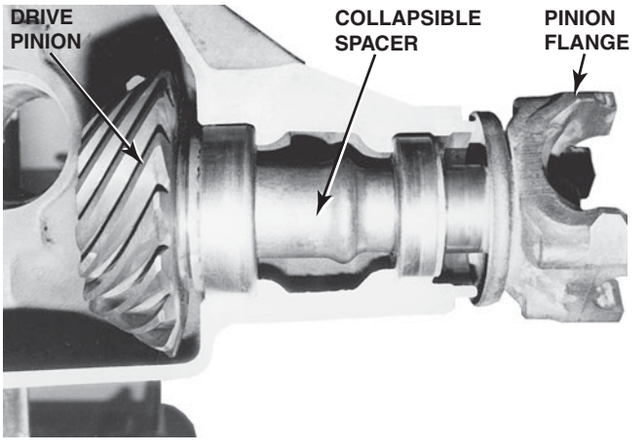


FIGURE 125–15 A collapsible spacer-type drive pinion shaft.

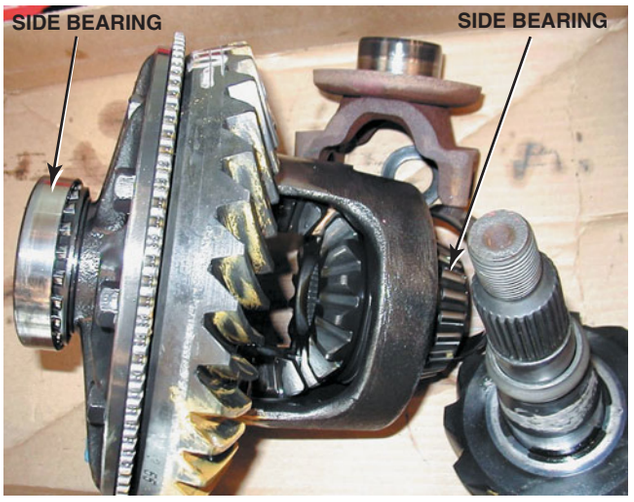


FIGURE 125–16 Side bearings are press fit on the differential case.

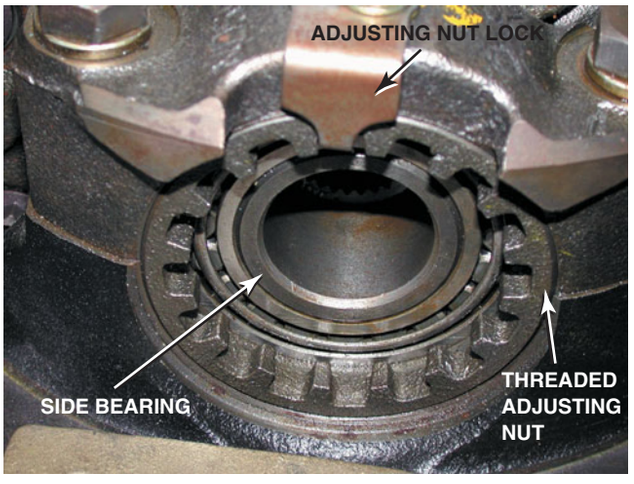


FIGURE 125–17 Some side bearings use threaded adjusters to adjust preload.

in the carrier. Unlike the overhung design, bearings supporting a straddle-mounted pinion lie on both sides of the pinion gear. Like the overhung design, a straddle-mounted pinion shaft usually has a compressible preloaded spacer positioned between the two larger differential case bearings. Straddle-mounted pinions are usually mounted in a pinion housing that can be removed from the carrier.

DRIVE PINION GEAR DEPTH The pinion shaft mounting method also determines how deeply the pinion gear meshes into the ring gear. This is called pinion depth and helps adjust the precise gear tooth relationship between the ring and pinion gears. You can vary the pinion depth adjustment by changing the thickness of a shim (spacer). This shim is located between the rear preloaded bearing and the pinion gear, or between the removable pinion housing and the carrier.

SIDE BEARINGS The differential case is supported by two side bearings pressed onto its sides. ● **SEE FIGURE 125–16.** These are usually tapered roller bearings and are preloaded to ensure case rotation without axial or radial movement.

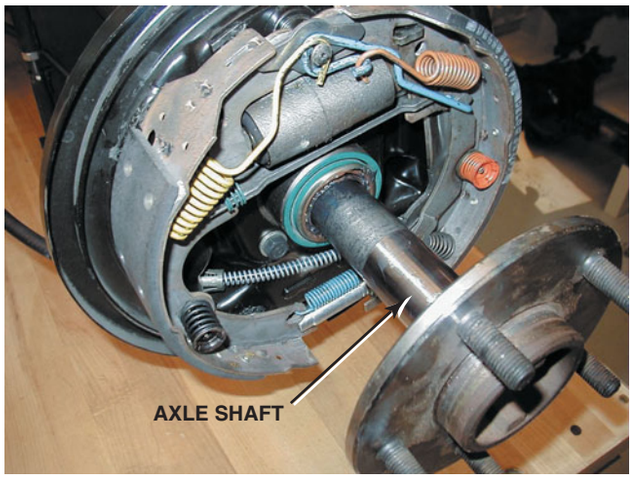
Side bearing preload is adjusted either by threaded adjusting nuts as shown in ● **FIGURE 125–17,** or by placement of adjusting shims (spacers) on either side of the case between the bearing outer races and the inside of the carrier. The method used to adjust side bearing preload is also used to adjust ring gear-to-pinion backlash (tooth clearance between one gear and the other). This is necessary to ensure enough space between the teeth of the two gears to allow for expansion of the gear tooth dimensions as the unit warms up to operating temperature. When the unit is warm, there must be just enough space between the gear teeth to allow adequate lubrication of the tooth surfaces and still allow full tooth contact for good transfer of torque from one gear to the other. Too much clearance between the gears will allow one to travel too far before contacting the other when the powertrain goes from drive to coast and back again. Excess clearance can result in final drive noise and gear tooth damage.

DIFFERENTIAL AXLE BEARINGS

BALL BEARINGS/REAR AXLES If ball bearings are used, the bearing itself absorbs the radial forces. The bearing is placed on the axle and retained by a pressed-on collar. A stamped steel plate bolts to the axle housing and keeps the axle in place. The bearing is prelubricated when it is manufactured. An oil seal is located on the inboard side of the bearing retainer collar, and keeps the hypoid lubricant from reaching the bearing or the brake assembly. In this design, there is no axle shaft end play (thrust) adjustment.

STRAIGHT ROLLER BEARINGS/REAR AXLES If a straight roller bearing is used, the axle surface serves as the inner race. ● **SEE FIGURE 125–18.** The outer race is pressed into the housing, and a grease seal is pressed in afterward. The bearing is lubricated by the hypoid lubricant. This design uses a C-washer on the inboard end of the axle, which prevents the axle from moving outward. Outward thrust forces are taken by the C-washer through the axle's side gear and thrust washer, to the differential case and side bearing. Inward thrust forces are taken by the axle shaft inner end pushing on the spider pinion shaft, and passed on to the differential case and the opposite side bearing. There is no axle shaft end play adjustment with this design.

TAPERED ROLLER BEARINGS/REAR AXLES If a tapered roller bearing is used, axle shaft end play is adjustable. The bearing is pre-lubricated before it is installed and is held by a press fit on the axle shaft. A retaining ring is then pressed on the shaft next to the bearing to secure it in place. The axle is prevented from moving outward by a stamped steel retainer plate that bolts to the axle housing. The inner diameter of the plate is threaded to accept a bearing-adjusting nut, which is similar in appearance and function to a differential side bearing adjuster. A variation of this design has the end play adjustment made by shims between the axle housing and the brake backing plate. Thrust is taken from the inner end of the axle by a thrust block mounted on the spider pinion shaft, and passed on to the opposite axle, through its length to the opposite wheel bearing.



(a)



(b)

FIGURE 125–18 (a) The axle shaft itself is the inner race if a straight roller bearing is used. (b) The straight roller bearings are lubricated by the rear axle fluid, and a leak at the rear axle seal can cause this fluid to get onto brake components.

DIFFERENTIAL IDENTIFICATION

Before any service work is performed on a differential assembly, the *exact* axle specification must be determined. Vehicle manufacturers often use differentials from more than one axle manufacturer, and each manufacturer has its own individual ratios, parts, service procedures, and specifications. Differential assembly identification includes

- **Visual identification**—usually identifies the manufacturer and size only
- **Axle assembly number**—usually stamped in the axle tube of the differential assembly and identifies the gear ratio and other information
- **Limited-slip identification tag**—often the only external identification whether or not the axle assembly is an open design or limited-slip design
- **Differential cover shape** and number of bolts used to retain the cover

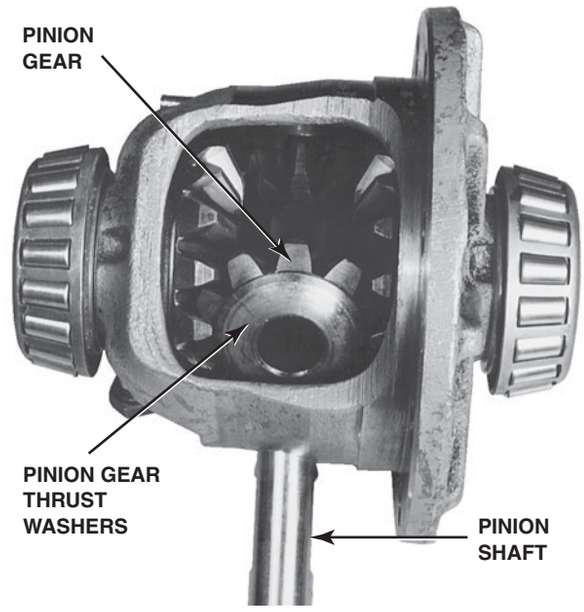


FIGURE 125–19 The pinion gear thrust washers can be destroyed by spinning one wheel for an extended period of time.

TECH TIP

Don't Spin Those Wheels!

While driving on ice or snow-covered roads, it is common to see drivers moving slowly up a hill by simply spinning one drive wheel. However, when one wheel is spinning and the other wheel is stationary (or close to stationary), the pinion gears are spinning twice as fast as the drive wheel. This spinning of the drive wheel has been known to completely wear down the pinion gear thrust washers in less than one minute! ● **SEE FIGURE 125–19.** The same wear can occur if different-size tires are used on the same drive axle. Therefore, to prevent expensive repairs, avoid unnecessary tire spinning and check that both tires on the same axle are the same size, brand name, and condition.

DETERMINING THE AXLE RATIO OF A DIFFERENTIAL

To determine the axle ratio of a differential without having to remove the axle housing cover, simply follow these steps:

STEP 1 Hoist the vehicle safely.

STEP 2 Mark the rear tires with masking tape at 12 o'clock position.

STEP 3 Mark the driveshaft with masking tape.

STEP 4 Have an assistant hold one drive tire to keep it from moving and slowly rotate the other drive tire exactly 10 times while the assistant counts the driveshaft revolutions.

STEP 5 Multiply the driveshaft revolutions by 2 (except for a limited-slip differential), and then move the decimal point one place to the left. For example, if 10 turns of the tire result in 18.5 turns of the driveshaft, that multiplied by 2 equals 37.0; then, moving the decimal point to the left one place equals a 3.70:1 gear ratio.

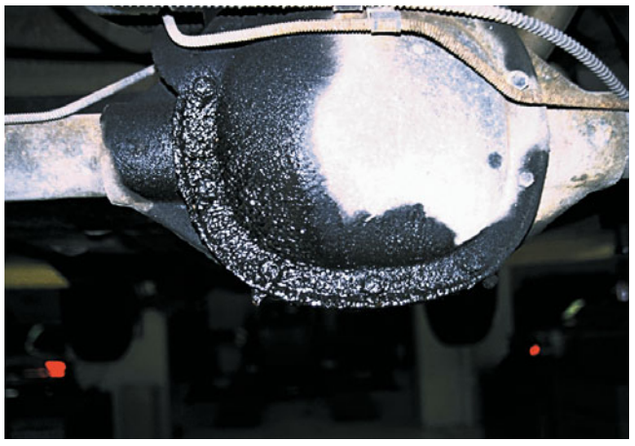
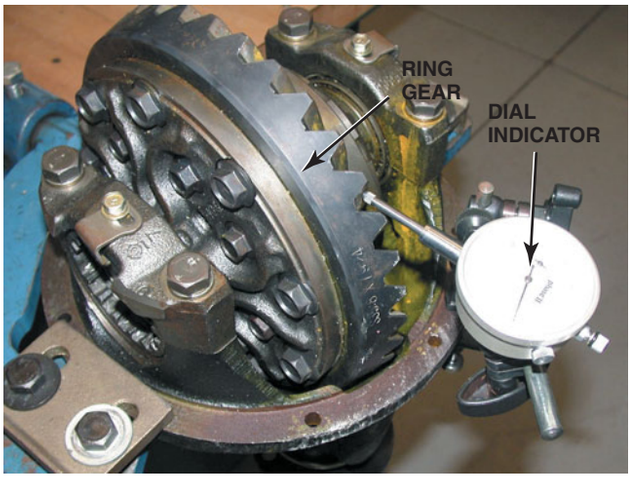
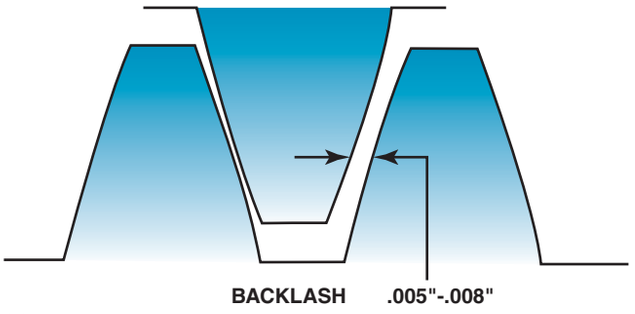


FIGURE 125–20 This differential has obviously been leaking. If the differential lubricant is low, wear may have occurred that would require further inspection.



(a)



(b)

FIGURE 125–21 (a) Backlash is determined by mounting a dial indicator to the differential housing and placing the button of the gauge against a tooth of the ring gear. Moving the ring gear back and forth will indicate on the dial indicator the amount of backlash. (b) Backlash is the clearance between the drive pinion and the ring gear teeth.

REAR END NOISE DIAGNOSIS

One of the major reasons why differentials are serviced is to correct a noise problem. Knowing when and under what conditions the noise is noticeable is a big help in identifying which bearing or component is the likely cause. Typical noise and its sources include

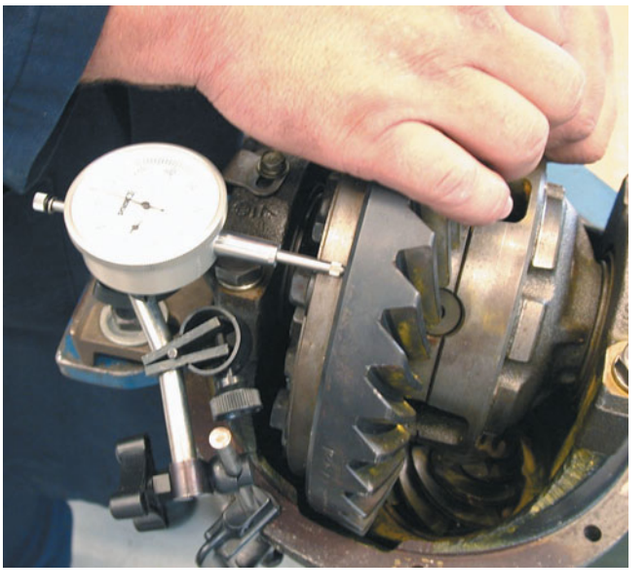


FIGURE 125–22 Ring gear runout should be less than 0.002 inch (0.05 mm) as measured by a dial indicator.

TECH TIP

A Quick-and-Easy Backlash Test

Excessive clearance (lash) between the drive pinion and the ring gear can cause driveline clash noise during a gear selector change. To check if the cause is due to the differential, simply hoist the vehicle and, while one wheel and the driveshaft are being held stationary, use your hand to move the opposite wheel. The maximum amount the tire should move is 1 inch (2.5 cm) measured at the tread of the tire. If backlash is greater than this, then further inspection of the differential assembly is required. Beside excessive clearance between the drive pinion and the ring gear, the wear may also be between the pinion and the side gears.

- **Grinding or growling noise while turning**—usual cause is a defective axle bearing.
- **Whine noise during cruise**—drive pinion bearings are the likely causes of this type of noise.

DIFFERENTIAL INSPECTION

Carefully inspect the differential for obvious damage or wear. ● **SEE FIGURE 125–20.** Check the backlash. The backlash is the amount of clearance between the drive pinion and the ring gear; excessive backlash could indicate excessive wear. Use a dial indicator as shown in ● **FIGURE 125–21** to check and compare the results with specifications.

Also use a dial indicator to check **ring gear runout** (● **SEE FIGURE 125–22**). If any of the visual measurement tests indicate a problem or a noise analysis indicates a bearing problem, the axle assembly should be disassembled for further analysis and service.



FIGURE 125–23 Force has to be applied to the ring gear to achieve a proper contact pattern.

TOOTH CONTACT PATTERN TEST

A tooth contact pattern test is an excellent method for checking proper drive pinion depth as well as proper backlash between the drive pinion and the ring gear. Any faults in these areas will be reflected in the pattern. The pattern test involves the following steps:

STEP 1 Clean the gear teeth of the ring gear and the drive pinion.

STEP 2 Using a small brush, apply a light coating of iron oxide compound.

STEP 3 Use a small pry bar to apply a load to the ring gear to achieve a more accurate contact pattern. ● **SEE FIGURE 125–23**.

STEP 4 Rotate the drive pinion until the ring gear turns one revolution (about three revolutions of the drive pinion gear).

STEP 5 Repeat rotating the drive pinion in the opposite direction. This will create a contact pattern on both the drive side and the coast side of the ring gear.

NOTE: The drive side is the convex surface of the ring gear teeth. The coast side is the concave side of the ring gear. This is true except for many differentials used on the front of four-wheel-drive vehicles. In this case, the drive side in the front differential is the concave surface and the coast side is the convex surface of the ring gear teeth. Always check the service information for the vehicle being serviced for the correct interpretation of the pattern results.

● **SEE FIGURE 125–24** for good and bad tooth contact patterns and what could have caused them.

DIFFERENTIAL DISASSEMBLY

Start the differential disassembly by removing the axle housing cover. Be sure that the old rear end lubricant is drained into a disposal container according to local, state, provincial, and federal laws and regulations. After the cover has been removed, complete the disassembly by following these steps:

STEP 1 After the cover has been removed, remove pinion shaft lock bolt.

STEP 2 Remove pinion shaft.

STEP 3 Remove two spider gears and two axle side gears.

STEP 4 Push axles in and remove C-clips.

STEP 5 Remove axles.

STEP 6 Mark and remove case caps.

STEP 7 Using a case spreader or two pry bars, pry up and remove carrier case keeping the shims separate. ● **SEE FIGURE 125–25**.

STEP 8 Remove pinion shaft nut and washer. Discard the nut.

STEP 9 Mark and remove companion flange with suitable puller.

STEP 10 Remove front pinion seal and front pinion bearing.

STEP 11 Using suitable punch, drive pinion gear rearward until it is free of housing.

STEP 12 Remove crush collar (never re-use) ● **SEE FIGURE 125–26**.

CAUTION: Do not use an air impact wrench to remove or install the drive pinion nut. The hammer action of the impact wrench can cause the roller bearings to be pounded into the race. This denting of the race is called *brinelling* and can cause premature bearing failure.

PINION SHAFT BEARING REPLACEMENT

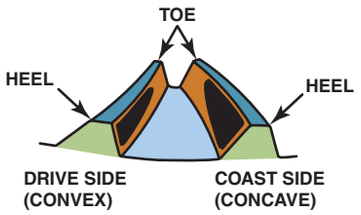
The pinion shaft usually has two tapered roller bearings; the small diameter of each bearing faces the other. This arrangement allows the two bearings to absorb thrust load in both directions. When tapered roller bearings are used in a differential, it is very important that they have the proper preload. If a tapered roller bearing is too loose (too little preload), then the bearing cannot properly support and position the pinion shaft. If the preload is too great, excessive heat will quickly destroy the bearing as it expands with heat during normal operation of the rear axle assembly. Two methods are used to ensure proper drive pinion gear preload (● **SEE FIGURE 125–27).**

- Preload shims
- Collapsible spacer

The rear pinion shaft bearing (closest to the drive pinion gear) is usually pressed out the drive pinion. A shim is usually located between the drive pinion gear and the rear drive pinion bearing to properly position the drive pinion in relation to the ring gear. The ring gear and pinion are manufactured as a matched pair and must be installed correctly to be assured of quiet operation and long service life. ● **SEE FIGURE 125–28.** The drive pinion bearing must be pressed off using a hydraulic press or a special tool.

DRIVE PINION DEPTH

The drive pinion gear and ring gear are manufactured as a matched set and must be installed as a set. Due to variances in the production of these gears, it is often necessary to vary the thickness of a shim



CONDITION

PINION DEPTH CORRECT.

BACKLASH INCORRECT - TOO MUCH CLEARANCE BETWEEN THE PINION AND RING GEARS.

CORRECTION

INCREASE THE THICKNESS OF THE LEFT (RING GEAR SIDE) SHIM AND DECREASE THE THICKNESS OF THE RIGHT SHIM AN EQUAL AMOUNT.

SERVICE HINTS

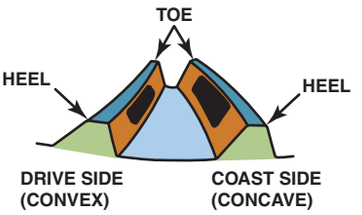
HOW TO CHECK PATTERNS:

BRUSH GEAR MARKING COMPOUND ON THE RING GEAR TEETH.

APPLY BRAKES SO THAT 50 LB. FT. IS NEEDED TO ROTATE THE PINION.

ROTATE THE PINION SIX TIMES CLOCKWISE AND SIX TIMES COUNTERCLOCKWISE.

OBSERVE THE TOOTH CONTACT PATTERN AND MAKE ANY NECESSARY CORRECTIONS.



CONDITION

PINION DEPTH CORRECT.
BACKLASH CORRECT.

CORRECTION

NONE.

SERVICE HINTS

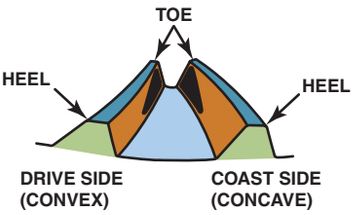
PATTERNS THAT VARY MAY BE CAUSED BY LOOSE BEARINGS ON THE PINION OR THE DIFFERENTIAL CASE. CHECK THESE BEARING PRELOAD SETTINGS:

TOTAL ASSEMBLY

DIFFERENTIAL CASE

PINION

IF THESE SETTINGS ARE GOOD, LOOK FOR DAMAGED OR INCORRECTLY ASSEMBLED PARTS.



CONDITION

PINION DEPTH CORRECT.

BACKLASH INCORRECT - TOO LITTLE CLEARANCE BETWEEN THE PINION AND RING GEARS.

CORRECTION

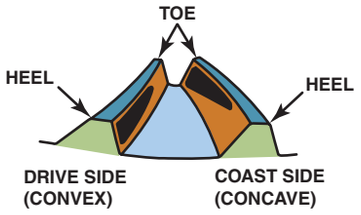
INCREASE THE THICKNESS OF THE RIGHT (RING GEAR SIDE) SHIM AND DECREASE THE THICKNESS OF THE LEFT (RING GEAR SIDE) SHIM.

SERVICE HINTS

SIDE BEARING GEAR LOCATIONS:

BETWEEN THE SIDE BEARING CONES AND THE DIFFERENTIAL CASE.

BETWEEN THE SIDE BEARING CUPS AND THE REAR AXLE HOUSING.



CONDITION

PINION DEPTH INCORRECT - PINION GEAR IS TOO FAR AWAY FROM THE RING GEAR.

BACKLASH CORRECT

CORRECTION

INCREASE THE PINION SHIM THICKNESS.

SERVICE HINTS

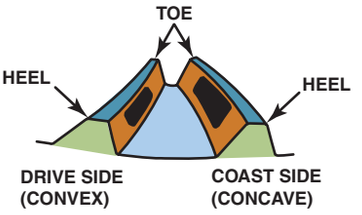
HOW TO CHECK PATTERNS:

BRUSH GEAR MARKING COMPOUND ON THE RING GEAR TEETH.

APPLY BRAKES SO THAT 50 LB. FT. IS NEEDED TO ROTATE THE PINION.

ROTATE THE PINION SIX TIMES CLOCKWISE AND SIX TIMES COUNTERCLOCKWISE.

OBSERVE THE TOOTH CONTACT PATTERN AND MAKE ANY NECESSARY CORRECTIONS.



CONDITION

PINION DEPTH CORRECT.
BACKLASH CORRECT.

CORRECTION

NONE.

SERVICE HINTS

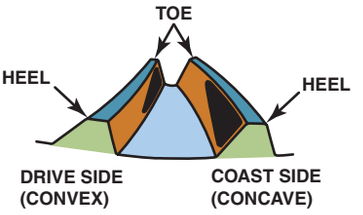
PATTERNS THAT VARY MAY BE CAUSED BY LOOSE BEARINGS ON THE PINION OR THE DIFFERENTIAL CASE. CHECK THESE BEARING PRELOAD SETTINGS:

TOTAL ASSEMBLY

DIFFERENTIAL CASE

PINION

IF THESE SETTINGS ARE GOOD, LOOK FOR DAMAGED OR INCORRECTLY ASSEMBLED PARTS.



CONDITION

PINION DEPTH INCORRECT - PINION GEAR IS TOO CLOSE TO RING GEAR.

BACKLASH CORRECT.

CORRECTION

DECREASE THE PINION SHIM THICKNESS.

SERVICE HINTS

PINION DEPTH SHIM LOCATIONS:

BETWEEN THE INNER PINION BEARING CONE AND THE HEAD OF THE PINION GEAR.

BETWEEN THE INNER PINION BEARING CUP AND THE REAR AXLE HOUSING.

FIGURE 125–24 Tooth contact pattern.

(thin metal spacer) between the rear pinion bearing and the pinion gear to provide the correct contact tooth pattern when the gears are assembled. Correct drive pinion depth measurement can be determined in several different ways:

- **Wear pattern analysis.** This method is useful as a first step and a last step to verify correct setup (discussed earlier in the chapter). It is time consuming to use this method to determine the thickness of the drive pinion shim because the rear pinion bearing must be pressed off and then back on for each shim change.
- **Plus (+) and minus (−) markings on the drive pinion.** The end of the pinion gear is usually marked as to the variance

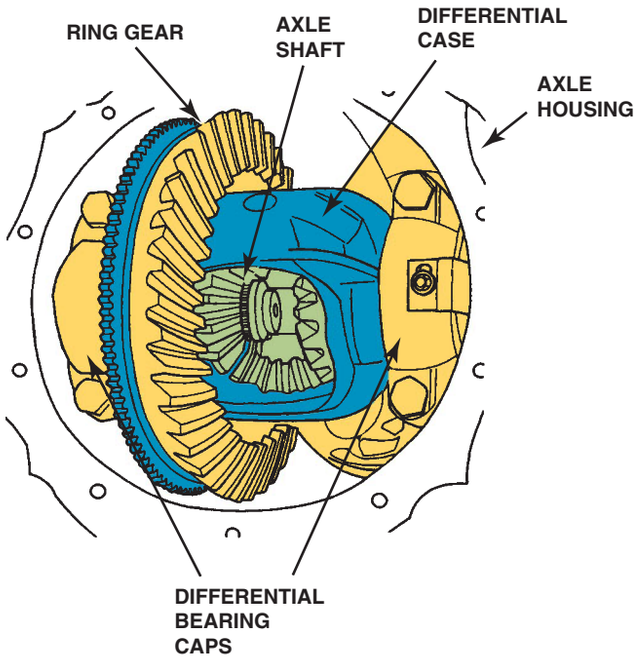


FIGURE 125–25 Mark the differential bearing caps before removing them to make sure that they are replaced in the same location.

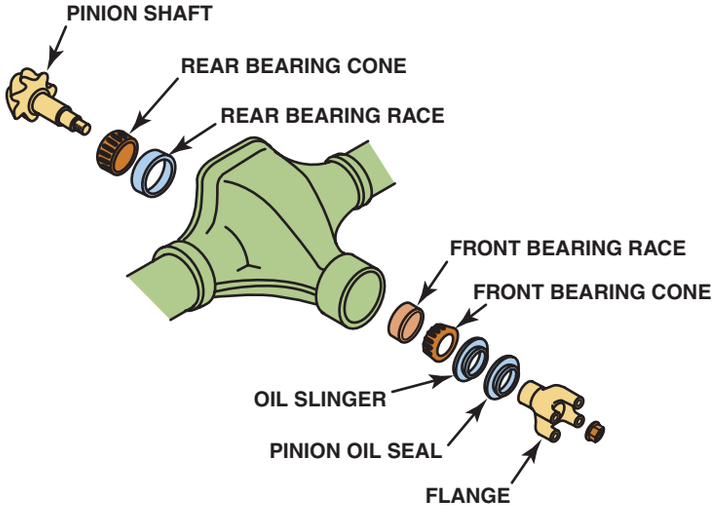


FIGURE 125–26 Pinion gear and associated parts. The pinion end yoke is also called the pinion flange.

needed to create the proper ring gear-to-drive pinion pattern:

A plus (+) sign means the gear is too long and removing a shim(s) is required when assembling the drive pinion into the axle housing.

A minus (−) sign means that the gear is too short and a shim(s) will be needed when assembling the drive pinion into the axle housing.

- **A gauging set and depth micrometer.** This is a common method used to determine the correct shim thickness necessary to provide the proper gear pattern. ● **SEE FIGURE 125–29.**

PINION GEAR PRELOAD

After the proper drive pinion depth has been determined, the correct size shim is installed and the rear drive pinion bearing is pressed onto the drive pinion. The outer races of the pinion bearing

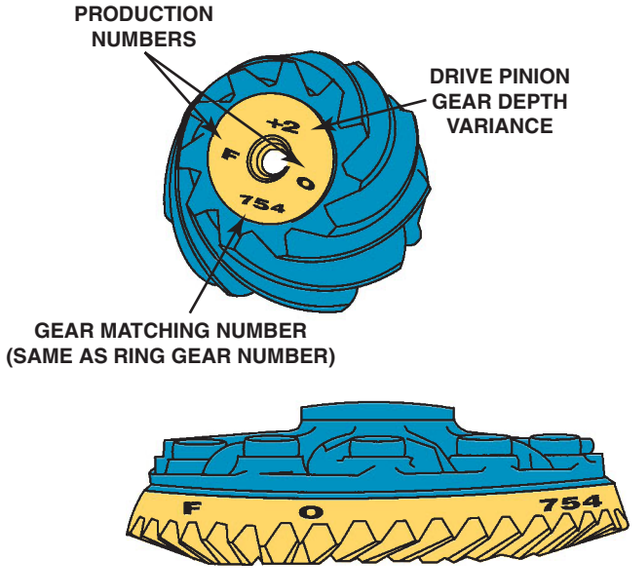


FIGURE 125–28 The ring and pinion gears are a matched set and are marked for correct pinion depth variance.

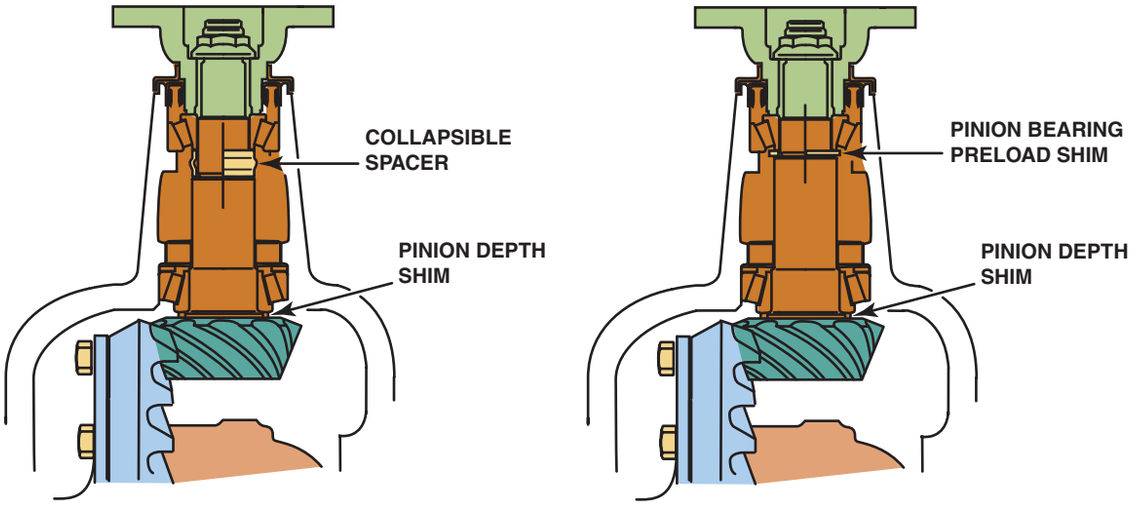


FIGURE 125–27 The pinion on the left uses a collapsible spacer, and the pinion on the right uses shims to provide the necessary preload to the pinion shaft bearings.

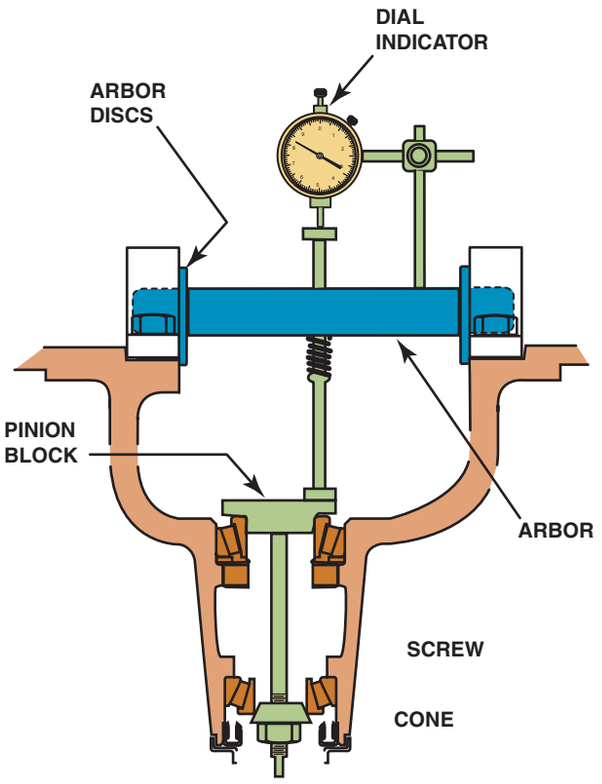


FIGURE 125–29 Special tool kit used for determining the correct pinion shaft shim thickness.

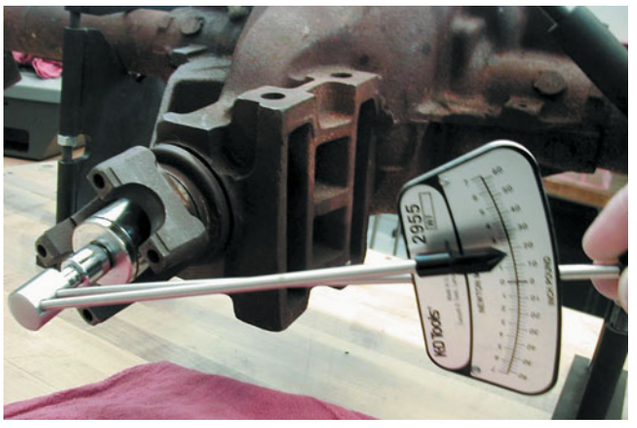


FIGURE 125–30 Using an inch-pound torque wrench to check the rotating torque of the drive pinion. This procedure is very important if the axle uses a collapsible spacer. The drive pinion nut should be gradually tightened and the rotating torque checked to prevent overtightening the nut. If the rotating torque is higher than specifications, the collapsible spacer will require replacement and the installation procedure must be repeated.

should be replaced in the axle housing and the pinion shaft placed in the housing. It is then necessary to apply the specified preload to the pinion bearings. A new drive pinion nut should be used and tightened to specifications. After the nut has been tightened, torque needed to rotate the drive pinion should be measured using a beam-type torque wrench. The drive pinion nut is then tightened farther until the **turning torque** is within specifications. ● **SEE FIGURE 125–30.**

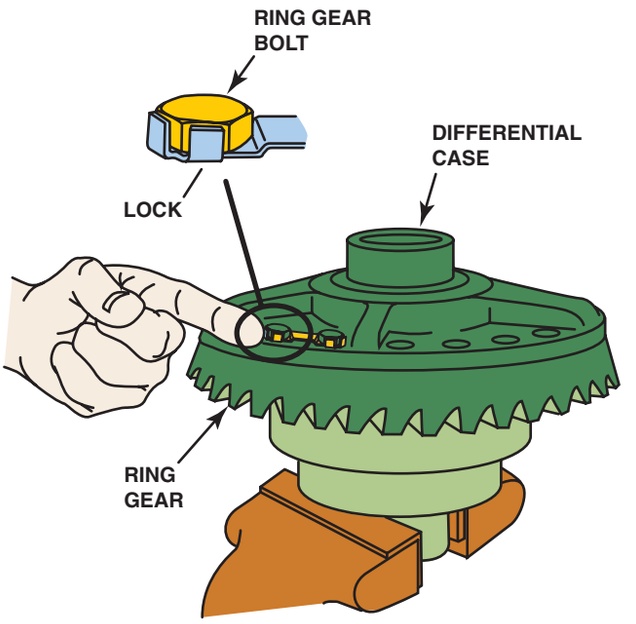


FIGURE 125–31 If the ring gear has been removed from the differential case or if a new ring gear is being installed, always replace the ring gear bolts.

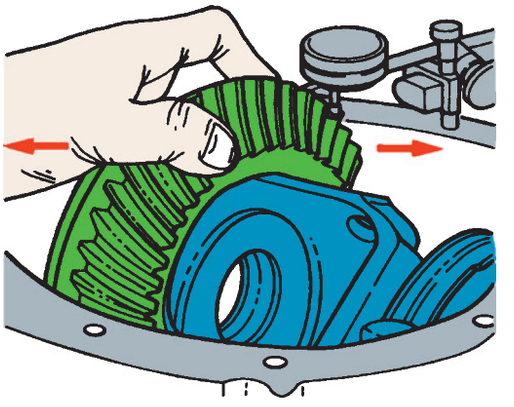


FIGURE 125–32 Backlash should be between 0.005 and 0.008 inch on most differentials. If the backlash is too great, add shim thickness to the ring gear side and subtract shim thickness from the opposite side.

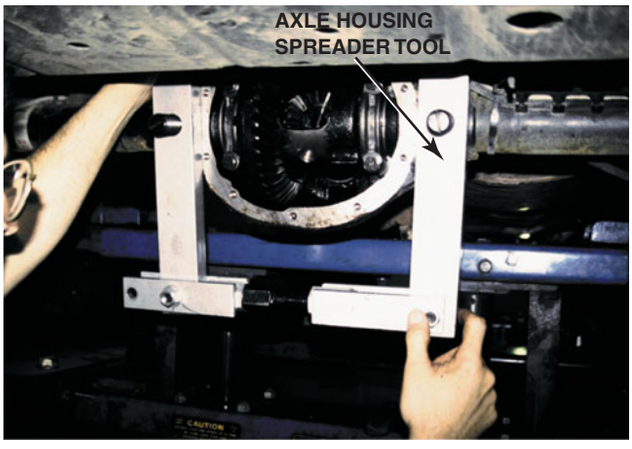
CHECKING AND CORRECTING BACKLASH

If the ring gear and pinion are being replaced, the bolts that hold the ring gear to the differential case *must* be replaced. ● **SEE FIGURE 125–31.** The differential case with the ring gear is then placed into the differential housing. Backlash is the clearance between the drive pinion gear and the ring gear. A dial indicator is used to measure backlash, as shown in ● **FIGURE 125–32.** The backlash should be checked at three or four points around the ring gear and the lash should not vary over 0.002 inch (0.05 mm). Backlash normally is between 0.005 and 0.008 inch (0.10 and 0.20 mm) for most axle assemblies. Always check the specifications for the differential being serviced. ● **SEE FIGURE 125–33.**

Backlash is corrected by moving the ring gear either closer or farther away from the drive pinion gear. The correction is made by

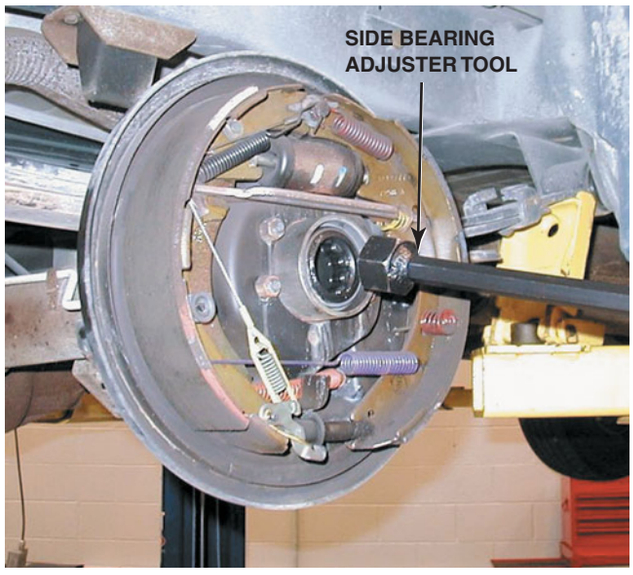


(a)

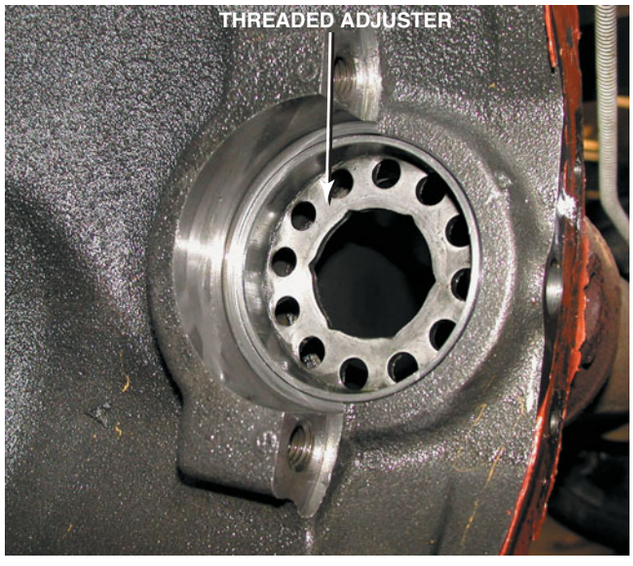


(b)

FIGURE 125–33 (a) Some vehicle manufacturers recommend using a housing spreader tool that fits into the round openings on both sides. (b) The spreader tool being installed. The housing is spread a specified amount and the differential is then installed into the housing.



(b)



(a)

FIGURE 125–34 (a) Note the hex shape of the threaded adjuster used to adjust side bearing preload and ring gear backlash on a Dodge Dakota truck. (b) A long handled adjuster tool is needed to turn the side bearing adjuster on this truck.

TECH TIP

"Click-Click" Is Okay—"Clunk-Clunk" Is Not

An experienced service technician was observed checking the backlash on a differential. The technician was simply turning the drive pinion by grasping the pinion flange and using wrist action to quickly rotate it first in one direction and then the other. The technician explained that if it made a "click-click" sound, the backlash was usually between 0.005 and 0.008 inch, which is usually within specifications for most differentials. If however, the sound made was more like a "clunk-clunk," then the backlash was greater than 0.010 inch and had to be corrected. To summarize what the sounds mean when the drive pinion is moved back and forth:

- **No sound when moved back and forth**—too little or no backlash; backlash must be adjusted.
- **A "click-click" sound**—backlash is usually within specifications; double-check with a dial indicator and compare against specifications for the axle being serviced.
- **A "clunk-clunk" sound**—usually too much backlash; correction is required to restore proper backlash.

either of two methods depending on the manufacturer and the type of differential:

- Transferring shims from one side of the axle housing to the other
- Turning threaded adjusters located in the differential housing bores, as shown in ● **FIGURE 125–34.**

SETTING SIDE BEARING PRELOAD

After the correct backlash has been determined, the side bearing must be correctly preloaded. To accomplish the proper preload, thicker shims than were used to set proper backlash are placed between the housing and the differential to provide for the proper preload on the side bearings. ● **SEE FIGURE 125–35.** Always follow

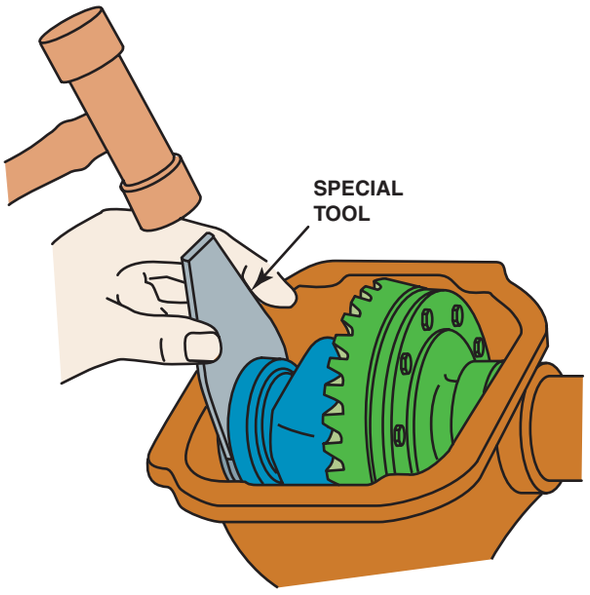


FIGURE 125–35 On many axles, it is necessary to use a special tool to install steel spacers (shims) to achieve the specified backlash and side bearing preload.



FIGURE 125–36 A spool used in a rear end for drag racing only.



FIGURE 125–37 Install the axle shaft, being careful to not damage the seal.

FREQUENTLY ASKED QUESTION

What Is a Spool Rear End?

A spool is a solid piece of metal that takes the place of the side gears and pinion gears in a differential assembly (● **SEE FIGURE 125–36).** A spool used in drag racing is not suitable for street driving because the spool does not allow for any differences in the speeds of the drive wheel during cornering. Obviously, drag vehicles do not turn corners while racing and the spool rear end is one of the reasons they bounce when turning around at the end of the strip to return to the pits.

FREQUENTLY ASKED QUESTION

What Do I Do About Drive Pinion Bearing Preload When I Replace Just the Pinion Seal?

To replace a pinion seal, the drive pinion nut and pinion flange must be removed.

CAUTION: Do not use an air impact wrench on the drive pinion nut. The pinion bearings can be damaged by the impact of the wrench.

Before the nut is removed, make a mark on the pinion nut and on the axle housing. After the new pinion seal is installed, tighten the pinion nut to the same position it was in before disassembly and then rotate the nut 1/16 inch (1.5 mm) farther. This extra rotation makes sure that the collapsible space (crush sleeve) is still able to maintain the proper preload on the pinion bearing. Another method is to measure the rotating torque of the drive pinion using an inch-pound beam-type torque wrench after removing both rear wheels and brake drums. After installing the replacement pinion shaft seal, tighten the drive pinion nut until the rotating torque is 3 to 5 in-lb more than the reading obtained before the pinion nut was removed.

the procedures specified for the axle being serviced. A typical axle may require the installation of a shim 0.004 thicker on both sides. After setting the preload, double-check that the backlash is within specification.

REASSEMBLY OF THE DIFFERENTIAL ASSEMBLY

After the backlash has been checked to be within factory specifications, the axle shafts can be installed. ● **SEE FIGURE 125–37.** Install the retaining "C" clip or bolt the retainer to the axle housing. Clean and install the differential cover and fill with the specified differential lubrication.



FIGURE 125–38 A container of GL-5 SAE 80W-90 gear lubricant.

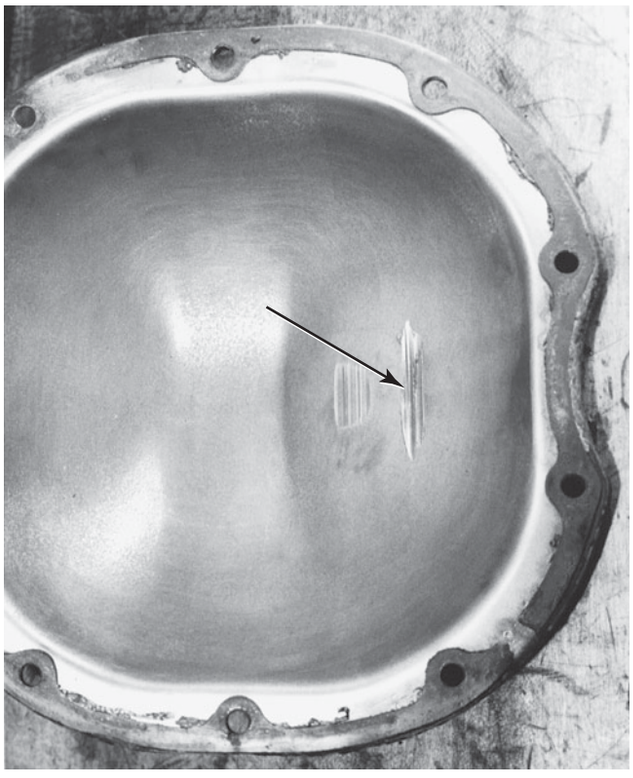


FIGURE 125–39 The beginning automotive student did not realize that the axle housing cover could fit the wrong way. The only problem was that the ring gear scraped against the cover.

DIFFERENTIAL LUBRICANT

Because all differentials use hypoid gear sets, a special lubricant is necessary because the gears both roll and slide between their meshed teeth. Gear lubes (GL) are specified by the American Petroleum Institute (API):

GL-1 Straight mineral oil

GL-2 Worm gear lubricant

GL-3 Mild EP lubricant (will *not* protect hypoid gears)

GL-4 Mild EP lubricant suitable for manual transmissions/transaxles

GL-5 EP lubricant okay for hypoid gears (meets military Mil-L2150B requirements)

● **SEE FIGURE 125–38.**

NOTE: EP additives contain sulfurized esters and organic sulfur phosphorous compounds. These ingredients give the lubricant a very strong pungent smell. To avoid possible skin irritation, always wear protective gloves or wash your hands thoroughly with soap and water if exposed to differential lubricant.

Most differentials require

1. SAE 80W-90 GL-5
2. SAE 75W-90 GL-5
3. SAE 80W GL-5

NOTE: Always check the *exact* specification before adding or replacing rear axle lubricant.

REAL WORLD FIX

I Didn't Know It Would Fit the Wrong Way!

An automotive student changed the differential lubricant by removing the housing cover. The cover was reinstalled and then filled with the correct lubricant. However, when the student drove the vehicle it made a grinding sound that was not there before the differential service. When the cover was removed, it was discovered that the cover had been installed with the raised area on the right side of the housing instead of on the left side and the ring gear had rubbed a groove in the cover, as shown in ● **FIGURE 125–39.** Installing the cover correctly stopped the grinding sound.

Limited-slip differentials (often abbreviated LSD) usually use an additive that modifies the friction characteristics of the rear axle lubricant to prevent chattering while cornering.

HINT: If chattering becomes noticeable while cornering, replace the old differential lubricant with the correct lubricant and add limited-slip additives if specified by the vehicle manufacturer. After refilling the differential, drive the vehicle in a figure-eight pattern at least four times to help all of the lubricant and additives get into the clutch plates. This usually stops the chattering-while-cornering problem.

REVIEW QUESTIONS

1. Explain how to determine the axle ratio without removing the housing cover.
2. Describe how to perform a ring gear tooth contact pattern test.
3. List three methods that may be used to determine the proper drive pinion gear depth.
4. Explain how to achieve proper drive pinion gear bearing preload.
5. Describe how to adjust the position of the ring gear to achieve the proper backlash.
6. List the steps for replacing a drive pinion gear seal while still maintaining proper preload on the drive pinion bearing.

CHAPTER QUIZ

1. Technician A says that the convex side of the ring gear is the drive side on most rear axle assemblies. Technician B says that the convex side of the ring gear is the drive side on differentials used in the front of many four-wheel-drive vehicles. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. The drive pinion gear is positioned with a shim that is too thick. This will cause contact with the ring gear teeth too close to the _____.
   a. Toe
   b. Heel
   c. Flank
   d. Face
3. The backlash exceeds specifications. The technician should position the ring gear _____.
   a. Closer to the drive pinion gear
   b. Farther from the drive pinion gear
4. The backlash is less than specifications (too low). This will cause the ring gear tooth pattern to be too close to the _____.
   a. Heel
   b. Flank
   c. Toe
   d. Face
5. A collapsible spacer is used in some differentials to provide _____.
   a. A lubrication path to the drive pinion bearing
   b. The proper preload for the side bearings
   c. The proper preload for the drive pinion bearings
   d. The proper amount of slippage in a limited-slip differential
6. A growling sound is heard from the rear of a rear-wheel-drive vehicle during cornering only. Technician A says that defective rear axle bearings may be the cause. Technician B says that defective drive pinion bearings may be the cause. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. The spacer used on a drive pinion gear is used to properly position the gear so that it can correctly mesh with the _____.
   a. Ring gear
   b. Side gear
   c. Differential pinion gears
   d. Both b and c
8. What part(s) wears rapidly if a vehicle equipped with an open differential spins one wheel on ice or snow for an extended period of time?
   a. Ring gear and pinion
   b. Side gear
   c. Pinion bearings
   d. Pinion and side gear thrust washers
9. Technician A says that if the backlash is okay, then the side bearing preload is also okay. Technician B says that a ring gear tooth pattern check will indicate if the drive pinion depth is correct. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. Two technicians are discussing which lubricants are used in a limited-slip differential. Technician A says to use SAE 80W-140. Technician B says that most vehicle manufacturers usually specify SAE 80W-90 be used with or without special limited-slip additives. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

chapter 126

FOUR-WHEEL DRIVE AND ALL-WHEEL DRIVE

OBJECTIVES: After studying Chapter 126, the reader will be able to: • Prepare for ASE Manual Drive Train and Axles (A3) certification test content area "F" (Four-Wheel Drive Component Diagnosis and Repair). • Explain the difference between a mode shift and a range shift. • Describe the purpose and function of the center differential. • Explain the purpose and function of a viscous coupling. • Describe the difference between four-wheel drive and all-wheel drive. • Explain how the front axle is disconnected when two-wheel drive is selected.

KEY TERMS: Annulus gear 1540 • Bevel gear differential 1541 • Electronically controlled clutch assembly 1536 • Input member 1541 • Interaxle differential (center differential) 1541 • Internal gear 1540 • Locking hubs 1534 • Low range 1539 • Mode shift 1539 • Output member 1541 • Part-time four-wheel drive 1534 • Planet carrier 1540 • Planet pinions 1540 • Range shift 1539 • Reaction member 1541 • Ring gear 1540 • Sun gear 1540 • Viscous coupling 1536

FOUR-WHEEL-DRIVE SYSTEMS

PURPOSE AND FUNCTION

Two-wheel drive vehicles use engine torque to turn either the front or the rear wheels. A differential is required to allow the drive wheels to travel different distances and speeds while cornering or driving over bumps or dips in the road. A four-wheel-drive vehicle, therefore, requires two differentials—one for the front wheels and one for the rear wheels.

NOTE: The term *4 × 4* means a four-wheeled vehicle that has engine torque applied to all four wheels (four-wheel drive). A *4 × 2* means a four-wheeled vehicle that has engine torque applied to only two wheels (two-wheel drive).

Four-wheel-drive vehicles require more than just two differentials. The front and the rear wheels of a four-wheel-drive vehicle also travel different distances and speeds whenever cornering or running over dips or rises in the road. There are three different methods used to allow for front-to-rear driveline speed variation.

TRANSFER CASE

Engine torque from the transmission is applied directly to the rear differential through the transfer case. ● **SEE FIGURE 126–1.** The transfer case permits the driver to select a low-speed, high-power gear ratio inside the transfer case while in four-wheel drive. These positions and their meanings include

- 4H four-wheel drive with no gear reduction in the transfer case.
- 4L four-wheel drive with gear reduction. Use of this position is usually restricted to low speeds on slippery surfaces.
- 2H two-wheel drive (rear wheels only) in high range, meaning no gear reduction in the transfer case.

CAUTION: Check the owner's manual or service manual for the recommended procedure to follow when changing from one position to another in the transfer case. Some vehicles require that the vehicle be stopped before selecting between two- and four-wheel drive and between high and low range.

METHOD 1—LOCKING HUBS

The transfer case also applies power to the front differential. Power is then applied to the front wheels through the drive axles to the **locking hubs.** In normal 4H driving on hard surfaces, the front hubs *must* be in the unlocked position. The front hubs are locked whenever driving on loose road surfaces to absorb and allow for tire slippage due to the different tire speeds front to back. This type of four-wheel-drive system is called **part-time four-wheel drive** because it can only be driven in four-wheel drive on slippery surfaces. ● **SEE FIGURE 126–2.**

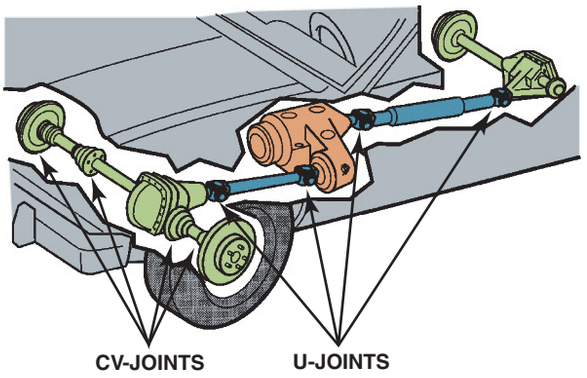
CAUTION: Failure to unlock the front wheel hubs while driving on a hard road surface can cause serious driveline vibrations and damage to driveshafts, U-joints, and bearings as well as to the transfer case, transmission, and even the engine.

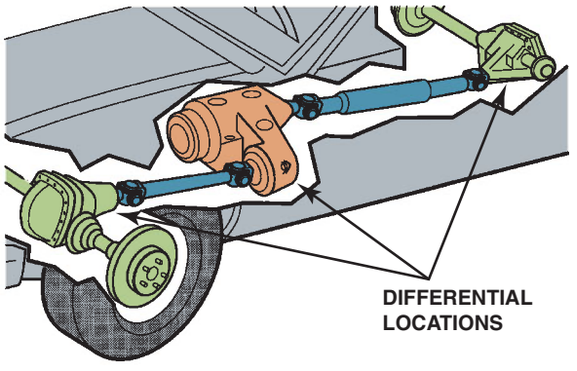
METHOD 2—AUTOLOCKING HUBS

Another method of locking the hubs on a part-time four-wheel-drive system is with a clutch arrangement built into the hub assembly. Whenever driving on smooth, hard road surfaces, the hubs "free wheel" and allow the front wheels to rotate at different speeds from the rear wheels. When the speed difference between the wheels and the front drive axle is great, the hubs will automatically lock and allow engine torque to be applied to the front wheels. ● **FIGURE 126–3** shows an autolocking hub with the cover removed. Automatic-locking hubs are unlocked by disengaging four-wheel drive at the transfer case and driving in reverse for several feet.

METHOD 3—FULL-TIME FOUR-WHEEL DRIVE

This method uses a center differential to allow front and rear wheels to travel at different speeds under all operating conditions, as shown





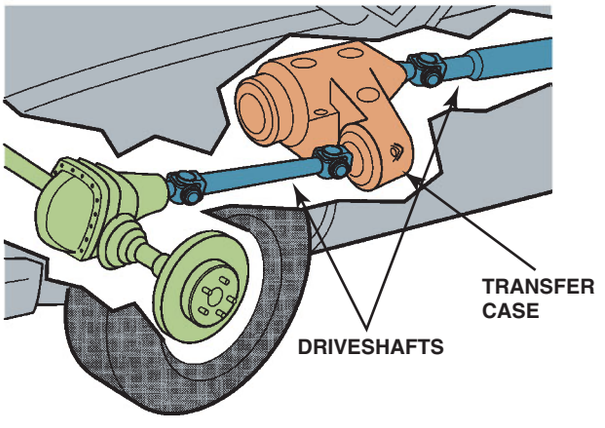


FIGURE 126–1 Many light trucks and sport utility vehicles use a transfer case to provide engine torque to all four wheels and to allow a gear reduction for maximum power to get through mud or snow. *(Courtesy of Dana Corporation, Perfect Circle Products)*

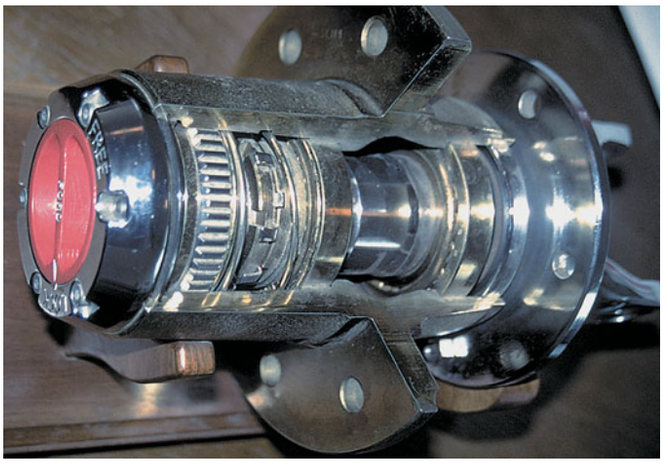


FIGURE 126–2 Cutaway of a manually-operated locking hub.

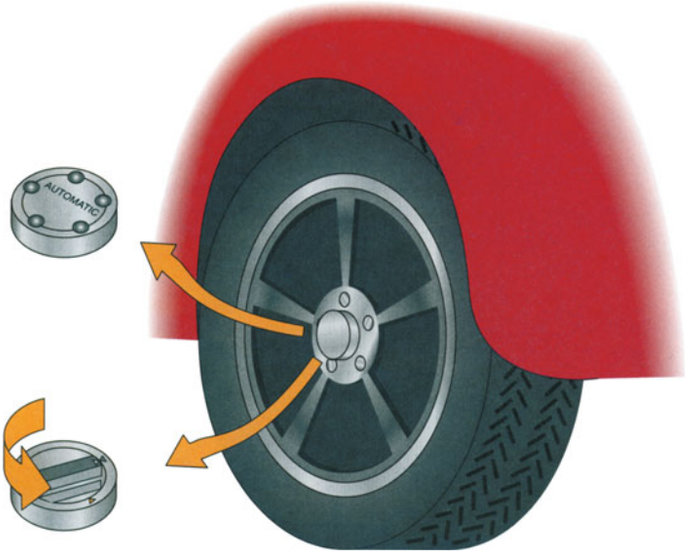


FIGURE 126–3 Manual locking hubs require that the hubs be rotated to the locked position by hand to allow torque to be applied to the front wheels. Automatic locking hubs enable the driver to shift into four-wheel drive from inside the vehicle.

FREQUENTLY ASKED QUESTION

What Is the Difference Between Four-Wheel Drive (4WD) and All-Wheel Drive (AWD)?

The major difference between four-wheel drive and all-wheel drive is that four-wheel-drive units contain a transfer case with a low range. Most all-wheel-drive vehicles do not have low range and are in high four-wheel drive all the time. Both use a center (interaxle) differential and both usually use a viscous coupling or an electronically controlled clutch to control (lock) the center differential.

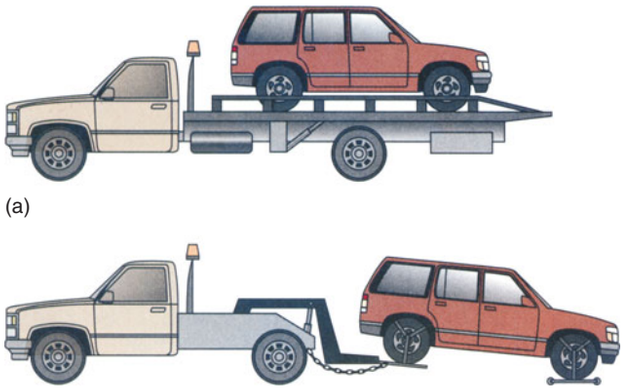
TECH TIP

How to Tow a Four-Wheel-Drive Vehicle Without Doing Harm

If any of the drive wheels are on the ground, the wheels are turning the axles. Depending on the exact type of four-wheel-drive vehicle being towed, this rotation of the wheels can cause severe wear; therefore most experts suggest the following options:

- **Placing the vehicle on a flatbed or trailer.** This keeps all four wheels off the ground and is the safest method for transporting a four-wheel-drive (or all-wheel-drive) vehicle without doing any harm.
- **Hoisting the front wheels off the ground and placing the rear wheels on a dolly.** This procedure also keeps all wheels off the ground and therefore prevents any damage being done to the powertrain as a result of towing. ● **SEE FIGURE 126–4.**

Always check with vehicle specific information for exact towing procedures.



(a)

(b)

FIGURE 126–4 If a four-wheel-drive vehicle must be towed, it should be either on (a) a flatbed truck or (b) a dolly.

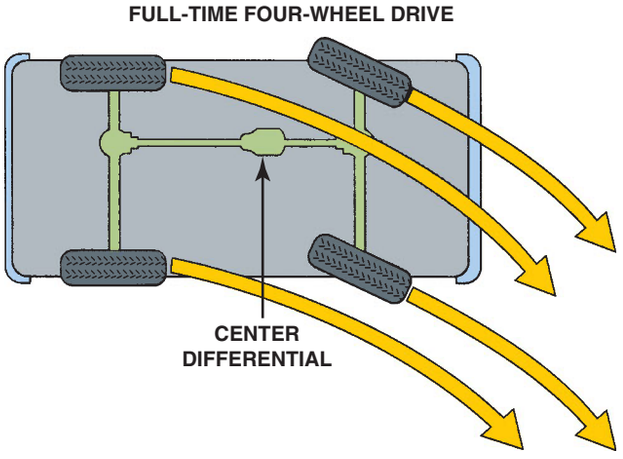


FIGURE 126–5 When turning a corner, each wheel takes a slightly different path and rotates at a slightly different speed. Unlike a part-time four-wheel-drive system, which when engaged locks the front and rear axles together, a full-time system uses a center differential that allows for any speed differences between the front and rear axles. It can therefore be activated on any surface—slippery or dry.

in ● **FIGURE 126–5.** Although this drive train design is the easiest to operate both on and off the road, the center differential can cause the vehicle to get stuck in mud or snow even though it is a four-wheel-drive vehicle.

All open-style differentials allow for speed differences and torque is applied equally, so if one wheel is on ice or mud, the other wheel receives the same low torque. This is why many vehicles spin just one wheel when stuck on ice or snow. But if one rear wheel starts to spin, the vehicle may not move forward at all!

There are two methods used to lock the center differential to prevent this from happening.

- A **viscous coupling** is commonly used on many four-wheel-drive vehicles to provide an "automatic" lockup of the center differential. A viscous coupling is a type of fluid clutch. When the speed difference between the front and rear wheels is high enough, the silicone fluid inside the coupling stiffens to reduce the speed difference between the front and rear drive shafts. ● **SEE FIGURES 126–6 AND 126–7.**

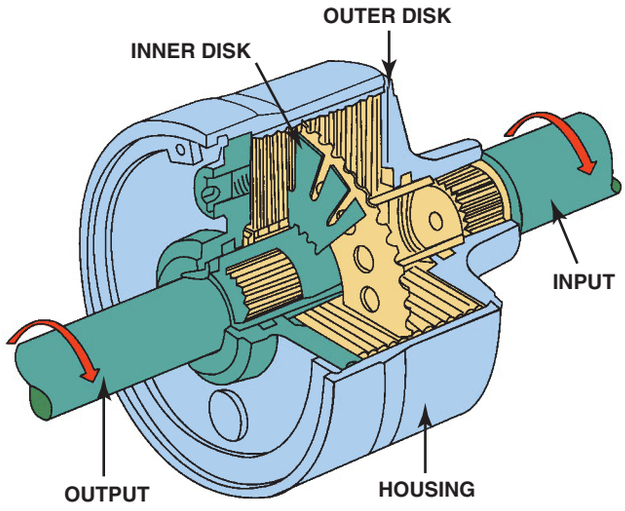
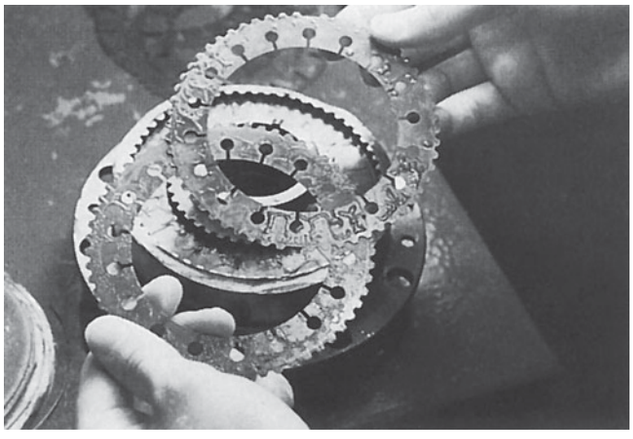
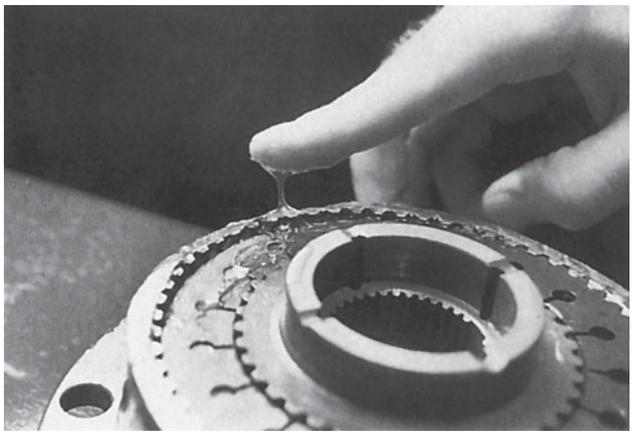


FIGURE 126–6 A viscous coupling is a sealed unit containing many steel discs. One-half of them are splined to the input shaft, with every other disc splined to the output shaft. Surrounding these discs is a thick (viscous) silicone fluid that expands when hot and effectively locks the discs together.



(a)



(b)

FIGURE 126–7 The inside of the viscous coupling consists of thin metal discs. (b) Viscous silicone fluid is used between the metal discs. (b) Viscous silicone fluid is used between the metal discs.

- An **electronically controlled clutch assembly** is actuated by the vehicle's computer based on inputs from the ABS wheel speed sensors. If a wheel starts to spin, the computer can pulse the clutch on and off as necessary to control the amount of wheel slippage.

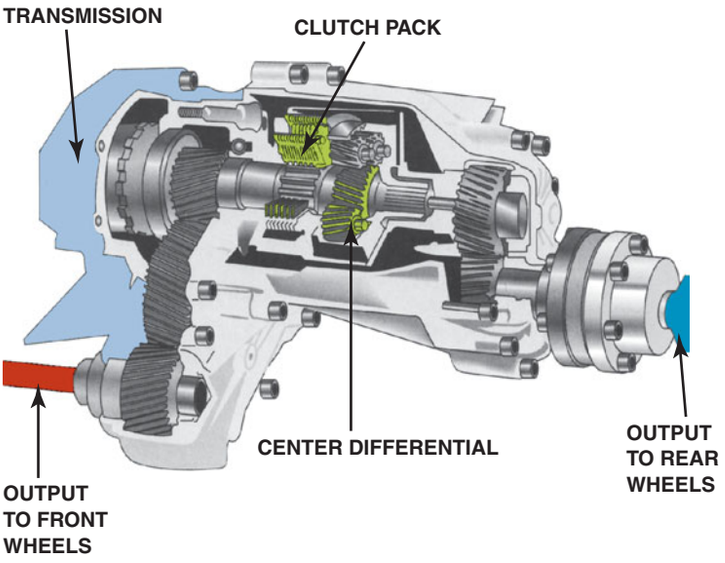


FIGURE 126–8 The center differential is the heart of a typical all-wheel-drive system. All-wheel-drive systems do not use a low range, and therefore the vehicle may not be able to go off-road like a vehicle equipped with a four-wheel drive with a low range.

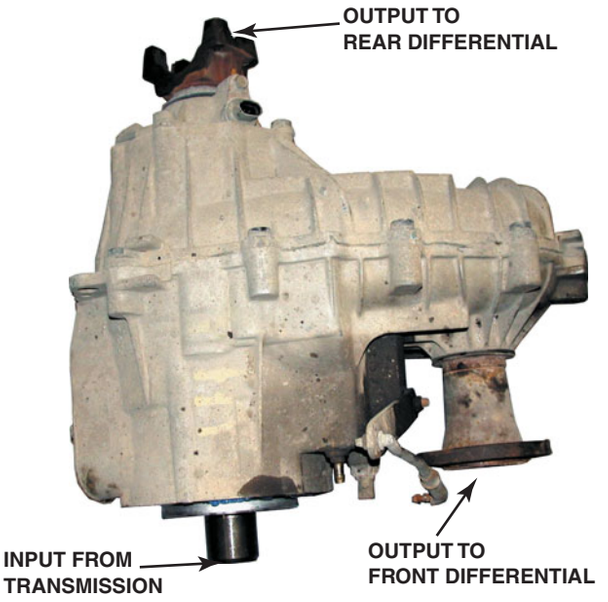


FIGURE 126–9 A typical transfer case is attached to the output of the transmission and directs engine torque to the rear or to the front and rear differentials.

? FREQUENTLY ASKED QUESTION

What Is Brake-Actuated Traction Control?

The engine torque of a full-time four-wheel-drive vehicle (with the center differential unlocked) is split into four nearly equal parts. One quarter of the torque is applied to each wheel. If a brake is applied to a spinning wheel, the torque to that wheel is increased, which will increase the torque to all of the other wheels. The increased torque applied to the wheels that have contact with a surface that has some traction will enable the vehicle to proceed. This is the principle involved in brake-controlled traction control such as is used on the Mercedes M4 sport utility vehicle (SUV).

ALL-WHEEL DRIVE

Some cars and light trucks are equipped with an all-wheel-drive system that uses a transfer case with a center differential and only one speed (high). Low-range gear reduction is not used. A viscous coupling is usually incorporated into the center differential to provide superior all-weather traction. Combined with a limited-slip differential in the rear, and sometimes also in the front, an all-wheel-drive system can provide ideal road traction under all driving conditions without any action by the driver. ● **SEE FIGURE 126–8.**

FRONT AND REAR DIFFERENTIAL AXLE RATIOS

In most four-wheel-drive vehicles, the overall gear ratio of the front differential is slightly higher than the overall ratio of the rear differential. The overall ratio is determined by multiplying the gear ratio by the differential ratio. See the following chart comparing the ratios for the front and rear differentials of a typical four-wheel-drive vehicle equipped with a manual five-speed transmission.

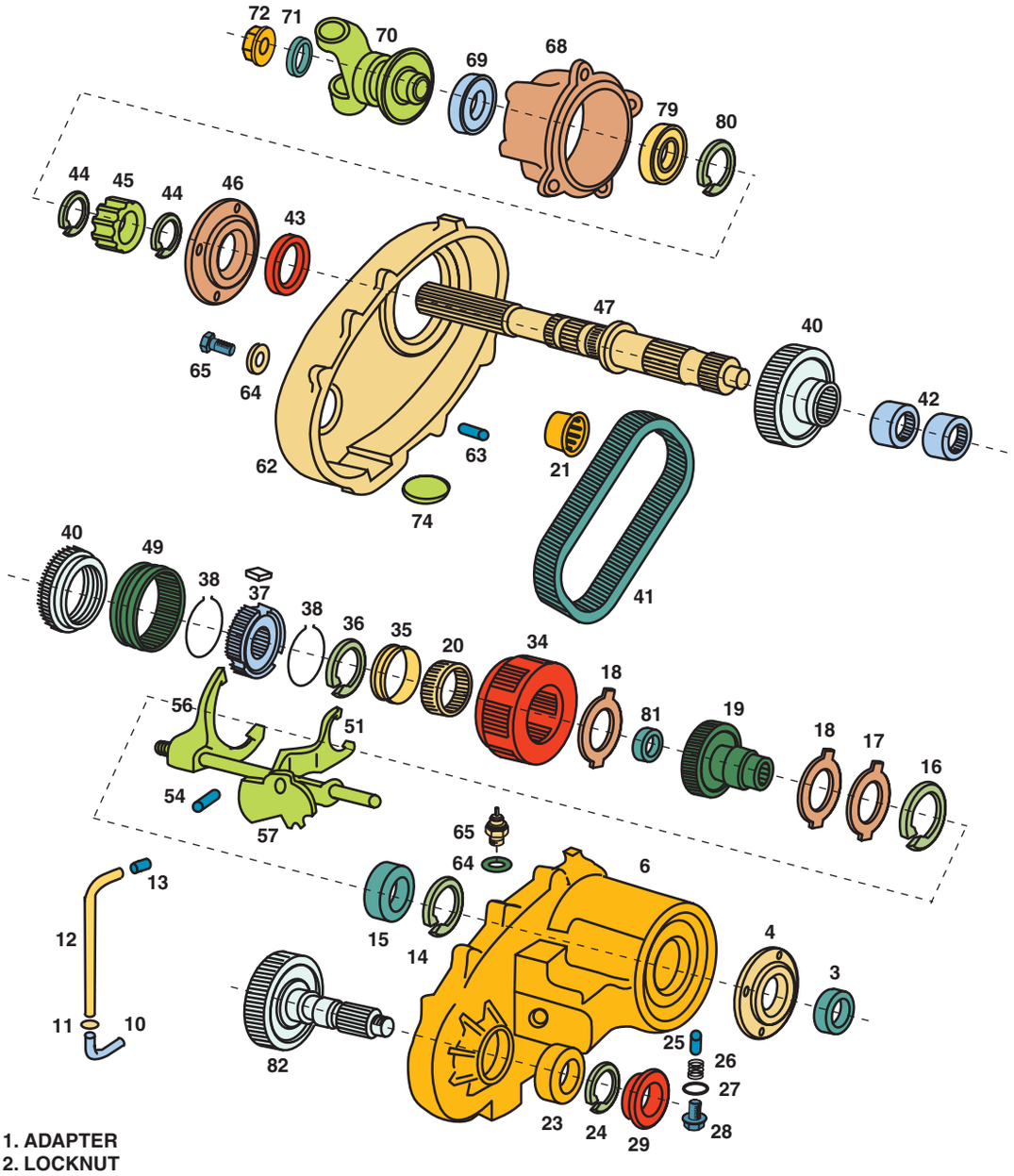
Manual Transmission and Final-Drive Gear Ratios

Speed	Gear Ratio	Final-Drive Ratio	Overall Ratio
1st	3.083:1	4.933 front 4.927 rear	15.208 front 15.190 rear
2nd	1.684:1	4.933 front 4.927 rear	8.307 front 8.297 rear
3rd	1.115:1	4.933 front 4.927 rear	5.500 front 5.494 rear
4th	0.833:1	4.933 front 4.927 rear	4.109 font 4.104 rear
5th	0.666:1	4.933 front 4.927 rear	3.285 font 3.281 rear

Although the difference between the ratios is small, the purpose is to prevent the drive train from binding. With the front differential ratio being just slightly higher, the tendency is for the front of the vehicle to pull the vehicle thereby eliminating the problem of having the rear pushing at the exact same ratio as the front is pulling. The different ratios also help reduce resonant vibration and noise created in the driveline.

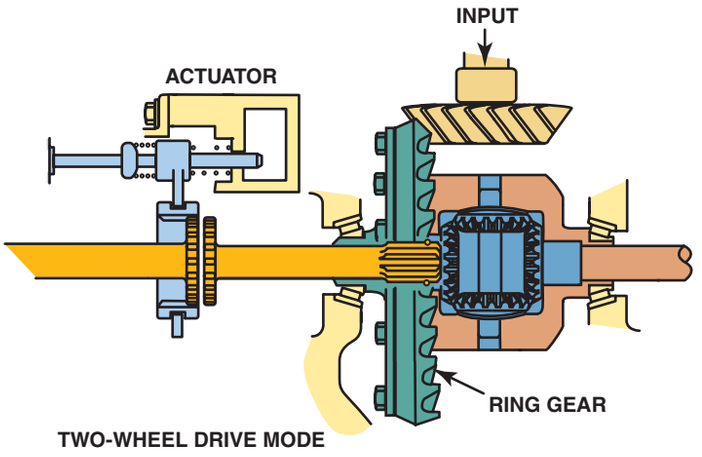
TRANSFER CASE

The purpose and function of the transfer case is to direct engine torque to the front and rear axle assemblies. ● **SEE FIGURE 126–9.** A four-wheel-drive transfer case is basically an auxiliary 2-speed transmission. It uses the transmission output as an input to a secondary gear train or planetary gear set, which provides a low and high range. The transfer of torque to the front axle output shaft can be accomplished either by a gear-to-gear transfer or a gear and chain transfer. The gear ranges can be engaged a number of ways, such as a manual lever, electrical, or vacuum actuators. A transfer case has one input shaft (connected to the output of the transmission) and two output shafts (● **SEE FIGURE 126–10).** The two

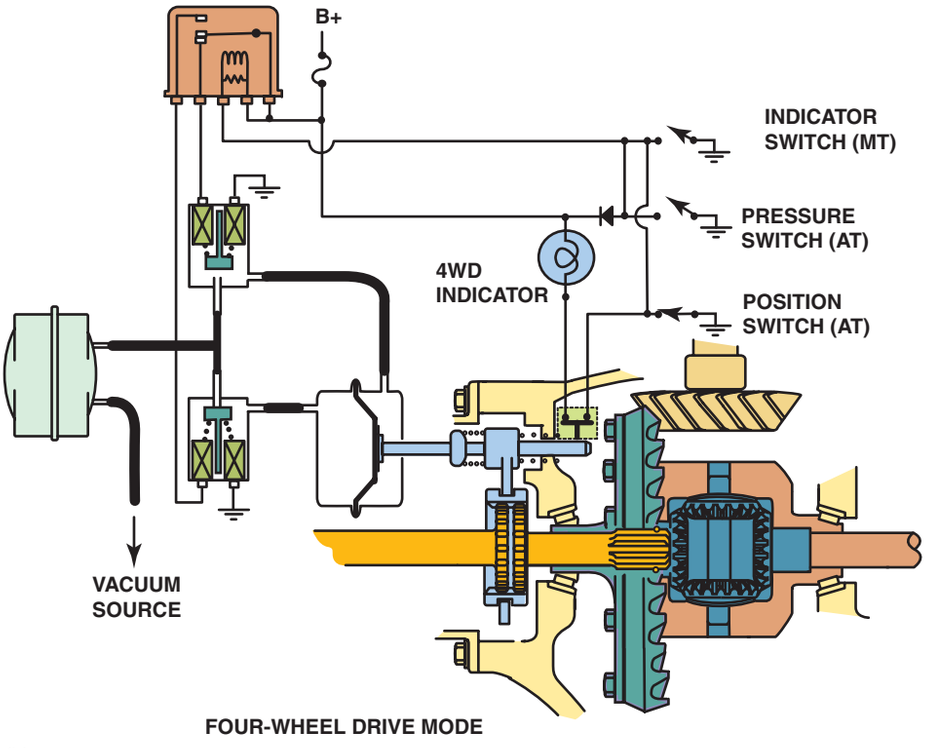


1. ADAPTER
2. LOCKNUT
3. FRONT RETAINER SEAL
4. FRONT BEARING RETAINER
5. RETAINER SCREW
6. FRONT CASE
7. CASE STUD
8. VACUUM SWITCH
9. O-RING
10. VENT
11. CLAMP
12. HOSE
13. HOSE END CAP
14. SNAP RING
15. BEARING
16. SNAP RING
17. RETAINER
18. THRUST WASHER
19. INPUT GEAR
20. PILOT BEARING
21. BEARING
22. OUTPUT SHAFT
23. BEARING
24. SNAP RING
25. DETENT PLUNGER
26. SPRING
27. O-RING
28. PLUG
29. SEAL
30. OIL SLINGER
31. YOKE
32. WASHER
33. NUT
34. LOW RANGE GEAR
35. SHIFT HUB
36. SNAP RING
37. SYNCHRONIZER
38. SPRINGS
39. STOP RING
40. SPROCKET
41. DRIVE CHAIN
42. BEARING
43. SEAL
44. SNAP RING
45. SPEEDOMETER GEAR
46. OIL PUMP
47. MAINSHAFT
48. SHIFT FORK PADS
49. RANGE FORK PADS
50. MODE FORK PADS
51. MODE FORK
52. SPRING
53. SHIFT RAIL
54. PIN
55. BUSHING
56. RANGE FORK
57. SHIFT SECTOR
58. O-RING
59. RETAINER
60. RANGE LEVER
61. NUT
62. REAR CASE
63. ALIGNMENT DOWEL
64. WASHER
65. BOLT
66. CASE BOLT
67. RETAINER SCREW
68. RETAINER
69. SEAL
70. YOKE
71. SEAL
72. YOKE NUT
73. WASHER
74. MAGNET
75. O-RING
76. OIL TUBE
77. TUBE CONNECTOR
78. SCREEN
79. BEARING
80. SNAP RING
81. PLUG
82. FRONT SHAFT
83. SNAP RING
84. GASKET

FIGURE 126–10 An exploded view of a New Venture 241 transfer case.



(a)



(b)

FIGURE 126–11 (a) When one axle shaft is disconnected, both front wheels can rotate independently, reducing excessive tire wear. (b) In four-wheel-drive mode, vacuum is applied to the front part and the opposite side is vented to atmospheric pressure retracting the shift motor stem. The shift fork and collar move into engagement with both axle shaft gears. Engine torque from the front differential can now be applied to both front axles. When the transfer case is placed in two-wheel drive, the vacuum is applied to the other side of the diaphragm and the shift collar moves, unlocking the front axles.

output shafts are connected to the driveshafts and transfer torque to the front and rear differentials. Most transfer cases also provide for two types of shifts:

- **Mode shift.** Either two-wheel drive or four-wheel drive may be selected. Many transfer cases also have a neutral position. The mode shift is achieved by the use of a floor-mounted lever to engage and disengage a clutch inside the transfer case. This shift is usually performed when the vehicle is stopped. However, new designs allow the mode shift to be performed under most driving conditions.

  NOTE: The mode shift is not available on all-wheel-drive vehicles.

- **Range shift.** A **low range** may be selected to deliver high torque at low speeds to the drive wheels. Low range usually provides a 2:1 to 3:1 gear reduction. High range (usually 1:1) simply transfers engine torque at the same speed as the output shaft of the transmission.

NOTE: Part-time four-wheel drive means that the transfer case does not include a differential.

GEAR-TO-GEAR TRANSFER CASES

Gear-to-gear transfer cases are simple in design. Three gear shafts are in mesh within the transfer case. One gear shaft is attached to the transmission output shaft. The second shaft acts as an idler, and the third shaft is the output to the front axle. Gear-to-gear transfer cases, in most cases, have two speeds. The first, 4-wheel-drive low, is a gear reduction that is usually around two to one (2:1). The second gear in the transfer case is a direct drive. The gears are engaged by sliding collars or synchronizers to lock the gears to the shaft. Neutral is accomplished when neither gear collar is locking a gear in place.

TWO-WHEEL-DRIVE OPERATION. When the transfer case controls are in two-wheel drive, the front differential assembly is disconnected from the transfer case. This disconnection is usually accomplished by disconnecting one of the drive axles, as shown in ● **FIGURES 126–11 AND 126–12.** The disconnect mechanism

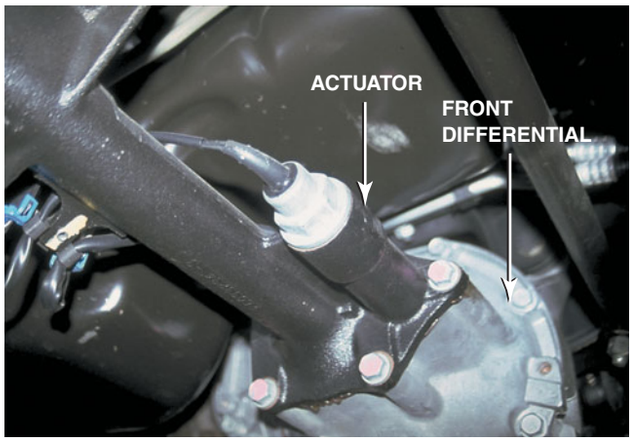


FIGURE 126–12 A General Motors sport utility vehicle front axle showing the electric axle disconnect actuator.



FIGURE 126–13 The range shift selector on a Hummer H1 sport utility vehicle. This vehicle is always in four-wheel drive, but the driver can select neutral (N) or low range.

in the front axle and a synchronizer assembly in the transfer case combine to remove torque for the front wheels.

FOUR-WHEEL-DRIVE OPERATION. To achieve four-wheel drive, two things must occur:

- A synchronizer assembly connects the torque from the engine to the front driveshaft in the transfer case.
- The drive axles must be connected to allow the torque from the front differential to be applied to the drive wheels. ● **SEE FIGURE 126–13.**

PLANETARY GEAR SET TRANSFER CASES

Many transfer cases use a planetary gear set for gear reduction in low range. A planetary gear set includes the following three elements:

1. **Sun gear.** This gear is in the center like the position of the sun is in our solar system.
2. **Planet pinions.** The planet pinion gears rotate around the sun gear, like the planets around the sun, and are attached by a **planet carrier.**
3. **Ring gear.** The outer ring gear has teeth on the inside that mesh with the teeth of the planet pinion gears. The ring gear is also called the **annulus gear** or **internal gear** because the gear teeth are on the inside (rather than the outside) portion of the gear.

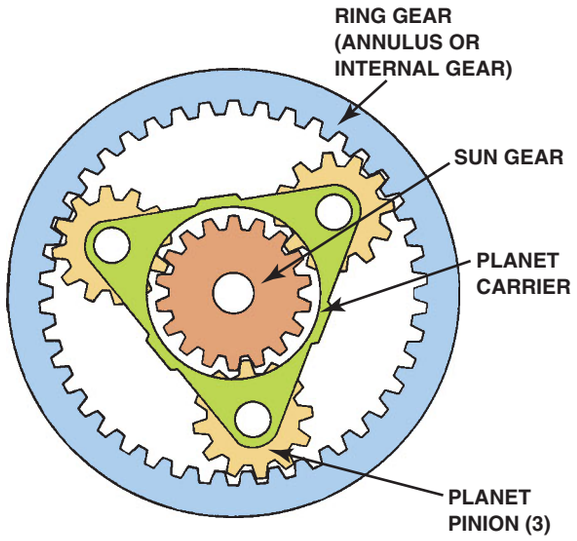


FIGURE 126–14 A typical planetary gear set used in a transfer case.

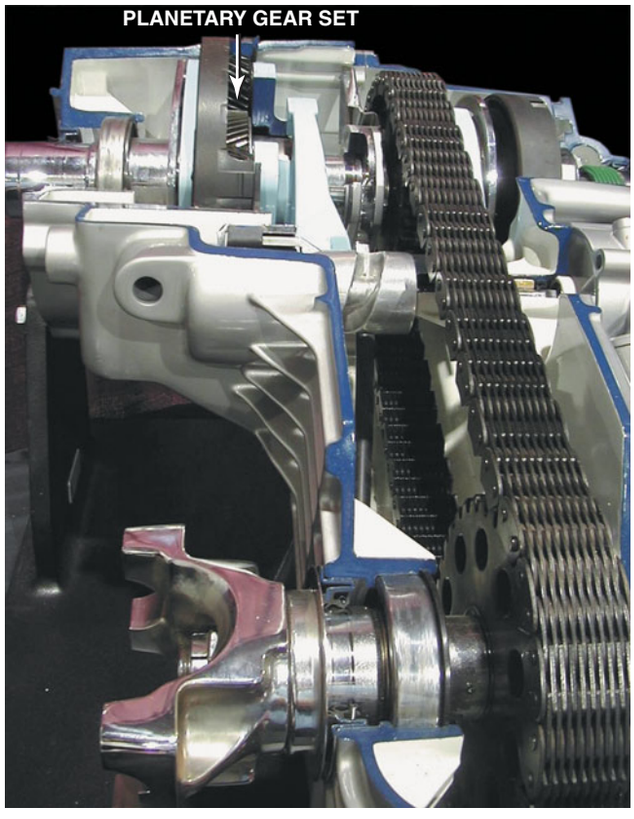


FIGURE 126–15 Cutaway of a planetary gear set transfer case.

The gear teeth of a planetary gear set remain in constant mesh. When gear reduction is needed, the sun gear is often the drive gear and the planet carrier is often the driven gear. The gear ratio reduction depends on the number of teeth on the various gears used in a planetary gear set. ● **SEE FIGURES 126–14 AND 126–15.** To achieve direct 1:1 output from the transfer case, any two of the three elements can be locked together and the entire assembly will rotate as a unit.

Power flows through a planetary gear set in several steps to get from the drive action of the first member to the driven action of the last member. The terms “drive” and “driven” simply describe

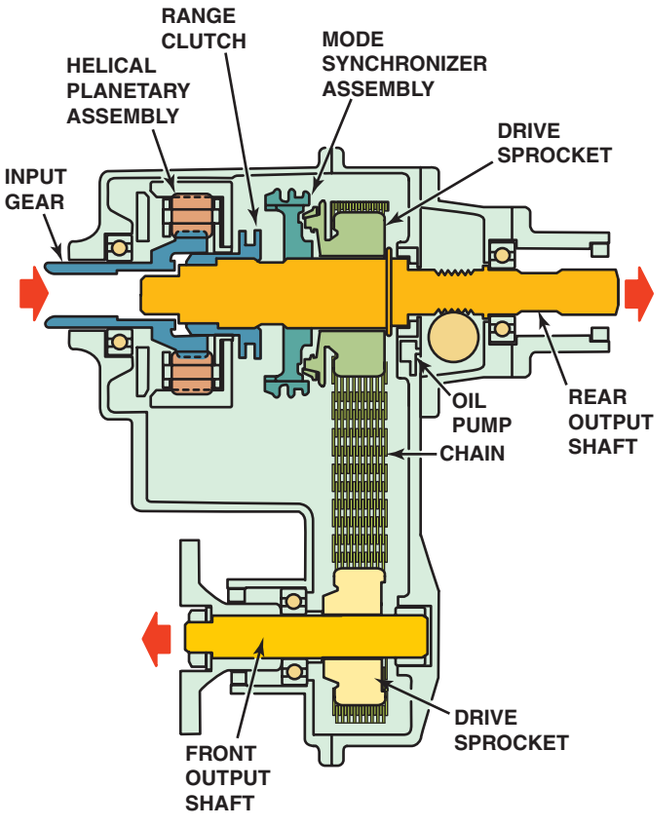


FIGURE 126–16 Two-wheel-drive/high-range torque flow in a NV231 transfer case. The sliding range clutch is shifted to the forward position by the range lever and fork, which connects the input gear to the output shaft and rear axle. The mode synchronizer sleeve is moved out of engagement from the drive sprocket to remove torque from the front axle.

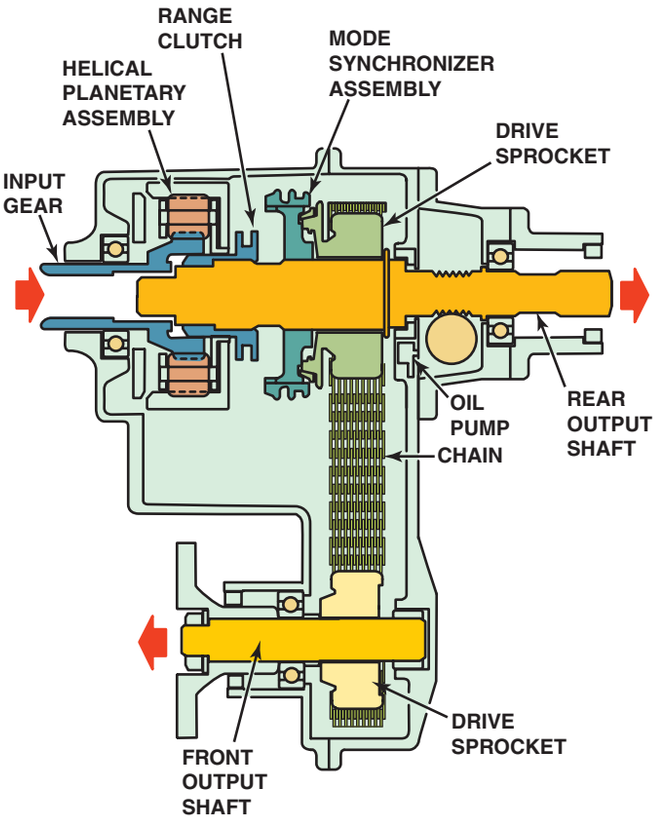


FIGURE 126–17 Four-wheel-drive/high-range torque flow in a NV231 transfer case. The range clutch position remains the same as in two-wheel drive/high-range, but the synchronizer sleeve is moved rearward and engages the drive sprocket clutch teeth. This action connects the drive sprocket to the rear output shaft, thereby applying equal torque to both front and rear output shafts.

how any two gears work together. When three or more gears are involved, the second gear is a *driven* gear in relation to the first, but a *drive* gear in relation to the third. For this reason, the drive member of a planetary gear set is called the **input member,** the held member, the **reaction member,** and the driven member, the **output member.** ● **SEE FIGURES 126–16 THROUGH 126–18.**

INTERAXLE DIFFERENTIAL

All-the-time four-wheel-drive, all-wheel-drive, and full-time four-wheel-drive systems use an **interaxle differential (center differential)** to prevent driveline harshness and vibration, commonly referred to as driveline windup. An interaxle differential can be found in various configurations including:

- Standard bevel gear differential
- Planetary gear differential
- Viscous coupling

Although they are different in appearance, interaxle differentials serve the same purpose, to maintain smooth operation while making turns in a four-wheel-drive/all-wheel-drive vehicle. The **bevel gear differential** uses two bevel gears or spider gears attached to the output shaft of the transmission. Two to four differential pinion gears are attached to a carrier, which is attached to the transfer gears. In other words, it operates in the same fashion as the differential in a rear axle; power is transferred to the tire with the least traction. When there is unequal traction between the front and rear axles, the axle with the most traction is allowed to slip enough to prevent damage to driveline components. ● **SEE FIGURE 126–19.**

With this setup, the loss of traction at one wheel could effectively disable the vehicle. For example, if one wheel had zero traction, the majority of engine torque would be applied to that wheel. In a standard bevel gear setup, torque is split between the front and rear axles. If there is a loss of traction in the front, the transfer of torque to the rear axle will be significantly lowered. To remedy this condition, auto manufacturers incorporate an internal clutch mechanism, much like a limited-slip unit, to increase torque transfer and still lessen driveline vibration and harshness.

A planetary gear set is often incorporated in transfer cases to act as a differential.

A viscous coupling is nothing more than a selection of steel plates housed in a sealed steel drum. ● **SEE FIGURE 126–20.** The viscous coupling is not active during equal traction conditions. The viscous coupling does actively transfer torque during light to moderate cornering, but there is a certain amount of slippage under these conditions to prevent driveline windup. If there is a significant loss of traction, the speed differences between the front and rear axles increase, and this increase in plate speed heats the silicon fluid in the viscous coupling, causing it to thicken to the point that it transfers more torque to the axle that is losing traction. During a severe loss of traction, the viscous fluid thickens enough to lock the plates together, dividing engine torque equally 50/50 between the front and rear axles.

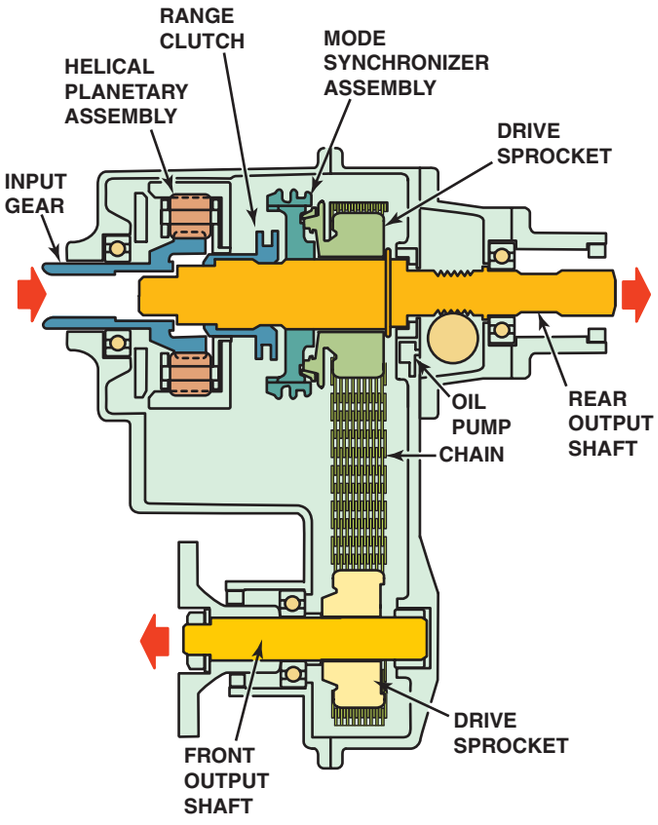


FIGURE 126–18 Four-wheel-drive/low-range torque flow in a NV231 transfer case. The mode synchronizer assembly remains engaged and the range clutch is moved to the rearward position. The annulus (ring) gear is fixed to the case and the input (sun) gear drives the pinion gears, which walk around the stationary annulus gear and drive the planetary carrier and output shaft at a speed lower than the input gear.

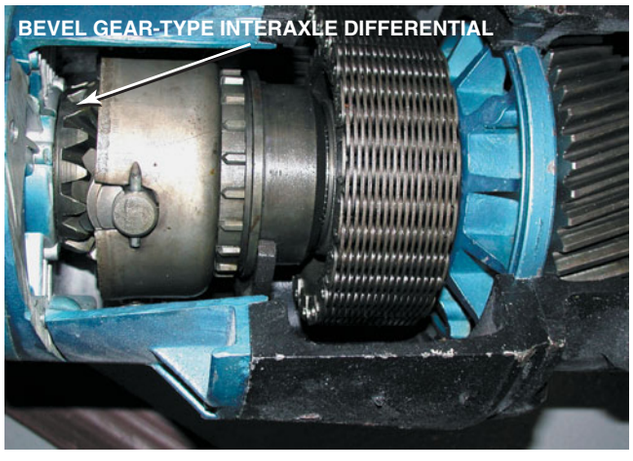


FIGURE 126–19 A bevel gear-type interaxle differential.

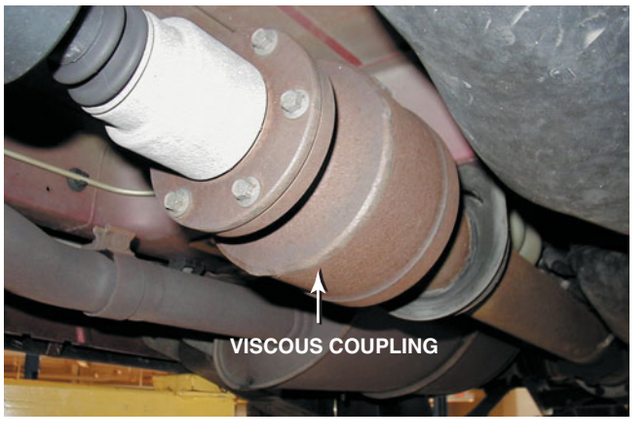
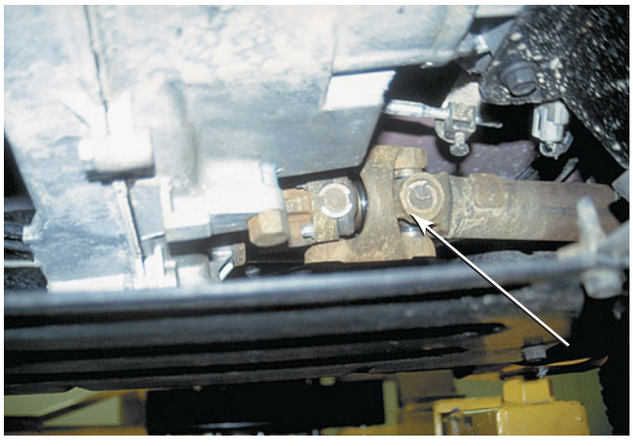


FIGURE 126–20 A viscous coupling. Note that the unit is attached to the output shaft between the transfer case (or transaxle) and the rear differential. A typical viscous coupling in a sealed unit is serviced as a complete assembly.



(a)



(b)

FIGURE 126–21 (a) A standard Cardan U-joint used on the output driveshaft from the transfer case to the front differential assembly. (b) A Cardan-type U-joint at the front drive wheels on a Jeep Wrangler.

FOUR-WHEEL-DRIVE AXLES

Four-wheel-drive vehicles use a variety of driveshafts and U-joint designs:

- **Standard Cardan-type U-joints.** ● **SEE FIGURE 126–21.** If this type of U-joint is used on the front wheels of a four-wheel-drive vehicle, the different speeds it creates can cause the front wheels to skip, hop, and shake if engine torque is applied while on dry pavement and turning a corner at the same time. This is normal for this type of U-joint used on the front wheels of a four-wheel-drive vehicle.

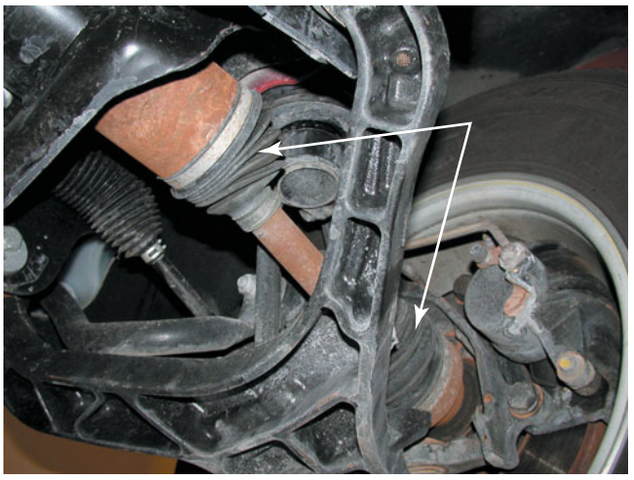


FIGURE 126–22 Constant velocity (CV) joints are used on the front axles of many four-wheel-drive vehicles like this Chevrolet Blazer.



FIGURE 126–23 Most transfer cases use an internal oil pump to force the lubricant throughout the unit. Using the correct lubricant is critical to the proper operation of the transfer case.

- **Constant velocity (CV) joints.** The use of CV joints at the front wheels allows engine torque to be applied without changes in wheel speed, as can often occur if standard U-joints are used. ● **SEE FIGURE 126–22.**

NOTE: Constant velocity (CV) joints are commonly used on vehicles that have the differential assembly attached to the frame of the vehicle. This design reduces the amount of weight that has to move up and down during suspension movement and helps provide a smooth ride.

TRANSFER CASE SERVICE AND PROBLEM DIAGNOSIS

Four-wheel-drive transfer cases and related components are usually built strong enough for heavy-duty use. However, there is some preventative maintenance that may need to be done:

- **Draining and refilling the transfer case.** Most transfer cases require automatic transmission fluid (ATF), yet some (especially older) units require SAE 80W-90 GL-4 gear lube. Obviously, any fluid leaks should be corrected as soon as possible to avoid damage from low lubricant level. ● **SEE FIGURE 126–23.**
- **Drive chain.** The chain in chain-drive transfer cases can stretch and start hitting the inside of the transfer case. ● **SEE FIGURE 126–24.** This occurs most frequently in vehicles that use four-wheel drive under heavy loads for extended periods of time. The noise the chain makes is very loud, and the chain should be replaced as soon as possible to avoid excessive damage to the case.
- **Bearings.** Transfer case bearings may cause noise whenever the input shaft is rotating even if the transfer case is in neutral. Consult the factory service information for details on transfer case bearing noise diagnosis procedures.
- **Shifting.** Shifting problems can be caused by several items: shift linkage bent or binding, worn shift fork or synchronizer assembly (● **SEE FIGURE 126–25),** incorrect transfer case lubricant.

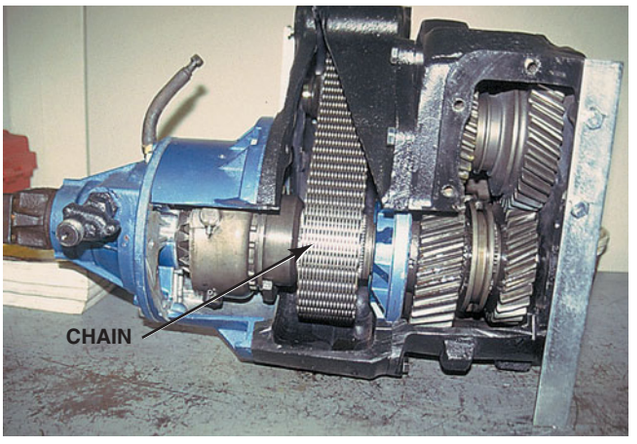


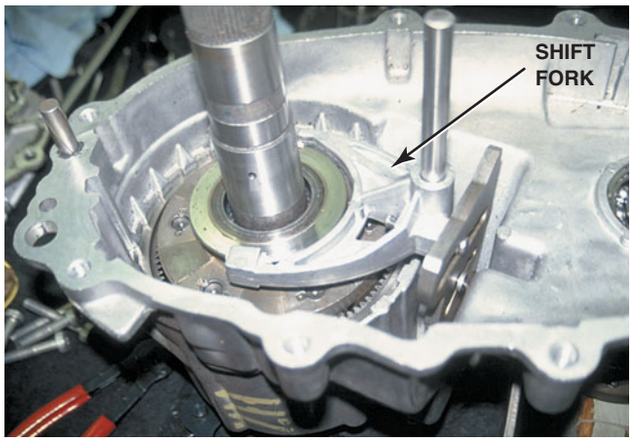
FIGURE 126–24 A cutaway view of a transfer case showing the drive chain.

TECH TIP

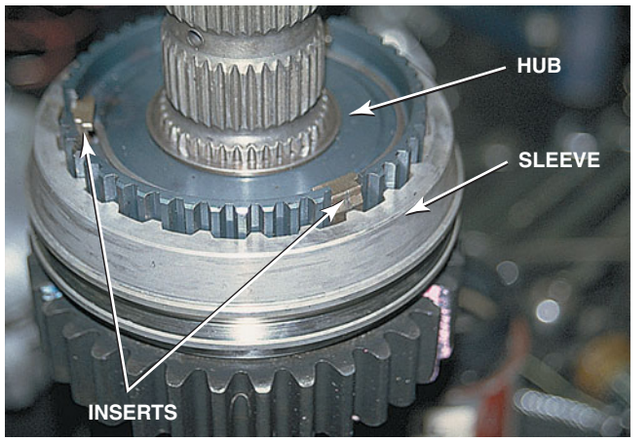
Please Install Snap Rings Correctly

Many snap rings are tapered at their opening, as shown in ● **FIGURE 126–26.** This allows the snap ring pliers to grasp the points of the snap ring so that it can be expanded and easily removed. If the points are facing down, it is very difficult for snap-ring pliers to grasp the end of the snap ring. Therefore, to make it easier to disassemble a transfer case later, always install snap rings as they were designed to be installed.

NOTE: The transfer case may be difficult to shift if the recommended procedure is not followed. For example, many manufacturers recommend that the vehicle be completely stopped before attempting to make a mode and/or a range shift. Verify proper shifting procedures before further testing or disassembly.



(a)



(b)

FIGURE 126–25 The transfer case shift forks attach to the synchronizer sleeve. (b) The sleeve, hub, and inserts are similar in design except larger than those used in a manual transmission/transaxle.

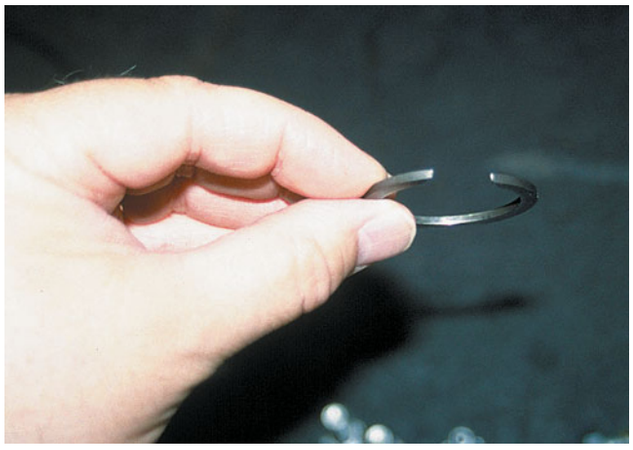


FIGURE 126–26 When reassembling a transfer case (or another automotive component) that includes a snap ring, always be sure that the upper opening is tapered from the top to allow snap-ring pliers room to get a grip on the open end.

TECH TIP

Keep the Differential Vents Clear

All differentials are vented to allow for expansion and contraction of differential lubricant in all temperature ranges. Typically, these vents are shielded openings near the top of the differential. Most trucks, especially four-wheel-drive vehicles, use an extended vent hose to prevent water from getting into the differential if the vehicle is driven in deep water.

If mud gets into the vent, pressure can build up inside the differential and cause lubricant leakage past the rear axle seals. Therefore, whenever replacing rear axle seals, always check to make sure that the differential vent is clear. Remember that four-wheel-drive vehicles use two differentials and that both the front and rear vents plus the vent on the transfer case should be checked.

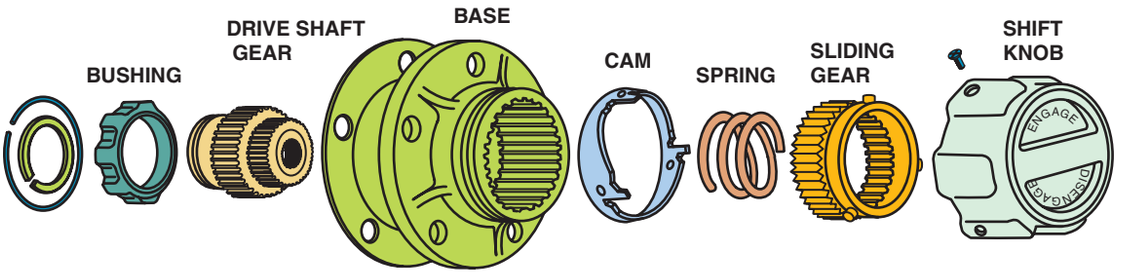
REAL WORLD FIX

The Differential Lubricant Story

A four-wheel-drive vehicle was serviced and both differentials were drained and refilled as recommended by the vehicle manufacturer. The owner returned shortly after picking up the vehicle and complained that the vehicle drove as if the parking brake was still applied. The vehicle lacked power and would decelerate rapidly whenever the accelerator pedal was released. Careful inspection of the parking brake revealed that everything was functioning correctly. Because all that was done was the differential fluid service, the fluid level was checked and again, the level was correct and not overfull. Then the technician checked the container of gear lubricant that was used and discovered that the parts store had accidentally sent SAE 80W-140 instead of the requested, and more commonly used, SAE 80W-90. Both lubricants were listed GL-5 meaning that they were acceptable for differentials. The container of lubricant had been installed in the portable lubricating dispenser when it was delivered, and therefore the label on the container was not visible to the technician. The correct lower viscosity lubricant was installed in the differential and normal vehicle performance was restored. The technician and the parts store learned to double-check the product before shipping or using it.

DIAGNOSING AND SERVICING LOCKING HUBS

Locking front hubs should be cleaned periodically, especially if the vehicle has been driven under water or in dusty conditions. Most vehicle manufacturers recommend that the hubs be cleaned and lightly coated with grease at the same time the front wheel bearings are serviced. Check the service information for the exact procedure for the vehicle being serviced. ● **SEE FIGURE 126–27.**



(a)



(b)

FIGURE 126–27 (a) An exploded view of a Dualmatic® manual locking hub. (b) A Warn® manual locking hub.

Start the inspection of the front hubs by removing the cover plate. Many problems associated with locking hubs can be corrected by cleaning and lubricating the components. If noise is heard from the hubs, carefully inspect the inner components on both sides of the vehicle. A damaged part can cause noise in the hub on the other side. Service kits are often available for the hubs. These kits contain the gaskets, seals, and retaining rings necessary for installing the hubs correctly after wheel bearing or front brake work has been completed.

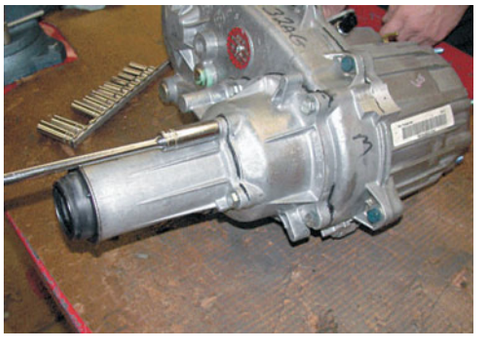
NOTE: Check the amount of axle end play. Excessive end play caused by defective bearings can cause the drive axle to move enough to damage the hubs.

TRANSFER CASE SERVICE

Transfer cases usually require occasional lubricant change during normal service life. However, driver abuse often causes parts to break, requiring the overhaul or replacement of the entire assembly. Always follow the vehicle manufacturer's recommended servicing procedure.



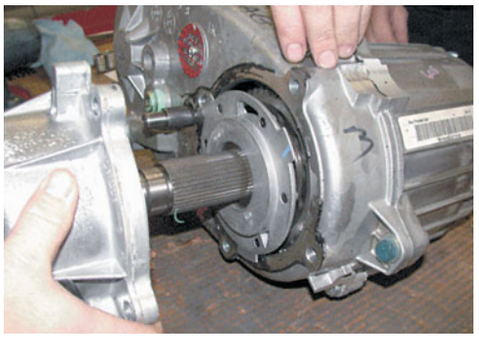
1 The identification plate on the housing indicates the transfer case is a New Venture (New Process) model #242 and has a low-range gear ratio of 2.72.1.



2 Rear output shaft housing being removed.



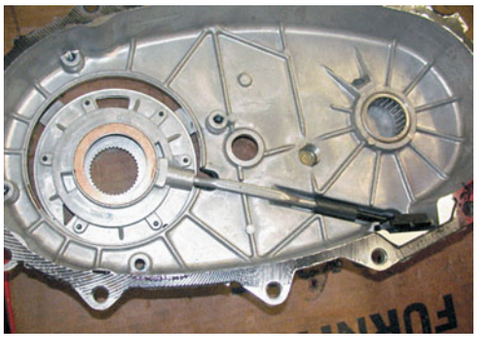
3 Before the case can be separated, the bearing retaining snap ring must be removed using snap-ring pliers.



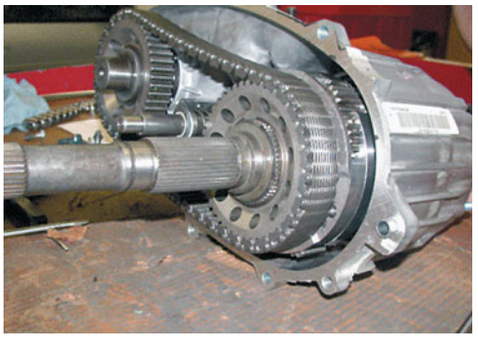
4 The lubricating oil pump is visible after the cover and bearing assembly have been removed.



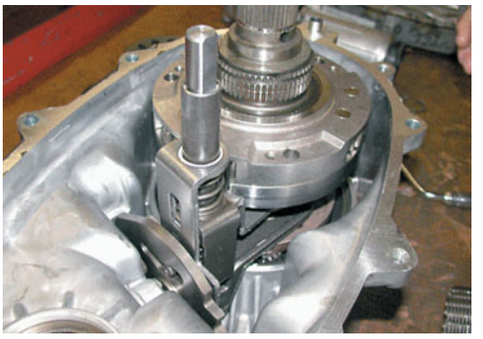
5 The two case halves are being separated.



6 The oil pump assembly, pickup screen, and tube are visible on the backside of the case cover.



7 The rear output shaft and sprocket are visible on the right. The front output shaft and sprocket are visible on the left connected by the drive chain.



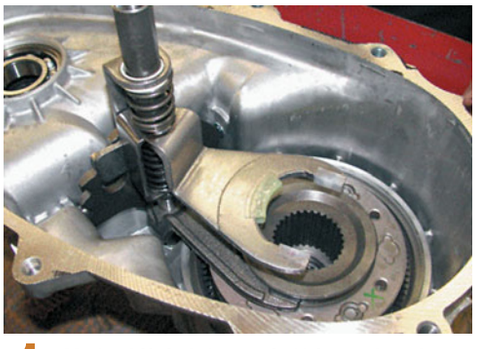
8 View of the shift levers and the center differential after the chain has been removed.



9 Differential being removed.



10 Center differential assembly after removal from the transfer case.

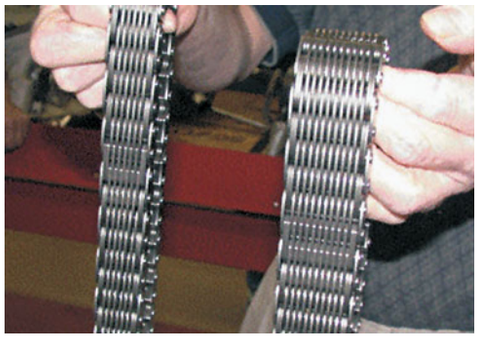


11 Mode shift fork (upper fork) is used to change two-wheel drive and four-wheel drive. The fork is attached to the range hub, which changes four-wheel drive high to four-wheel drive low.



12 Main shaft showing the range hub (left), which changes the transfer case between four-wheel high and four-wheel low.

CONTINUED ▶



13 The chain used on the NV-242 (right) is larger than the chain used in the smaller version NV-231 (left).



14 Reinstalling the components and the drive chain.



15 The drive chain should be installed with the black (dark) link(s) up.



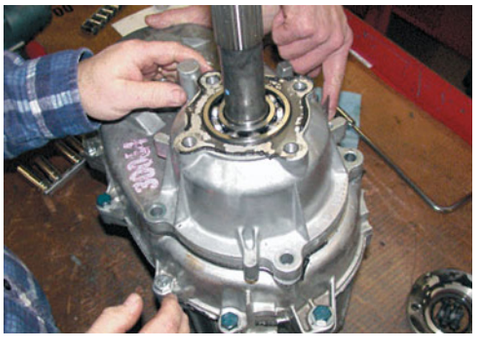
16 Install all snap rings so that the sharpest tips face up so snap-ring pliers can grab onto the tips for easier removal.



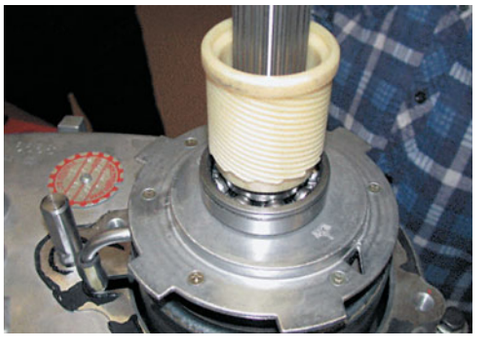
17 Assembling the case halves.



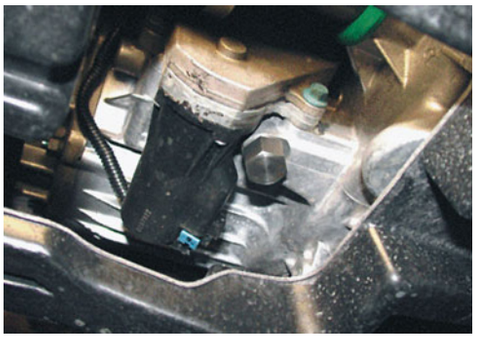
18 The parting surface should be sealed with RTV silicone. Do not use too much or the oil pump screen can become clogged.



19 After attaching the oil pump and tube, the output shaft housing is installed.



20 The output shaft speed sensor drive gear is correctly installed in this photo. The slip yoke of the drive shaft slips onto the splines and inside the nylon gear.



21 The electronically-shifted version of the case is identical except that the shifting is achieve an electric motor, shown here installed in a vehicle.

REVIEW QUESTIONS

1. Explain the difference between four-wheel drive and all-wheel drive.
2. Explain why part-time four-wheel-drive vehicles use locking front hubs.
3. Describe the difference between a mode shift and a range shift in a transfer case.
4. Describe how a viscous coupling works.
5. List the elements of the planetary gear set used in many transfer cases.

CHAPTER QUIZ

1. A customer complained of excessive vibration while cornering and accelerating at the same time. Technician A says that a fault in the transfer case is the most likely cause. Technician B says that the vibration may be normal if the vehicle is equipped with Cardan U-joints at the front wheels. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

2. Technician A says that the gear ratios of both differentials are the same in a four-wheel-drive vehicle. Technician B says that the rear differential has a slightly higher ratio (lower number) than the front differential. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

3. Technician A says that most transfer cases have a built in oil pump. Technician B says that most transfer cases use a heavy grease as a lubricant. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

4. Technician A says that a vehicle equipped with part-time four-wheel drive should be driven in four-wheel drive only on slippery surfaces. Technician B says that full-time four-wheel-drive vehicles use a center differential in the transfer case. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

5. Which type of system uses a one-speed transfer case and a center differential with a viscous coupling?
   a. Part-time four-wheel drive
   b. Full-time four-wheel drive
   c. Full-time four-wheel drive with automatic locking front hubs
   d. All-wheel drive

6. Technician A says that a transfer case may use GL-4 gear lube such as SAE 80W-90. Technician B says that a transfer case may use automatic transmission fluid (ATF) such as Dexron III. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

7. A transfer case is extremely noisy in all selections except neutral (N) whenever the vehicle is moving. Technician A says the drive chain may be stretched, causing the noise as it hits the inside of the case. Technician B says that one or more of the transfer case bearings could be defective. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

8. A transfer case is difficult to shift (range shift). Technician A says that the shift linkage or shift fork may be worn or damaged. Technician B says that the shift fork may be worn or damaged. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

9. Two technicians are discussing the towing of a four-wheel-drive vehicle. Technician A says that the vehicle should be transported on a flatbed truck to avoid the possibility of doing damage to the drive train. Technician B says that the wheels not lifted off the ground by the tow truck should be placed on a dolly to prevent doing damage to the drive train. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

10. Two technicians are discussing the front axle disconnect mechanism. Technician A says that the front axles are only disconnected if the vehicle is being towed. Technician B says that this unit is only used on all-wheel-drive vehicles. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

SECTION XIV

Automatic Transmissions and Transaxles

127 Automatic Transmission/Transaxle Principles
128 Hydraulic Components and Control Systems
129 Automatic Transmission/Transaxle Diagnosis and In-Vehicle Service
130 Automatic Transmission/Transaxle Unit Repair

chapter 127

AUTOMATIC TRANSMISSION/ TRANSAXLE PRINCIPLES

OBJECTIVES: **After studying Chapter 127, the reader will be able to:** • Prepare for the ASE Automatic Transmission/Transaxle (A2) certification test content area "A" (General Transmission/Transaxle Diagnosis). • Explain how a torque converter can transmit and multiply engine torque. • Describe how a planetary gear set can be used for gear reduction and reverse. • Explain how continuously variable transmissions work. • Describe how a dual clutch automatic transmission works.

KEY TERMS: Continuously variable transmission (CVT) 1561 • Coupling phase 1555 • Creep 1555 • Impeller 1551 • Input member 1559 • Lapelletier gear set 1560 • Output member 1559 • Planet carrier 1558 • Ravigneaux gear set 1560 • Reaction member 1559 • Ring (annulus) gear 1558 • Rotary flow 1554 • Simpson gear set 1559 • Stall speed 1555 • Stator 1551 • Sun gear 1558 • Torque converter clutch (TCC) 1556 • Turbine 1551 • Vortex flow 1554

BACKGROUND

Automatic transmissions were first used on a large scale in the early 1950s, and now about 85% of the vehicles in North America are so equipped. Unlike manual transmissions, most automatic transmissions shift gears by applying clutches (or bands) to hold or drive various elements of two or more planetary gear sets that provide different gear ratios.

The history of automatic transmission goes back over 100 years. ● **SEE CHART 127–1** for a timeline for automatic transmissions.

TORQUE CONVERTERS

PURPOSE AND FUNCTION The torque converter is located between the engine and the transmission/transaxle and performs the following functions.

1. Transmits and multiplies engine torque
2. Acts as a clutch between the engine and the transmission/transaxle
3. Allows slippage, which makes it possible for the transmission to be engaged in gear even when the vehicle and wheels are stopped

PARTS The three major parts of the torque converter include:

1. **Impeller.** The **impeller** is the driving member and rotates with the engine, and is located on the transmission side of the converter. The impeller inside the torque converter is also called the *pump* (not to be confused with the pressure pump).
2. **Turbine.** The **turbine** is located on the engine side of the converter. The impeller vanes pick up fluid in the converter housing and direct it toward the turbine. Fluid flow drives the turbine, and when the flow between the impeller and the turbine is adequate, the turbine rotates and turns the transmission input shaft.
3. **Stator.** A torque converter also contains the **stator,** or reactor, which is a reaction member mounted on a one-way clutch.

YEAR	BRAND NAME	NUMBER OF FORWARD SPEEDS	DESCRIPTION
1904	Sturtevant Brothers	2	Two forward speed gear ratios automatically shifted by flyweights
1908	Ford	2	Model T (two speeds plus reverse using a planetary gear set shifted with foot pedals)
1934	REO, GM***	2	A semiautomatic transmission with a foot clutch
1939	Chrysler Corp.**	3	First to use "fluid coupling" (Hy-Drive) with a manual three speed transmission
1940	Oldsmobile	4	Hydra-Matic unit used a fluid coupling plus three planetary gear sets, giving four forward speeds plus reverse (Other vehicles that used this transmission are Nash, Cadillac, Pontiac Bentley, Mercedes Benz, and Rolls-Royce.)
1948	Buick	2	First transmission to use a fully automatic torque converter (with fluid coupling and a planetary gear set); named the "DynaFlow" (1949–1967)
1949	Packard	2	First vehicle to have a lockup torque converter (Ultramatic transmission)
1950	Chevrolet	2	Powerglide (1950–1973)
1950	BorgWarner	3	Developed three speed torque converter transmissions for American Motors,**** Ford Motors (Ford-O-Matic), and Studebaker (1950–1968)
1953	Chrysler Corp.**	2	First two speed torque converter transmission called the PowerFlite (1953–1961) ● **SEE FIGURE 127–1.**
1956	Chrysler Corp.**	3	First three speed torque converter transmission called the TorqueFlite (1956–1977); first construction was a cast iron case, then changed to aluminum in 1962
1956	General Motors***	4	Introduced the Jet-A-Way unit; used two fluid couplings to improve shift quality; first transmission to use a "park" position (1956–1969)
1964	General Motors***	2	Two speed transmission (Jet-A-Way) (1964–1969)
1979	General Motors***	3	First transmission to use an electronically activated torque converter clutch (lockup torque converter) (THM-200C) (1979–1987)
1980	Ford	4	First overdrive transmission (AOD) (1980–1992)
1989	Chrysler Corp	4	First computer controlled transmission (A604/41TE) (1989–current)
2002	BMW	6	First to introduce a six speed transmission (2001–current)
2003	Mercedes	7	First to introduce a seven speed transmission (2003–current)
2007	Lexus	8	First to introduce an eight speed transmission (2007–current)
2007	Mercedes	7	Introduced an automatic transmission that replaced the torque converter with a lockup clutch

*Ford Motor Co. includes Ford, Lincoln, Mercury, and Ford trucks
**Chrysler Corp. includes Dodge, Plymouth, Chrysler, DeSoto, Jeep, and Dodge/Plymouth trucks
***General Motors Corp. includes Chevrolet, Oldsmobile, Buick, Cadillac, Pontiac, and Chevrolet/GMC trucks
****American Motors Corp. includes Nash, Rambler, Jeep, and Pacer

CHART 127–1

Automatic transmission use, while available in some models much sooner, increased in great numbers in the 1950s.

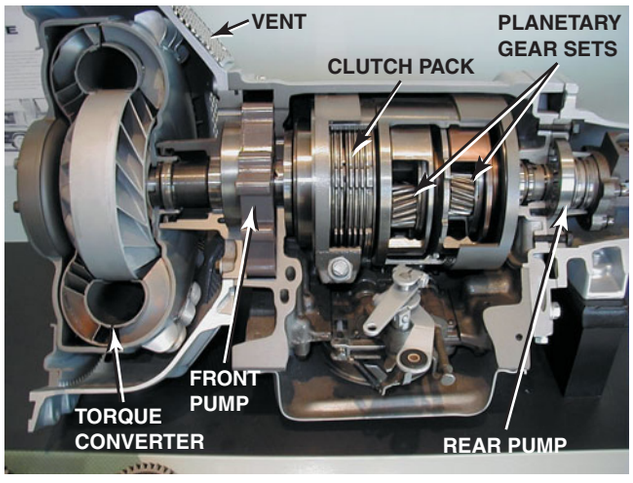


FIGURE 127–1 A cutaway of a Chrysler PowerFlite two speed automatic transmission used in the 1950s.

● **SEE FIGURE 127–2.**

The vanes used in each of the three elements of a torque converter are curved to increase the angle of the fluid flow. This also increases the force exerted by the fluid and improves the hydraulic advantage. The outlet side of the impeller vanes accelerates the fluid as it leaves the impeller to increase torque transfer to the turbine. The impeller and the turbine contain a curved shelf known as *split rings* to more efficiently move the fluid. ● **SEE FIGURE 127–3.**

OPERATION A torque converter acts like two fans pointing toward each other. Air pushed by the powered fan causes the blades of the nonpowered fan to rotate. In the case of a torque converter, the two fans are the turbine and the impeller. The transmission fluid is the air that is being forced to turn the nonpowered fan. ● **SEE FIGURE 127–4.**

The fluid only connection between the impeller and the turbine allows for absorption of sudden and harsh shocks in speed and/or

torque. The curve of the stator vanes is opposite to the curve of the impeller and turbine vanes.

Since the stator is located between the impeller and turbine, it changes the direction of the fluid as it leaves the turbine, and thereby multiplies the torque from the impeller.

Torque converters are single-piece, welded and balanced assemblies that cannot be disassembled or easily repaired. Although they can be rebuilt using specialized equipment, most shops simply replace converters as a unit if they fail.

TORQUE CONVERTER FLEXPLATE The torque converter is typically bolted to a thin metal disc called a flexplate. The center of the flexplate often has a pilot indention for the nose of the converter, and the flexplate itself is bolted to the rear flange of the engine. ● **SEE FIGURE 127–5.**

The flexplate replaces the heavy flywheel used with a manual transmission. An important function of a flywheel is to smooth out engine pulsations and dampen vibrations. An automatic transmission does not require a conventional flywheel because the weight of the torque converter provides enough mass to dampen engine vibrations.

An external ring gear generally attaches to the outer rim of the flexplate, while on some applications the ring gear may be welded to the outside of the torque converter cover. This ring gear engages the starter motor pinion gear to turn the engine during starting. Some manufacturers also place the crankshaft position sensor tone ring in the outer lip of the flexplate.

NOTE: Hybrid vehicles may use a torque dampener plate in place of the torque converter. The dampener plate contains springs to absorb driveline shock, similar to a manual transmission clutch disc. It also drives the mechanical fluid pump and input shaft; however, it does not have transmission fluid, turbine, impeller, or stator elements inside it.

TORQUE CONVERTER DRIVES THE PUMP Oil pump drive shafts generally pass through the converter inside a hollow input or transfer shaft and internally connect to the converter housing by splines or a hexagon-shape shaft. The torque converter is also responsible for driving the transmission oil pump, sometimes called the *front pump,* because some early 1950s transmissions used a *rear pump* attached to the output shaft to allow "push starting" of automatic transmission equipped vehicles. The inner portion of

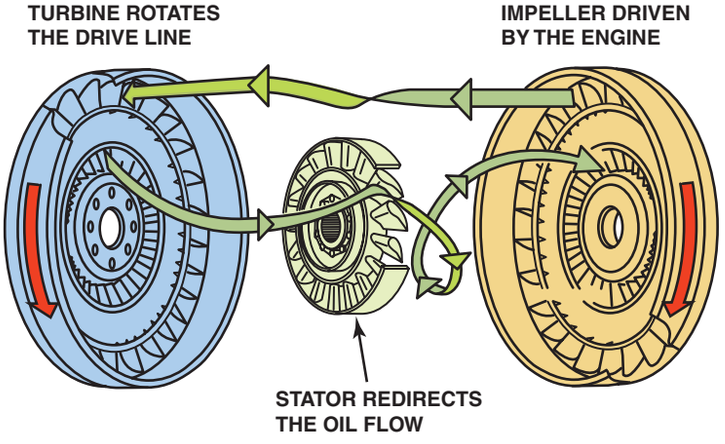


FIGURE 127–2 A torque converter is made from three parts: The impeller is located at the transmission end, attached to the housing, and is driven by the engine. The turbine is located at the engine side and is driven by the fluid flow from the impeller and drives the input shaft of the transmission. The stator redirects the flow to improve efficiency and multiply torque.

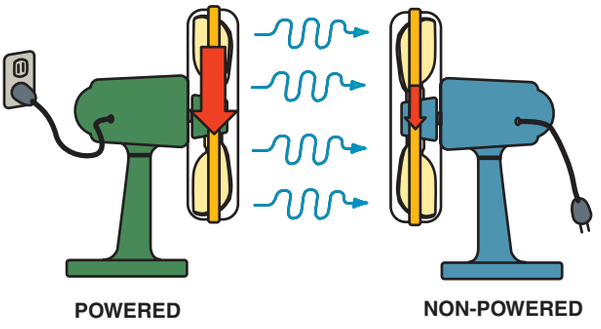


FIGURE 127–4 Two fans can be used to show how fluid, or air in the case of fans instead of automatic transmission fluid, can be used to transfer energy. If one fan is operating, the blades of a second fan will be rotated by the flow of air past the fan that is unplugged, causing the blades to rotate.

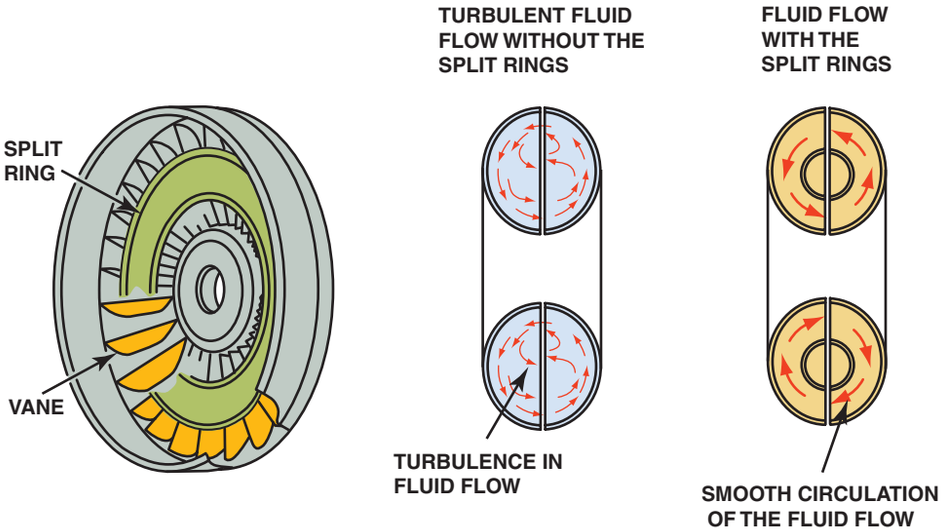


FIGURE 127–3 The slip rings help direct the flow of fluid and improve the efficiency of the torque converter by reducing turbulence.

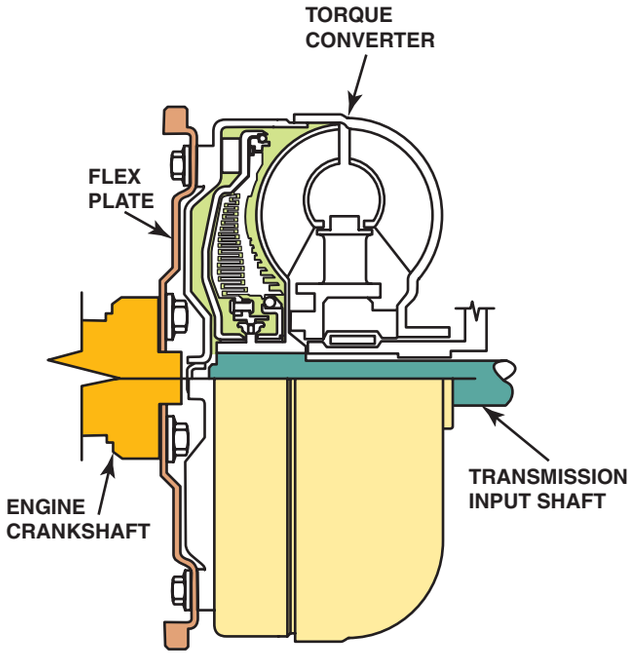


FIGURE 127–5 The torque converter bolts to the flexplate which is attached to the engine crankshaft and rotates at engine speed.

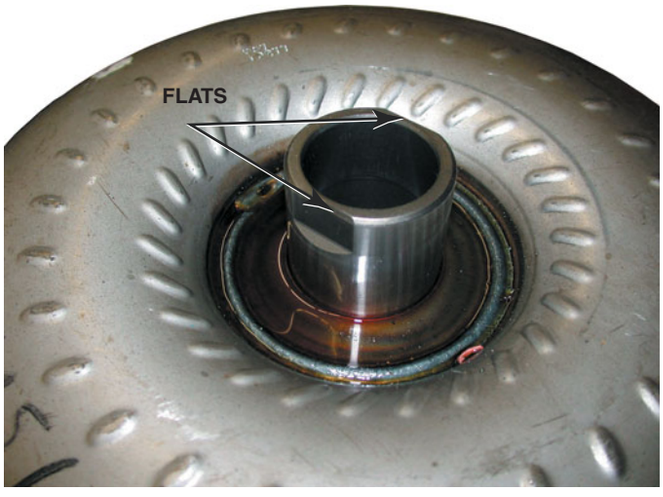


FIGURE 127–6 The flat sections that are cut into the hub of the torque converter are used to drive the fluid pump.

the front pump couples to the torque converter hub by using either "flats" or "tangs." The converter drive hub at the rear of the torque converter housing passes over the stator support and through the front oil seal to engage with and drive the oil pump. Because the shell of the torque converter is bolted to and rotates with the engine, this ensures that the fluid pump will only spin when the engine spins. ● **SEE FIGURE 127–6.**

One method is to attach the inner pump gear/rotor to the converter hub (most RWD transmissions); and the other is to use a separate oil pump drive shaft that connects the torque converter to the front oil pump (most FWD transaxles).

NOTE: Hybrid vehicles supplement the converter driven pump with an electric driven pump to ensure fluid flow and pressure even when the engine is stopped.

TRANSMISSION INPUT SHAFT

Most rear-wheel-drive transmissions use an inline method to drive the converter and provide a direct mechanical connection between the turbine and the transmission input shaft. In a typical design, splines on the turbine connect it to the transmission input shaft and the stator hub mounts on a one-way overrunning clutch. The one-way clutch mounts on splines to a stationary extension of the oil pump called the *stator support,* or *reaction shaft.* ● **SEE FIGURE 127–7.**

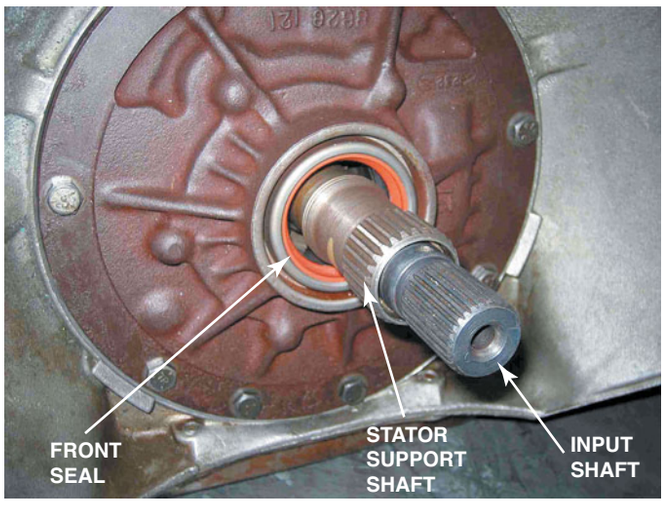


FIGURE 127–7 The internal splines inside the torque converter are connected to the splines on the stator support shaft and the turbine splines to the input shaft.

TORQUE CONVERTER OPERATION

Fluid sent to the torque converter from the transmission oil pump is picked up by the rotating vanes of the impeller and transferred to the turbine vanes. The two types of fluid flow inside a torque converter are rotary flow and vortex flow.

1. **Rotary flow** is created by the rotation of the torque converter and causes the oil (ATF) to flow around the circumference of the torque converter.
2. **Vortex flow** is the flow of the fluid from the impeller to the turbine and back to the impeller.

TORQUE MULTIPLICATION PHASE

Torque multiplication in a torque converter occurs due to the following series of events inside the torque converter.

1. Fluid leaving the turbine vanes strikes the concave, or front side, of the stator vanes.
2. The stator vanes change the direction of the fluid so that it pushes the back side of the impeller vanes.
3. The stator redirects fluid flow because it remains stationary during the torque multiplication phase.
4. The stator hub mounts on a one-way clutch, freewheeling in a clockwise direction, but locking when driven in a counterclockwise direction.
5. The stator redirects fluid flow because it remains stationary during the torque multiplication phase.
6. When fluid from the turbine strikes the concave face of the stator vanes, it tries to drive the stator counterclockwise. By locking the stator, it can redirect the fluid back to the impeller.
7. The force of the fluid redirected from the stator adds to the force of the fluid flowing to the impeller, to increase the overall torque being transferred from the impeller to the turbine. This is called the *torque multiplication phase.* ● **SEE FIGURE 127–8.**

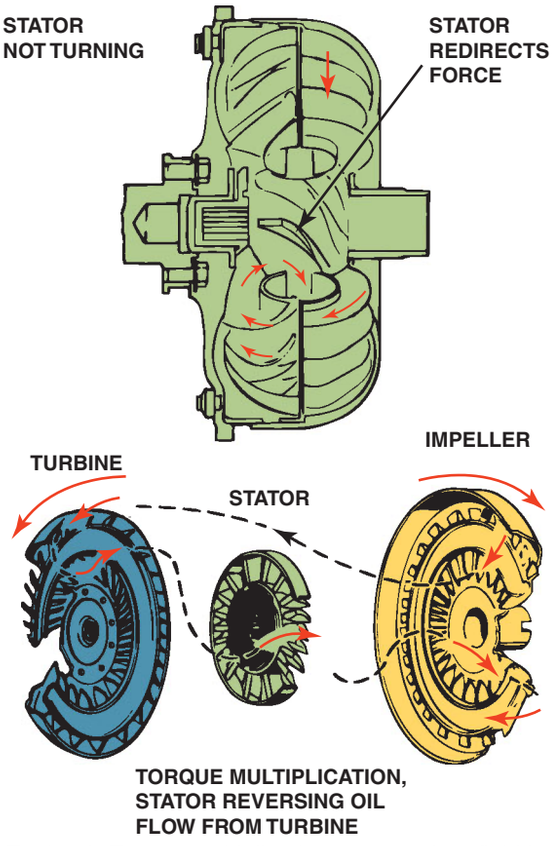


FIGURE 127–8 Torque multiplication occurs when fluid leaving the turbine strikes the front of the stator vanes and is redirected back to the impeller.

Torque multiplication occurs whenever the vortex flow makes a full cycle from impeller to turbine, through the stator and back to the impeller. A torque converter multiplies torque in relation to the speed ratio.

- At low speed ratios, the impeller (engine speed) is turning much faster than the turbine (transmission input shaft speed), so vortex flow is high and torque multiplication occurs.
- As turbine speed increases and approaches impeller speed, rotary flow increases, which reduces both vortex flow and torque multiplication.
- As the speed ratio approaches 90%, torque multiplication becomes minimal and a torque converter functions like a fluid coupling.

The stator hub mounts on a one-way clutch, freewheeling in a clockwise direction, but locking when driven in a counterclockwise direction. When fluid from the turbine strikes the concave face of the stator vanes, it tries to drive the stator counterclockwise. By locking the stator it can redirect the fluid back to the impeller. ● **SEE FIGURE 127–9.**

COUPLING PHASE When the speed ratio is 90° or more, fluid flow in the torque converter is mostly rotary flow and the angle of flow from turbine to stator increases. This is called the **coupling phase.** When the torque converter reaches this phase, the turbine is traveling at nearly the same speed as the impeller, rotary flow is much greater than vortex flow, and the torque multiplication drops. During this phase, fluid from the turbine strikes the convex side, or backside, of the stator vanes rather than the concave side. As the force of fluid striking the backside becomes great enough to drive the stator clockwise, the stator one-way clutch overruns. With the

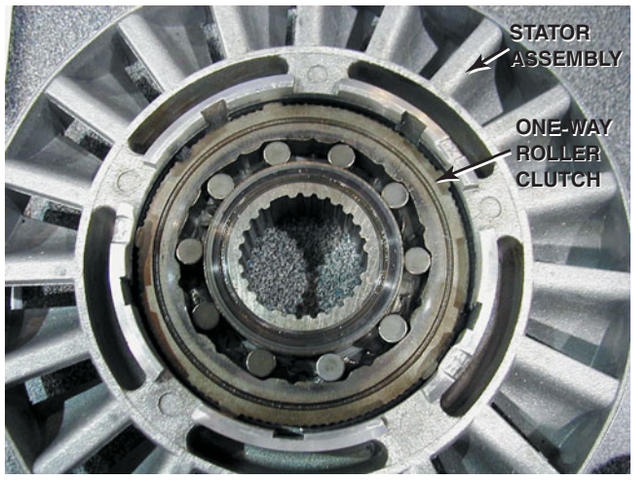


FIGURE 127–9 A stator contains a one-way roller clutch which locks it from rotating in one direction and allows it to rotate freely in the opposite direction.

clutch overrunning the turbine, impeller, and stator, all rotate in the same direction and at approximately the same speed. The stator unlocks and freewheels once the angle of fluid flow changes enough to strike the opposite side of the stator vanes and rotate the stator clockwise.

Torque multiplication drops as the torque converter approaches the coupling phase because the stator no longer redirects fluid to increase the flow from impeller to turbine. When the torque converter reaches coupling speed, the turbine is traveling at nearly the same speed as the impeller, rotary flow is much greater than vortex flow, and the torque converter simply transmits torque like a fluid coupling. During the coupling phase, most converters lose about 10% coupling efficiency, which means that there is a 10% speed difference between the impeller and turbine.

STALL SPEED **Stall speed** is the engine speed when the engine drives the impeller at the maximum speed possible without moving the turbine. The engine speed at which this occurs is called the torque converter stall speed. When the impeller rotates but the turbine does not, the speed ratio is zero. This is the lowest possible speed ratio and the greatest possible torque multiplication. Most modern torque converters multiply torque in the range of 2:1 to 2.5:1 at the stall speed. Typical stall speeds are designed to match the needs of individual vehicles and engines and range from a low of about 1,450 RPM to as high in some stock vehicles as 2,500 RPM or even higher for high-performance torque converters.

NORMAL OPERATION When the transmission selector is moved from park (P) or neutral (N) into a drive gear, some engine torque is transferred to the input shaft of the transmission or transaxle. The vehicle will move slightly if the brakes are released. This slight movement of the vehicle when the engine is at idle speed and the brakes are released is called **creep.** Therefore, a slight movement is normal for a vehicle equipped with an automatic transmission.

NOTE: Vehicle creep is more noticeable when the engine is cold due to the higher idle speed.

TORQUE CONVERTER DIAMETER The outside diameter of a torque converter and the angle of its stator blades determine the stall speed of the converter. When both a small and large diameter

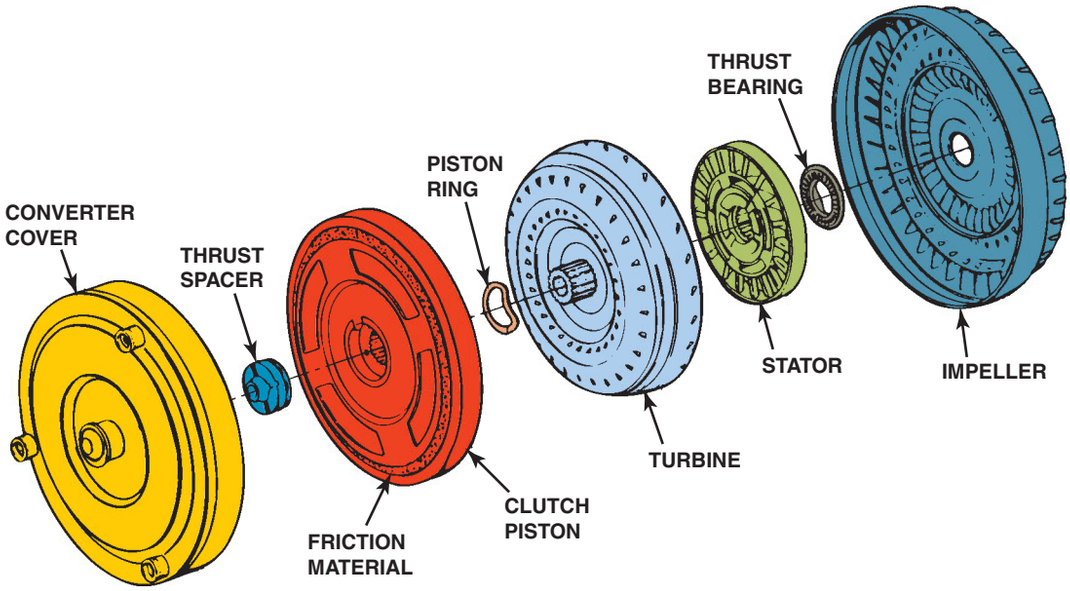


FIGURE 127–10 An expanded view of a typical torque converter assembly showing the torque converter clutch (TCC).

converter share the same stator blade angle and turn at the same speed, the smaller converter creates less centrifugal force to move the fluid inside. As a result, the small diameter converter has a higher stall speed, multiplies torque at higher engine speeds, and will not couple until the engine reaches high speeds. In comparison, the large diameter converter has a lower stall speed, multiplies torque at lower engine speeds, and also couples at a lower engine speed.

Vehicle manufacturers select torque converters to match the powertrain requirements and operating demands of each vehicle application.

- A vehicle with a large engine that produces a lot of torque at low RPM will often use a torque converter that couples at low speeds for greater fuel economy and lowest possible exhaust emissions.
- Vehicles with smaller engines that produce less torque at low RPM will use a torque converter that allows the engine to operate higher in its torque curve, where more power is available. High-performance vehicles with automatic transmissions use small diameter converters for the same reason.
- Therefore, the vehicle manufacturer selects the best stall speed based on the power band of the engine and the weight of the vehicle.

LOCKUP TORQUE CONVERTER

PURPOSE AND FUNCTION Even the most efficient torque converters slip 8% to 12% during operation, because the fluid that transmits torque exhibits a type of slippage known as fluid shear. Fluid shear creates friction heat, but performs no work when the different layers of fluid slide past each other.

Eliminating torque converter slippage can improve fuel economy approximately 4% to 5% during freeway cruising. With the increased emphasis on fuel economy and low exhaust emissions for late model vehicles, this became an important goal for automotive engineers. An additional benefit to reducing slippage is a reduction of transmission operating temperature, which increases transmission life expectancy. Lockup torque converters reduce slippage by using a **torque converter clutch (TCC)** to lock the impeller to the cover (shell). Similar to a clutch for a manual transmission, a TCC uses a friction disc operated by a hydraulic piston to mechanically couple the turbine to the converter (cover /shell). Engaging the clutch creates mechanical connection between the engine and transmission, resulting in a direct 1:1 drive ratio without slippage. ● **SEE FIGURE 127–10.**

CONVERTER CLUTCH CONTROL The first hydraulic lockup converters were controlled entirely by hydraulic pressure and spool valves in the transmission valve body. Some older designs added simple electric switches and solenoids to control pressure to the converter clutch. Since the early 1990s, the powertrain control module (PCM) or the transmission control module (TCM) regulates the timing and application of the clutch. The torque converter clutch operates under the following conditions.

- Lockup may also be limited to specific vehicle speeds or operating conditions. For most vehicles, lockup can occur at speeds over 25 to 30 mph (40 to 48 km/h) but can occur sooner in many newer transmissions/transaxles.
- Once lockup occurs, the clutch may disengage automatically during certain operating conditions such as part- or full-throttle downshift. At these times, the increased acceleration requirements generally override the need for better fuel economy.
- Most computer systems can lock and unlock or modulate a converter clutch hundreds of times per minute to meet the vehicle demands of the moment and some recent systems also allow partial lockup of the torque converter. Traditional lockup torque converters operate either locked or unlocked. Partial lockup converters allow a regulated amount of slippage at the clutch. Each type of torque converter requires a certain type of friction material. ● **SEE FIGURE 127–11.**
- This allows the converter to lock up smoothly, improving fuel economy and performance, without the drawback of shock to the driveline. Using the wrong type of automatic transmission fluid (ATF) can alter the frictional properties of the lockup clutch, leading to shudder or other similar customer complaints.

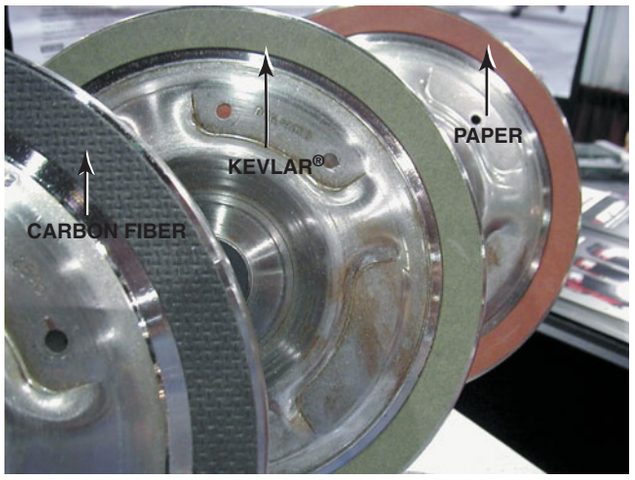


FIGURE 127–11 Torque converter clutch friction material is determined by the vehicle manufacturer to provide the needed coefficient of friction needed. For example, many older units use a paper-type friction material because they are fully applied or released, whereas most newer units use a synthetic material such as Kevlar® or carbon fiber because the torque converter clutch is pulsed on and off, therefore requiring a more robust material for long service life.

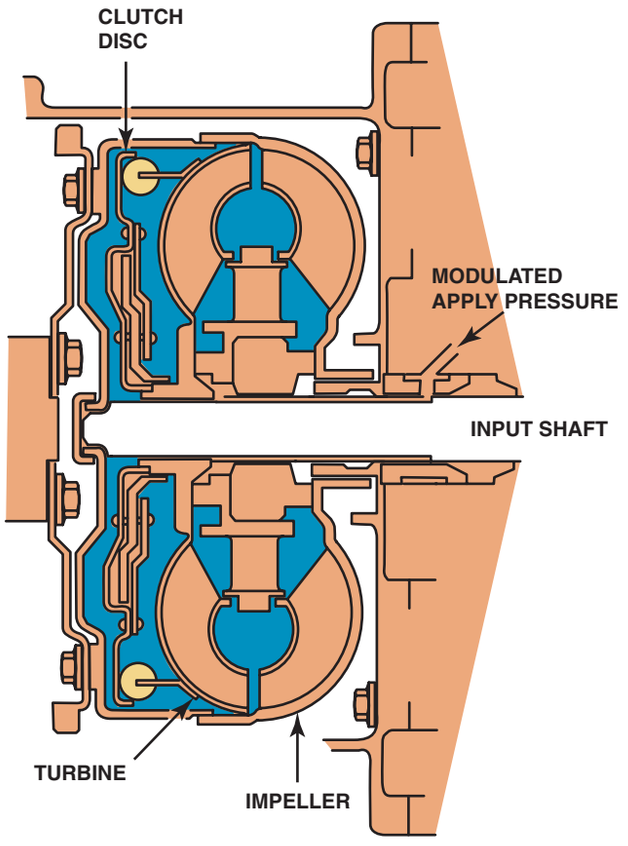


FIGURE 127–12 A cross-sectional view of a pulse-width-modulated (PWM) torque converter clutch. The powertrain control module (PCM) pulses the control solenoid which then controls the fluid flow to apply the torque converter clutch.

HIGH PERFORMANCE TIP

Use a Smaller Diameter Torque Converter for Improved Performance

A smaller-than-stock-diameter torque converter will not be capable of absorbing as much torque as a larger (stock) torque converter. As a result, the stall speed is increased. Because an engine develops more torque with increased speed (up to a point), the smaller torque converter will allow the engine to increase to a higher speed and create more torque to the transmission than would be capable with the stock torque converter.

This is especially helpful for modified engines because an engine having a camshaft with increased lift and duration usually lacks low RPM torque. By using a smaller torque converter, the stall speed is increased to better match the engine torque.

CAUTION: Using a torque converter with a different stall speed rating is likely to increase exhaust emissions and decrease fuel economy as well as void the warranty on the vehicle.



FIGURE 127–13 The gear selector is often called the "PRNDL," pronounced "prindle," regardless of the actual letters or numbers used.

- Most lockup converters automatically disengage the torque converter clutch each time the brake pedal is depressed by the driver or if the accelerator pedal is released for more than a couple of seconds, which is necessary for vehicle deceleration without stalling the engine. ● **SEE FIGURE 127–12.**

SHIFT MODES

Most automatic transmissions and transaxles include the following shift modes. ● **SEE FIGURE 127–13.**

- **Park.** In the park position, the output shaft is locked to the case of the transmission/transaxle, which keeps the vehicle from moving. No power is transmitted through the unit so the engine can remain running while the vehicle is held stationary. In the park position:
  1. The engine can be started by the driver.
  2. To move the shifter out of the park position on a late model vehicle, the brake pedal must be depressed to release the brake transmission shift interlock.
- **Reverse.** The reverse gear selector position is used to move the vehicle in reverse. Reverse usually uses a lower gear ratio than any of the forward gears.

- **Neutral.** In the neutral position no torque is being transmitted through the automatic transmission/transaxle. In this position the engine can be started by the driver.
- **Overdrive (OD).** The OD is the normal position for the shift selector for most driving conditions. This position allows the transmission or transaxle to shift through all forward gears as needed for the best fuel economy and lowest exhaust emissions.
- **Drive (D).** The D position includes the overdrive ratios in most vehicles. If there is an overdrive shift mode, however, then D is used to provide all forward gears except overdrive. Use this position when driving in hilly areas or when towing in the vehicle equipped with an overdrive selection.
- **Third (3).** In third position the transmission/transaxle will upshift normally to third gear but will not upshift to a higher gear. When the third (3) position is selected while driving in a higher gear, the transmission will downshift into third if the vehicle speed is low enough to prevent the engine from being overrevved. This gear selection is used for the gentle grades at a moderate vehicle speed.
- **Second (2).** The second position is used for slowing the vehicle while descending long grades. In this gear selection, the vehicle speed is controlled and the engine speed is increased to provide engine compression braking. This gear selection is used for the gentle grades at a moderate vehicle speed.
- **First (1 or Low).** The first (or low) position is used for slowing the vehicle while descending long grades. In this gear selection, the vehicle speed is controlled and the engine speed is increased to provide engine compression breaking. This gear selection is used for the steepest grades at the lowest possible speed.

NOTE: The overdrive button on many automatic transmissions is used to turn off the overdrive gear. It is used to prevent overdrive while towing or when driving in city traffic to prevent the transmission from shifting in and out of overdrive.

PLANETARY GEAR SETS

PURPOSE AND FUNCTION In a manual transmission, different gear ratios are obtained by sliding the gears into mesh. However, torque flow must be momentarily interrupted (accomplished by using a clutch) before the gears are shifted. With an automatic transmission there is no driver-operated clutch, so gear shifts are not made by sliding gears into mesh. Most automatic transmissions use a planetary gear set system that does not require manual gear shifting or an interruption of torque flow to change gear ratios.

PARTS AND OPERATION A simple planetary gear set consists of three primary components.

- Sun gear
- Planet carrier (including planet pinion gears)
- Ring (annulus) gear

As discussed in the last chapter on transfer cases, the **sun gear** gets its name from its position at the center of the gear set. The **planet carrier** holds the pinion gears, also known as planet gears, which revolve around the sun gear. The planet carrier assembly is commonly referred to simply as "the carrier."

The outermost member of the gear set is the **ring gear,** the internal type with teeth inside. The ring gear is sometimes called an annulus or internal gear. The pinion gears are in simultaneous mesh with both the sun gear and the ring gear. ● **SEE FIGURE 127–14.**

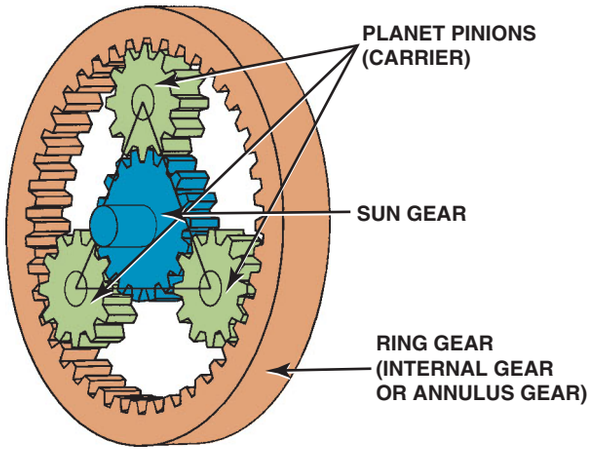


FIGURE 127–14 A typical planter gear set showing the terms that are used to describe each member.

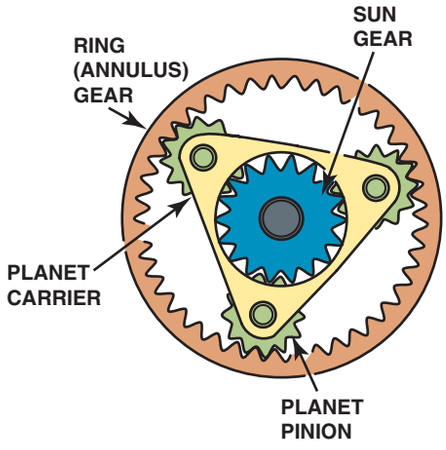


FIGURE 127–15 A typical planetary gear set showing the planet carrier which supports all of the pinion gears (also called planet pinion gears).

The pinion gears are free to rotate on pins that are part of the carrier, and the entire assembly rotates to direct torque flow. Most transmission gear sets use three, four, or even five planet pinions.

The pinions are fully meshed with both the sun gear and internal ring gear *at all times.*

The planetary gears never disengage to change gear ratios; torque is simply redirected.

The torque flow through a planetary gear set, both input and output, occurs along a single axis.

The parts in a planetary gear system may be known by several different names.

PLANETARY GEAR SET TORQUE FLOW In a planetary gear set, the following is done to achieve the various gear ratios and reverse.

- One of the members is being driven (input).
- One of the members is being held (reaction member).
- One of the members is the output.

Therefore, driving one gear will cause all of the other gears to rotate as well. This allows the gear set to provide different gear ratios, depending upon how torque is distributed through the assembly. To transmit torque through a planetary gear set, a drive member rotates while a second member is held, which causes a third member to be driven. ● **SEE FIGURE 127–15.**

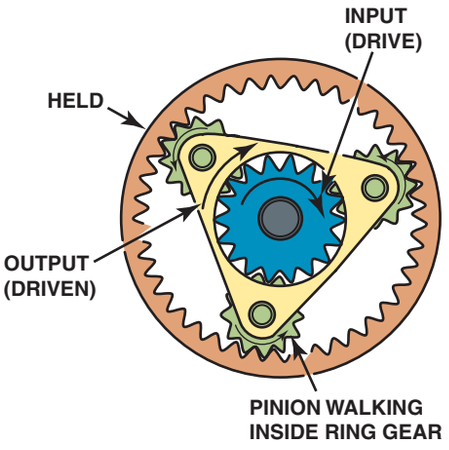


FIGURE 127–16 Maximum reduction can be achieved by using the sun gear as the input, holding the ring gear and using the planet carrier as the output.

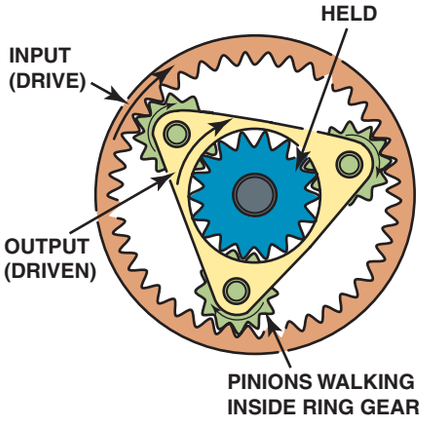


FIGURE 127–17 Minimum reduction can be achieved by using the ring gear as the input, holding the sun gear and using the planet carrier as the output.

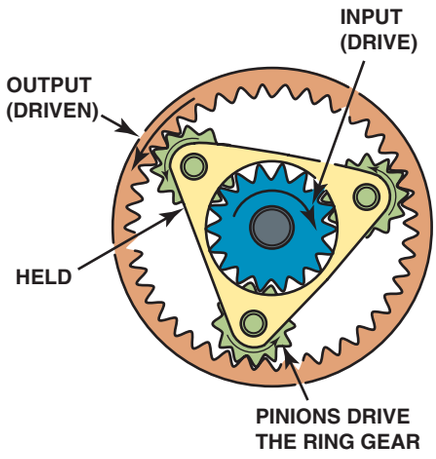


FIGURE 127–18 Reverse can be achieved by using the sun gear as the input, holding the planet carrier and using the ring gear as the output.

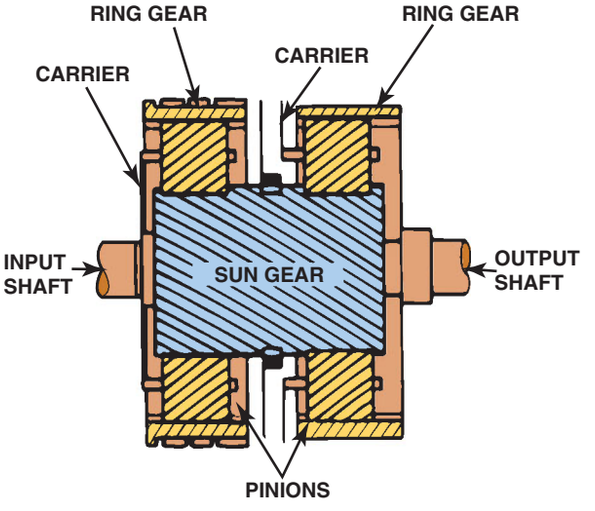


FIGURE 127–19 A Simpson planet gear set is composed of two ring gears and two planet carrier assemblies that share one sun gear.

Each member of a planetary gear set can play any one of these three roles to transmit torque. The various combinations of drive, held, and driven members result in the number of gear ratios available and change the direction of rotation as well for reverse.

NOTE: The held member can also be allowed to move one direction or another as it is being held and does not necessarily need to be held to zero RPM to create a variable gear ratio. This is done in hybrid electric vehicle transmissions.

Torque flows through a planetary gear set in several steps to get from the drive action of the first member to the driven action of the last member.

- The terms “drive” and “driven” simply describe how any two gears work together.
- When three or more gears are involved, the second gear is a *driven* gear in relation to the first, but it becomes a *drive* gear in relation to the third gear.
- For this reason, the drive member of a planetary gear set is known as the **input member,** the held member is the **reaction member,** and the driven member is the **output member.**

SIMPLE PLANETARY GEAR SET SYSTEMS A simple planetary gear set system consists of one sun gear, the carrier, and a ring gear. A single planetary gear set can provide all of the necessary gear ratios for a basic automatic transmission. ● **SEE FIGURE 127–16 THROUGH 127–18.**

A simple planetary gear set is often used together with a compound planetary gear set to provide additional gear ratios.

● **SEE CHART 127–2** for the six possible gear ratios and how they are achieved.

COMPOUND PLANETARY GEAR SET

A *compound planetary gear set* system is a configuration that contains more than just the three basic members of a simple planetary system. A compound planetary gear set is one or more simple planetary gears sets with one or more common gears. Compound planetary gear sets are capable of providing various combinations of gear reduction, direct drive, neutral, reverse, and overdrive.

SIMPSON GEAR SET One of the most popular compound planetary design is the **Simpson gear set.** Named for its inventor, Howard Woodworth Simpson (1892–1963), an American automotive engineer, the Simpson gear set consists of two simple planetary gear sets that share a common sun gear. ● **SEE FIGURE 127–19.**

SUN GEAR	PLANET CARRIER	RING GEAR	SPEED	TORQUE	DIRECTION
Input (Drive)	Output (Driven)	Held	Maximum reduction	Increase	Same as Input
Output (Driven)	Input (Drive)	Held	Maximum increase	Reduction	Same as Input
Held	Output (Driven)	Input (Drive)	Minimum reduction	Increase	Same as Input
Held	Input (Drive)	Output (Driven)	Minimum increase	Reduction	Same as Input
Input (Drive)	Held	Output (Driven)	Reduction	Increase	Reverse of Input
Output (Driven)	Held	Input (Drive)	Increase	Reduction	Reverse of Input

CHART 127–2

If any two members are locked together, then the resulting output is 1:1 ratio in the same direction as the input (direct drive). If no member is held (locked) then there is no output (neutral).

FREQUENTLY ASKED QUESTION

What Companies Build Automatic Transmissions?

Many larger automobile manufacturers make their own automatic transmissions, including General Motors, Ford, Chrysler, and Honda. However, several companies manufacture automatic transmissions and transaxles that are used in a variety of vehicles. These include:

- **ZF Friedrichshafen AG.** This German company manufactures manual and automatic transmissions and transaxles for many vehicle manufacturers, including Mercedes, BMW, Volvo, VW, Audi, Jaguar, Chrysler, Bentley, and Maserati.
- **Aisin AW.** This Japanese company makes automatic transmissions for many vehicle manufacturers including Ford, Toyota, Nissan, Mazda, Mitsubishi, Subaru, Kia, and VW.
- **JATCO (Japan Automatic Transmission Company).** This is a Japanese manufacturer of automatic transmissions and transaxles for many vehicle manufacturers, including Nissan, Mazda, Infinity, VW, Mitsubishi, and Suzuki.

This combination is capable of providing three forward gears, as well as neutral and reverse. Basic operation, construction, and methods of obtaining various gear ratios with a simple planetary gear set also apply to the Simpson gear set. The main difference is the number of gear ratios that are available using more than one planetary gear set.

RAVIGNEAUX GEAR SET Another popular compound planetary design is the **Ravigneaux gear set.** The Ravigneaux system has the following:

- Two sun gears
- Two planet pinion sets, one longer than the other, supported in one carrier
- A single ring gear

SEE FIGURE 127–20.

This design provides four forward gears (two in reduction, one direct, and one overdrive) as well as neutral and reverse. Basic planetary gear set operation, construction, and control methods also apply to the Ravigneaux gear set. An overdrive ratio means the following:

- The output shaft is rotating faster (higher RPM) than the engine crankshaft.
- The ratio is always expressed to the relative ratio of the input shaft speed so that all overdrive ratios are less than 1. For example, 0.75:1 is an overdrive ratio meaning the output is rotating 25° faster than the input shaft speed.

FREQUENTLY ASKED QUESTION

What Do All the Letters and Numbers Mean in Transmission Designations?

The numbers and letters usually mean the following:

- **Number of forward speeds.** The number of forward speeds may include four, five, or six (such as GM 4T60-E four speed unit).
- **Front-wheel drive or rear-wheel drive.** The letter **T** usually means *transverse* (front-wheel-drive transaxle) such as the Chrysler 41-TE; the **L** means *longitudinal* (rear-wheel-drive transmission) such as the General Motors 6L80; and the **R** means *rear-wheel drive* such as the Ford 5R55E.
- **Electronically controlled.** The letter **E** is often used to indicate that the unit is electronically controlled, and **M** or **H** is used to designate older mechanically (hydraulically) controlled units. All automatic transmissions built since the early 1990s are electronically controlled; therefore, **E** is often included in the designation of newer designs of transmission or transaxles.
- **Torque rating.** The torque rating is usually designated by a number where the higher the number, the higher the amount of torque that the unit is designed to handle. In a GM 6L80-E the torque rating is 80.

Always check service information for the exact transmission designation for the vehicle being studied or serviced.

LAPELLETIER GEAR SET The **Lapelletier** (pronounced "la-plet-e-ay") **gear set** was invented by Pierre Lapelleties, a retired engineer who devised a unique way to create a simple and efficient six-speed automatic transmission gear set. It was first produced by ZF in 2002. The Lapelletier gear set is constructed by connecting a planetary gear set in front of a Ravigneaux gear set. Besides ZF, General Motors uses the Lapelletier gear set in the 6L45, 6L50, and 6L90 rear-wheel-drive transmissions and Ford uses it in the 6R60, 6R75, and 6R80 transmissions.

AUTOMATIC TRANSAXLES

TERMINOLOGY Automatic transaxles include a differential assembly as well as the planetary gear sets of an automatic transmission. The engine torque also needs to be transferred by the use of a chain or gears to provide a shorter overall length so it can be used with an engine mounted transversely in the engine compartment. Some use gears and others use a chain to transfer engine torque to either the planetary gear sets or to the differential (final drive) assembly. ● **SEE FIGURES 127–21 AND 127–22.**

A transaxle can be used in the following applications.

- Front engine, front wheel drive
- Rear engine, rear wheel drive
- Front engine, all wheel drive
- Mid engine rear wheel drive

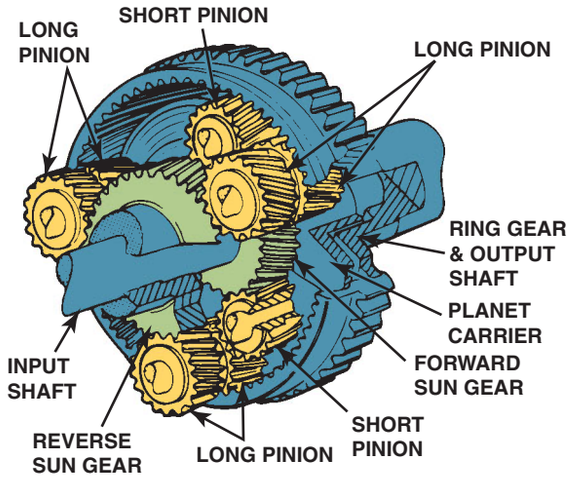


FIGURE 127–20 A Ravigneaux gear set is composed of two sun gears, one planet carrier that supports two sets of pinion gears, and a single ring gear.

FINAL DRIVE UNITS A transaxle includes a differential assembly, often called a *final drive* assembly as part of the transaxle. This final drive assembly connects the output from the gear sets to the drive axle shafts. The final drive assembly includes the side gears and pinions gears as well as the housing. ● **SEE FIGURE 127–23.**

NONPLANETARY GEAR AUTOMATIC TRANSAXLES

Honda and Saturn vehicles use an automatic transmission with no planetary gear sets. This type is similar to and uses many of the same parts as their manual transaxles. This design uses hydraulic clutches instead of synchronizers to make the shift between gears. By using the same parts as manual transaxles, this automatic transaxle has the following advantages.

1. It allows both manual and automatic transmissions to be manufactured in the same plant, therefore reducing cost.
2. By using many of the same parts for both manual and automatic transaxles, manufacturers see a cost reduction.
3. Honda automatic transaxles are diagnosed, and if an internal fault is detected, the entire assembly is replaced with a remanufactured unit. Honda dealership technicians do not repair automatic transaxles. ● **SEE FIGURE 127–24.**

CONTINUOUSLY VARIABLE TRANSMISSION

TERMINOLOGY A **continuously variable transmission (CVT)** is usually found on some front-wheel-drive vehicles that use a transaxle. Instead of using three or more gears, a continuously

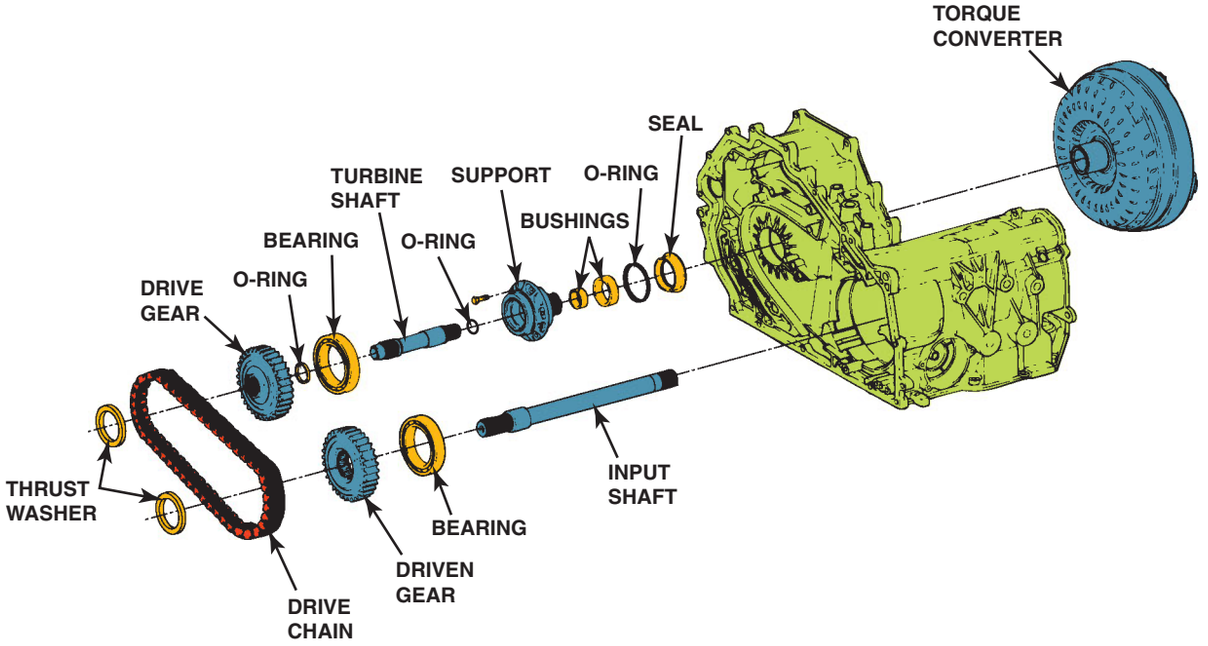


FIGURE 127–21 On one style of transaxle the turbine shaft drives the input shaft through a drive chain assembly.

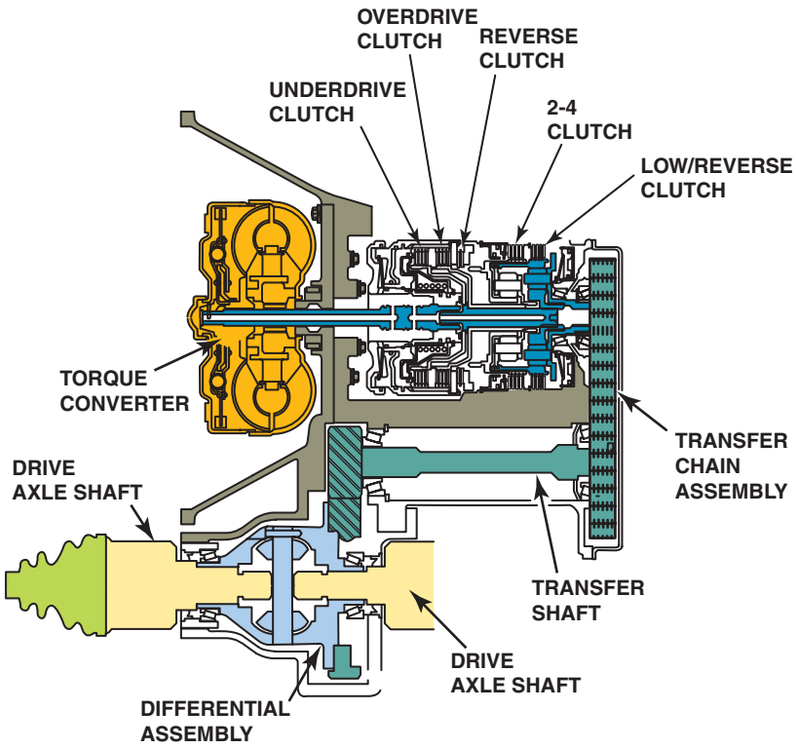


FIGURE 127–22 Another type of transaxle uses a chain to transfer engine torque from the output of the gear sets to the differential assembly (final drive).

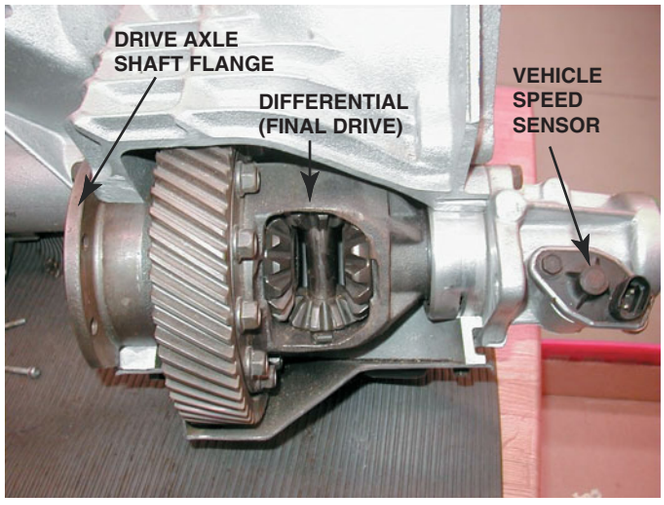


FIGURE 127–23 A cutaway showing the final drive assembly of a transaxle.

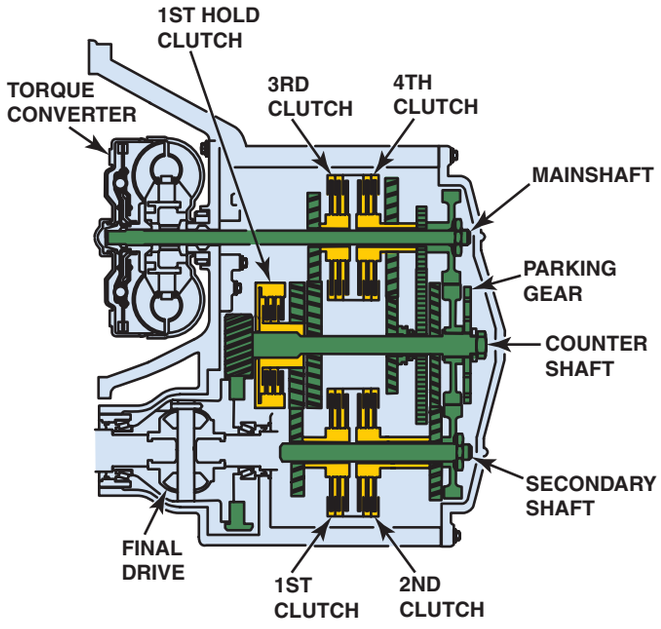


FIGURE 127–24 A Honda nonplanetary gear set type automatic transmission that uses helical cut gears instead of planetary gears. Hydraulically applied clutches as commanded by the PCM with fluid flow controlled by shift solenoids to make the shifts.

variable transmission uses two variable width pulleys, sometimes called *variators,* to change the gear ratio from about 2.5:1 to an overdrive ratio of 0.5:1. ● **SEE FIGURE 127–25.**

PURPOSE AND FUNCTION The purpose and function of a continuously variable transmission is to allow the engine to operate in a speed range where it is most efficient. Therefore, instead of causing the engine speed to vary as the transmission shifts gears, the engine speed is more constant as the pulleys change to increase the speed of the vehicle. The result of using a CVT is improved fuel economy and reduced exhaust emissions.

PARTS AND OPERATION The two pulleys are moved at the same time. One pulley is made smaller in diameter while at the same time the other pulley is enlarged. This change in pulley effective diameter allows the drive chain to move, thereby changing the ratio between the input and output pulleys. The chain is *pushed* rather than pulled through the pulleys and is made of hundreds of individual steel elements. ● **SEE FIGURE 127–26.**

The Honda CVT is constructed very similar to other electronically controlled transaxles, with the primary difference being the use of a belt-and-pulley system instead of multiple planetary gear sets or meshed helical gears.

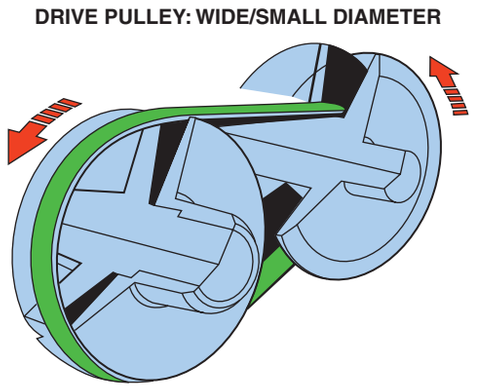


FIGURE 127–25 A belt and pulley CVT uses variable width pulleys and a special chain to provide an infinite number of speed ratios.

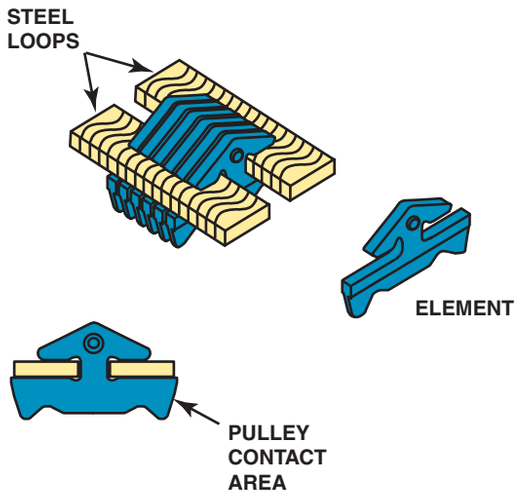


FIGURE 127–26 Honda CVT belt construction.

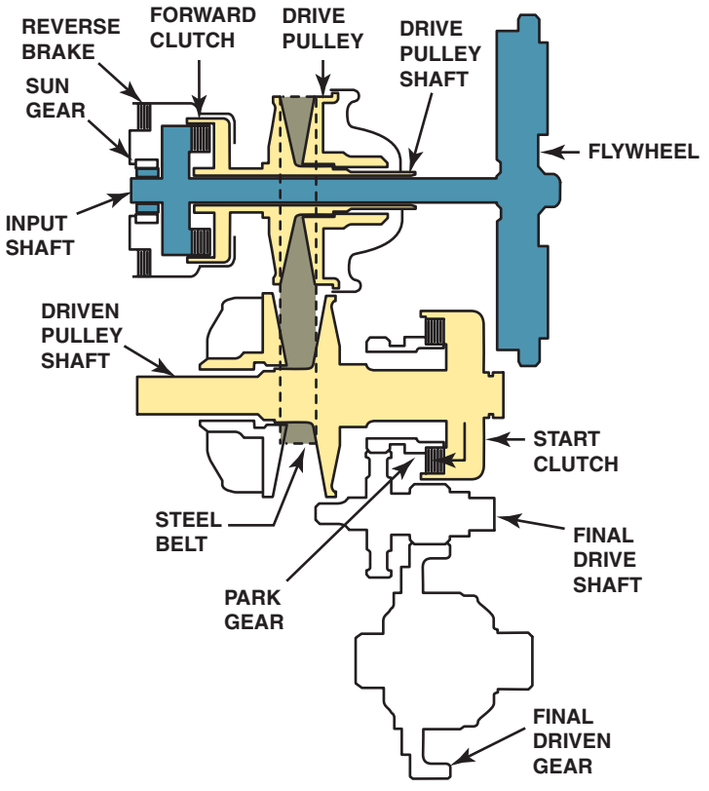


FIGURE 127–27 Honda CVT power flow in park (P) and neutral (N).

The transmission has a total of four parallel shafts:

- Input shaft
- Drive pulley shaft
- Driven pulley shaft
- Secondary gear shaft

The secondary gear shaft is comprised of the secondary driven gear and the final drive gear. The final drive gear is meshed with the final driven gear, which is attached to a conventional open differential assembly. When the transmission is placed in park, the parking pawl interlocks with the park gear, which then holds the secondary drive gear stationary. ● **SEE FIGURE 127–27.**

HONDA CVT OPERATION

The Honda CVT is used as part of the hybrid system on some Honda vehicles. The pulleys used in this CVT design can vary their width by varying the hydraulic pressure applied to them. Each pulley has a movable face and a fixed face. The movable face for each pulley is attached to a piston that has hydraulic control pressure applied to it.

- Higher application pressure on the movable face causes the pulley to become narrow, which makes the steel belt ride closer to the outside diameter of the pulley.
- A lower application pressure will allow the pulley to become wider and the belt to ride closer to the pulley's axis. If a low hydraulic pressure is applied to the drive pulley and a high hydraulic pressure is applied to the driven pulley, a low speed ratio is achieved.
- As the vehicle speed increases, the drive pulley will have progressively higher pressure applied to it, while the driven pulley application pressure is lowered. This results in a higher speed ratio, allowing the engine to operate at a lower RPM. See Figure 127–25.

There are three multiple-disc clutches used in the internal gear train, one for each of the following:

- Forward clutch
- Reverse brake
- Start clutch

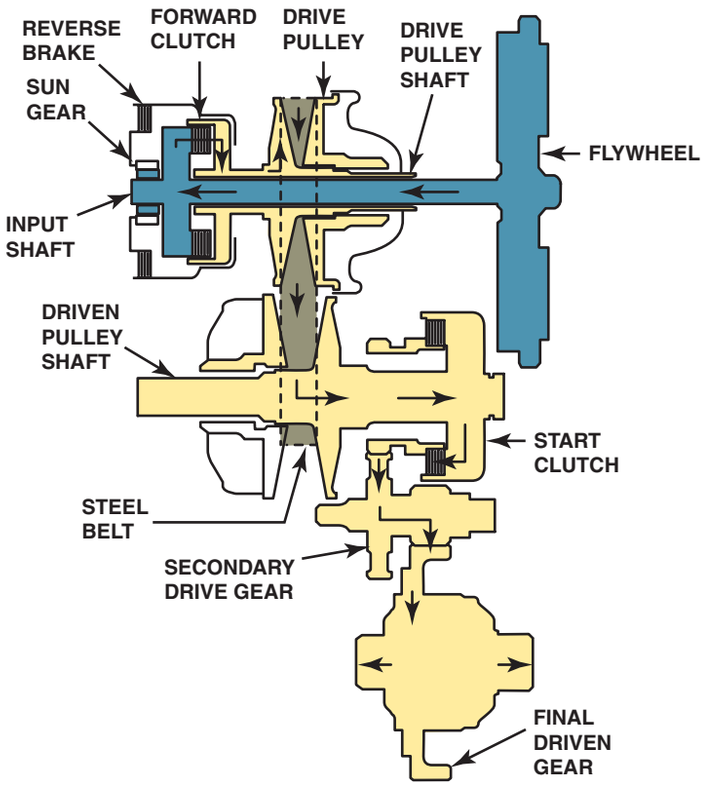


FIGURE 127–28 Honda CVT operation in drive (D) or low (L).

In the Honda Civic CVT, a start clutch is used instead of a torque converter which slips when the vehicle is stopped with the engine running. ● **SEE FIGURE 127–28.**

In park (P) or neutral (N), none of the clutches have hydraulic pressure applied to them, which prevents engine torque from being applied to the drive pulley shaft.

The forward clutch and the start clutch are in operation whenever the transmission is placed in a forward gear position (D or L). ● **SEE FIGURE 127–29.**

The start clutch has multiple responsibilities, including:

1. The start clutch is engaged whenever the vehicle is moving, either in forward or reverse.
2. It helps the vehicle accelerate from a standstill by slipping and then fully engaging once the vehicle is moving, similar to a manually operated clutch.

The Honda CVT, like any other automatic transmission, uses hydraulic pressure to perform its various functions. The belt drive, the multiple-disc clutches, and the control system would all stop functioning without hydraulic pressure. This pressure is supplied by a chain-driven pump that is driven by the transmission input shaft. Since the input shaft is driven directly by the internal combustion engine (ICE), hydraulic pressure is only present when the ICE is running. Automatic transmission fluid (ATF) is held in a pan that is bolted to the bottom of the transmission case. The ATF pump draws fluid through a strainer that is located in the pan, and sends this fluid on to the system through a pressure regulator valve.

NOTE: Some vehicles equipped with a continuously variable transmission (CVT) have shifter paddles on the steering wheel or a manual shift mode on the gear selector. When using these paddles to upshift or downshift, the transmission control module selects preprogrammed ratios, which give the driver a sense that it is actively shifting gears.

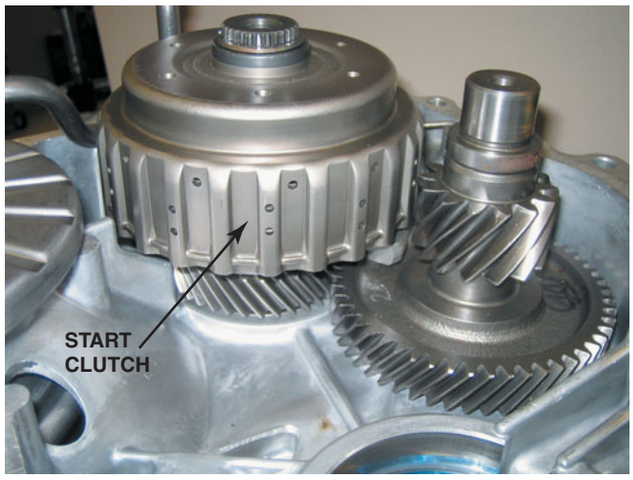


FIGURE 127–29 Location of the Honda CVT start clutch.

? FREQUENTLY ASKED QUESTION

What Is It Like to Drive a Vehicle Equipped with CVT?

For most, driving a vehicle equipped with a continuously variable transmission (CVT) is the same as driving the vehicle equipped with a conventional automatic transmission/transaxle. The vehicle creeps slightly when the brake is released and the vehicle accelerates normally when the throttle is opened. Because no shifts occur, the first thing the driver and passenger notice is that it is very smooth. If the vehicle is equipped with a tachometer, the driver may notice that the engine speed increases when first accelerating and often remains higher until the vehicle speed increases. During periods of rapid acceleration, the engine speed may be close to its maximum and thereby create noise and vibration often not experienced in a similar vehicle. However, the fuel economy savings of a CVT compared to a conventional automatic transmission makes the slight difference a reasonable trade-off.

SERVICING A CVT TRANSMISSION

The Honda CVT can be pressure tested and stall tested just like any other automatic transaxle when diagnosing transmission malfunctions. These tests must be performed according to manufacturer-approved procedures, and test results compared to charts published by the manufacturer.

One service item that is unique and very important is the *start clutch calibration.* This procedure must be performed whenever any of the following vehicle components is replaced or removed.

1. Battery
2. Backup fuse
3. Transmission control module (TCM)
4. Transmission assembly
5. Lower valve body assembly
6. Engine assembly replacement or overhaul

Details for performing these procedures can be found in Honda service information. The purpose of the procedure is to allow the TCM to memorize the feedback signal for the start clutch control. Malfunctions in the start clutch control system can occur if this procedure is not performed at the appropriate times. ● **SEE FIGURE 127–30.**

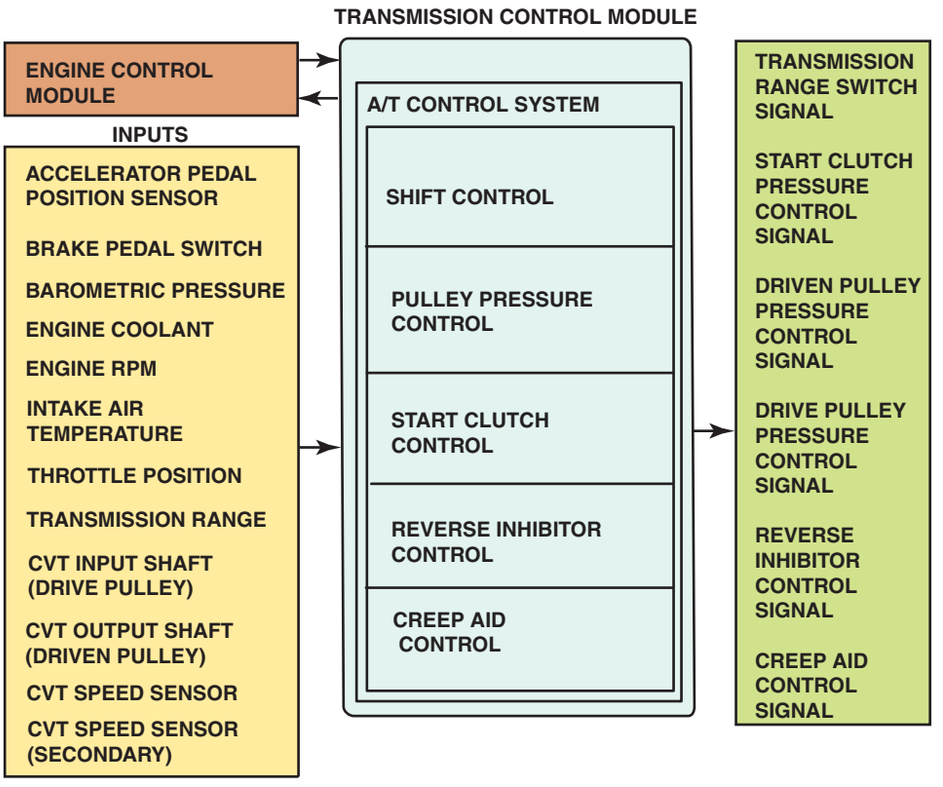


FIGURE 127–30 The Honda CVT transmission control module (TCM) showing the inputs (sensors) on the left and the outputs on the right.

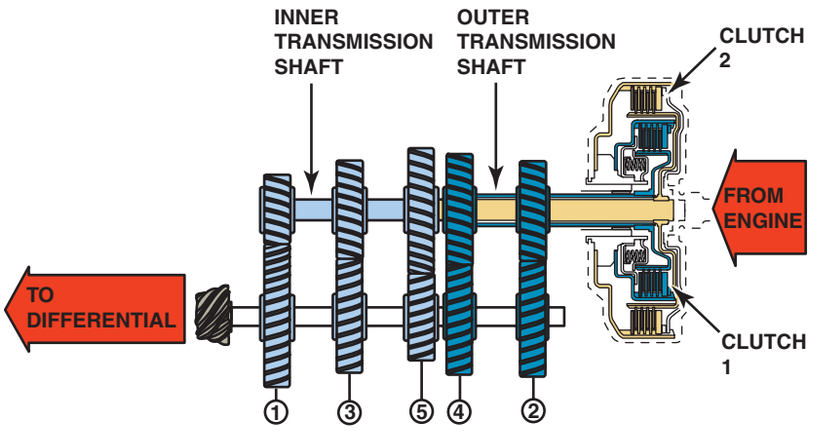


FIGURE 127–31 A dual clutch automatic uses the best features of an automatic transmission without the power loss of a torque converter.

Fluid level checks are performed with the vehicle sitting level, transmission up to the operating temperature, but with the *engine turned off.* A dipstick is used to check the level, and fluid may be poured into the dipstick pipe to bring the level up if it is low. Be sure to use only manufacturer-specified fluids when topping up or replacing transmission fluids.

DUAL CLUTCH AUTOMATIC TRANSMISSIONS

PURPOSE AND FUNCTION A dual clutch automatic transmission or transaxle uses a manual-type transmission and two clutches that engage either the main input shaft or the counter shaft to achieve the following goals, compared to a conventional automatic transmission or transaxle equipped with a torque converter and planetary gear sets.

1. Improve the fuel economy.
2. Reduce the cost of the assembly by using manual transmission components.
3. Improve the speed of the gear changes.
4. Provide smoother operation.

PARTS AND OPERATION

- A dual clutch automatic transmission uses two clutches that are mounted together concentrically. The larger clutch drives the odd number gears (first, third, fifth, and seventh).
- The smaller clutch drives the even number gears (second, fourth, and sixth). ● **SEE FIGURE 127–31.**

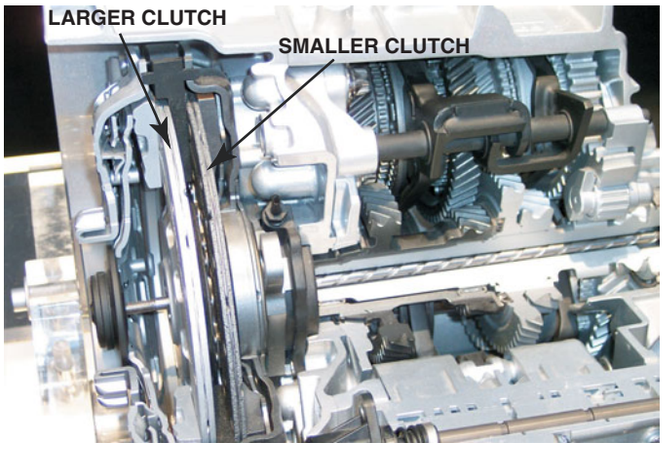


FIGURE 127–32 Dual clutch automatic transaxles that use two dry clutches. The larger clutch drives the odd number gear ratios (first, third, and fifth) and the smaller clutch drives the even numbered gear ratios (second, fourth, and sixth).

The shifts occur without interrupting the torque from the engine by applying torque to the clutch while at the same time disconnecting the other clutch. These actions result in a rapid shift without the slight delay usually associated with an automatic transmission.

There are two types of clutches used depending on application.

1. Dual dry clutches are used in low powered vehicles such as small front-wheel-drive vehicles. ● **SEE FIGURE 127–32**.
2. Dual wet clutches are often used in higher powered vehicles.

Vehicles that use a dual clutch automatic-type transmission include certain models of Audi, Nissan, Mercedes, BMW, Porsche, Ford, Ferrari, VW, and Mitsubishi.

ADVANTAGES The advantages of a dual clutch automatic transmission compared to a conventional automatic transmission include:

1. Quicker throttle response
2. No drop in engine speed when the driver releases the throttle
3. Instant gear changes
4. Improved fuel economy

DISADVANTAGES The disadvantages of a dual clutch automatic transmission compared to a conventional or continuously variable automatic transmissions include:

1. No torque multiplication advantage of a torque converter
2. Not as fuel efficient as a continuously variable (CV) transmission or transaxle

REVIEW QUESTIONS

1. How can torque converters double engine torque?
2. What are the three members of a planetary gear set?
3. How can various gear ratios and reverse be obtained by using a compound planetary gear set?
4. How does a continuously variable transmission provide variable ratios?
5. How does a dual clutch automatic transmission shift gears?

CHAPTER QUIZ

1. Two technicians are discussing automatic transmissions/transaxles. Technician A says that it is normal for a vehicle to move slightly when the gear selector is in the drive position with the brakes released. Technician B says that the stator may be defective if the vehicle moves while in gear when the engine is at idle speed. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
2. Technician A says that a five-speed automatic transmission will often use a compound planetary gear set. Technician B says that the torque converter clutch is often pulsed on and off to provide smooth engagement. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. Technician A says that a held member is also called the reaction member. Technician B says that if any two elements are locked together then the output will be 1:1. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. Technician A says that all dual clutch automatic transmissions use two dry clutches. Technician B says that some automatic transmissions do not use planetary gear sets. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
5. Technician A says that when an automatic transmission/transaxle shifts into overdrive, the output shaft is rotating faster (higher RPM) than the engine crankshaft. Technician B says that an overdrive ratio is a ratio where the first number is less than 1. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. Technician A says that one planetary gear set can provide gear reduction, overdrive, and reverse. Technician B says that most transmissions today use compound (multiple) planetary gear sets. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B

7. Using a torque converter smaller than stock size could result in _____.
   a. Slower than normal acceleration
   b. Faster than normal acceleration
   c. Reduced fuel economy
   d. Both b and c
8. Which compound planetary gear set is commonly used in six-speed transmissions?
   a. Simple gear set
   b. Simpson gear set
   c. Ravigneaux gear set
   d. Lapelletier gear set
9. Which compound gear set uses a planetary gear set in front of a Ravigneaux gear set?
   a. Simple gear set
   b. Simpson gear set
   c. Ravigneaux gear set
   d. Lapelletier gear set
10. How much is engine torque increased or multiplied when a typical torque converter is at stall speed?
   a. Double
   b. Four times
   c. Eight times
   d. Ten times

chapter 128

HYDRAULIC COMPONENTS AND CONTROL SYSTEMS

OBJECTIVES: **After studying Chapter 128, the reader will be able to:** • List the various types of automatic transmission fluids. • Explain how automatic transmission fluid is circulated through the system and how it is cooled. • Describe how a transmission cooler works. • Describe how clutch packs and bands work. • Discuss one-way clutches and how they are used. • Explain how shifts are controlled in an electronically controlled automatic transmission/transaxle. • Discuss how accumulators work. • Explain the difference between on and off solenoids compared to linear solenoids. • Explain the power flow through a typical automatic transmission.

KEY TERMS: Apply devices 1571 • Automatic transmission fluid (ATF) 1567 • Balance valve 1570 • Check balls 1577 • Clutch drum 1573 • Clutch pack 1572 • Default gear 1581 • Electronic pressure control 1570 • Force motors 1570 • Governor valve 1578 • Holding devices 1571 • Integral accumulator 1575 • Limp-in gear 1581 • Lube oil 1569 • Manual valve 1577 • Multiple-plate clutch 1572 • One-way clutch 1575 • One-way clutch 1575 • One-way valve 1576 • Pressure control 1570 • Pressure control solenoids 1570 • Pressure plate 1573 • Pressure regulator valve 1569 • Reaction member 1577 • Separator plate 1576 • Servo 1572 • Shift valve 1579 • Sprags 1575 • Transmission band 1571 • Valve body 1576 • Variable force solenoids (VFS) 1570 • Worm holes 1576 • Worm tracks 1576

AUTOMATIC TRANSMISSION FLUID

PURPOSE AND FUNCTION

Automatic transmission fluid (ATF) is highly refined oil with a viscosity similar to SAE 20W-20 oil, and is specially designed for use in an automatic transmission. Newer ATFs are lower in viscosity and are similar to SAE 0W-10 oil. Purposes and functions of ATF are as follows:

- Transfers power in torque converter
- Provides hydraulic pressure in clutches and servos
- Lubricates bearings, bushings, and gears
- Transfers heat to cool transmission parts
- Provides the correct friction for clutch and band application
- Acts as the medium to control transmission shifting by traveling through passageways, acting on valves, and being directed by solenoids

TYPES

The three basic types of ATF include:

1. **Non-friction modified.** The first ATF did not have friction reducing additives. This type of fluid was used in early band-type automatics (all first generation). Type F ATF is an example of a non-friction-modified ATF.
2. **Friction modified.** Friction-modified ATF types include Dexron.
3. **Highly friction modified.** All current original equipment manufacturers use automatic transmission fluids that are highly friction modified. These include Dexron VI, Mercon V, ATF + 4, and ATF WS. Friction modifiers add to the ATF, and along with hydraulic (orifices and accumulators) devices and electronic controls help produce "proper shift quality."

TYPICAL ATF APPLICATIONS

Automatic transmission fluid is formulated to work in specific transmissions. Using the specified fluid is the key to proper operation. ● **SEE CHART 128–1** for examples of the types and applications of selected vehicles and fluids.

GENERAL MOTORS	DESCRIPTION
Type A	1949
Type A, Suffice A	1957 (friction modified)
Dexron	1967 (lower viscosity)
Dexron II	1978 (lower viscosity)
Dexron II-E	1990 (improved low temperature fluidity)
Dexron III	1993–2005 (improved low temperature fluidity)
Dexron VI	2005 (improved viscosity stability)

FORD/JAGUAR	DESCRIPTION
Type F	1967 (non-friction modified; designed for older band-type automatic transmissions)
Mercon	1987 (friction modified)
Mercon V	1997 (highly friction modified)
Mercon SP	Used in the Ford six speeds such as the 6R60 6HP 26 and also the 2003 and up Torque Shift
Idemitsu K-17	Jaguar X-type

CHRYSLER	DESCRIPTION
Chrysler 7176	Designed for front-wheel-drive transaxles
ATF + 2	1997 (improved cold temperature flow)
ATF + 3	1997 (designed for four-speed automatics)
ATF + 4	Used in most 20000 and newer Chrysler vehicles

HONDA/TOYOTA	DESCRIPTION
Honda Z-1	For use in all Honda automatic transaxles
Toyota Type III	Specific vehicles and years
Toyota Type IV	Specific vehicles and years
Toyota WS	Lower viscosity than Type IV; used in specific vehicles and years

MAZDA/NISSAN/SUBARU	DESCRIPTION
Mazda ATF-III	Specific vehicles and years
Mazda ATF-MV	Specific vehicles and years
Nissan Matic D	Specific vehicles and years
Nissan Matic J	Specific vehicles and years
Nissan Matic K	Specific vehicles and years
Subaru ATF	Specific vehicles and years
Subaru ATF-HP	Specific vehicles and years

AUDI/BMW/MERCEDES/ VOLVO	DESCRIPTION
Audi G-052-025-A2	Specific vehicles and years
Audi G-052-162-A1	Specific vehicles and years
BMW LA2634	Specific vehicles and years
BMW LT1141	Lifetime fill (BMW warns to not use any other type of fluid)
Mercedes 236.1	Specific vehicles and years
Mercedes 236.2	Specific vehicles and years
Mercedes 236.5	Specific vehicles and years
Mercedes 236.6	Specific vehicles and years
Mercedes 236.7	Specific vehicles and years
Mercedes 236.9	Specific vehicles and years
Mercedes 236.10	Specific vehicles and years
Volvo 97340	Specific vehicles and years
Volvo JWS 3309	Specific vehicles and years

MITSUBISHI/HYUNDAI/KIA	DESCRIPTION
Diamond SP II	Specific vehicles and years
Diamond SP III	Specific vehicles and years

CHART 128–1

Selected samples of automatic transmission fluid and some applications. Always check service information for proper specified fluid when servicing any automatic transmissions/transaxles.

AUTOMATIC TRANSMISSION FLUID COOLER

PURPOSE AND FUNCTION The torque converter generates a great amount of heat because of fluid shear as its internal elements spin at different speeds in relation to each other. The greatest amount of heat is generated when the vehicle is operating under a heavy load and the torque converter clutch is disengaged. The ATF can reach high temperatures (over 250°F [120°C]) very quickly, which is why an automatic transmission fluid cooler is used. Most vehicles use a small section of the engine cooling system radiator to transfer heat from the ATF to the coolant, which cools the ATF.

PARTS AND OPERATION Automatic transmissions/transaxles use a pump to circulate ATF and to provide the necessary hydraulic flow to operate the hydraulic components of the unit. The ATF is pumped (directed) from the torque converter (greatest source of heat) to the cooler when the torque converter clutch is not applied. The ATF flows through the cooler which has the following characteristics.

- It is a separate section of the radiator tank.
- The hotter transmission fluid gives up heat to the cooler engine coolant.
- Some manufacturers use a *cooler bypass valve* that will allow fluid to bypass the cooler if restricted. Some vehicles also use a temperature controlled valve to block the flow of fluid during low temperature operation such as is used in Dodge (Ram) trucks.
- Many vehicles with towing packages use a larger cooler or a combination of a liquid-to-liquid and a liquid-to-air cooler in series with each other to handle the extra heat load of towing.

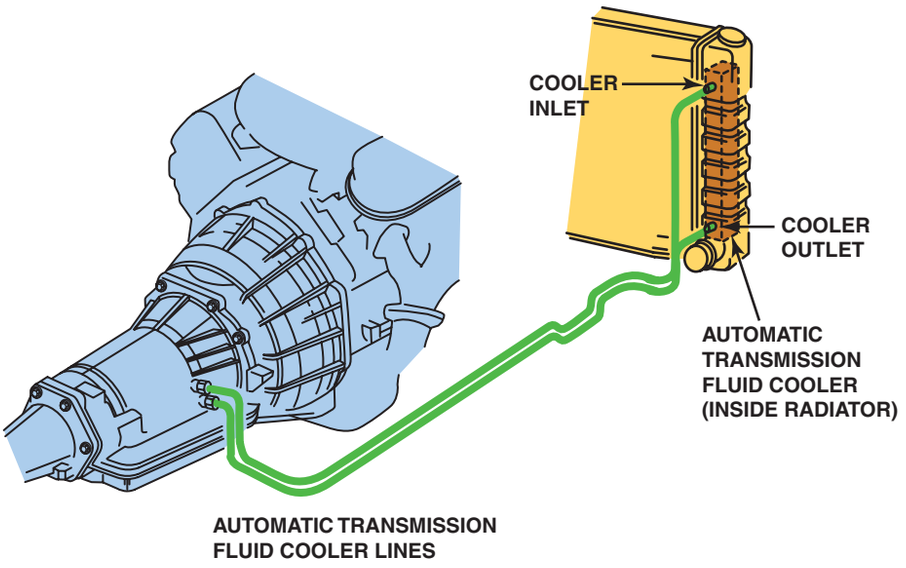


FIGURE 128–1 Automatic transmission fluid is routed from the torque converter, where most of the heat is generated, to the radiator where it is cooled. The fluid then returns to the transmission/transaxle to lubricate the bearings and bushings.

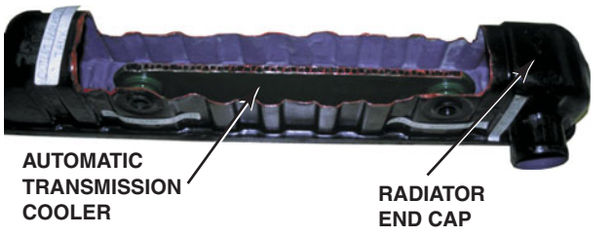


FIGURE 128–2 A cutaway of a typical radiator showing the automatic transmission cooler. The heat from the automatic transmission fluid is released to the engine coolant. The engine coolant also warms the fluid as soon as the coolant flows through the radiator.

The ATF returns to the transmission/transaxle to passages that lubricate the internal moving parts. This returned fluid is called **lube oil.** ● **SEE FIGURES 128–1 AND 128–2.**

CAUTION: Because the lube oil uses the ATF flowing from the cooler, if there is a blockage in the cooler, the transmission/transaxle may not have enough fluid flow to properly cool or lubricate the bearings and bushings inside the unit, leading to wear and eventually premature failure.

TRANSMISSION FLUID HEATER The cooler is located in the radiator in most vehicles and, as a result, the coolant will also warm the ATF when the temperatures are cold. Some vehicles are equipped with a transmission fluid heater that uses the coolant to warm the fluid when it is cold. Warm fluid works better than cold fluid to lubricate moving parts inside the unit. ● **SEE FIGURE 128–3.**

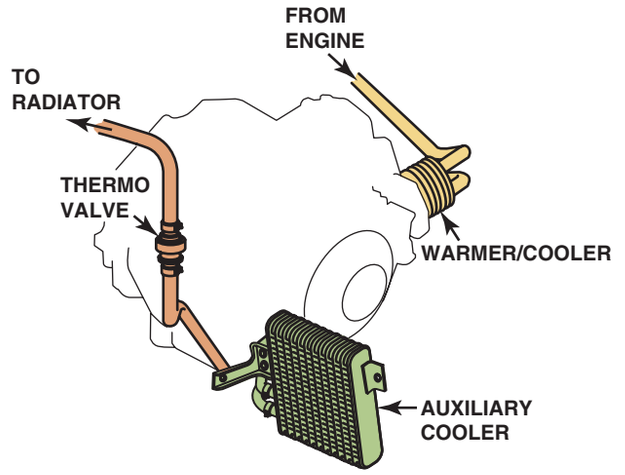


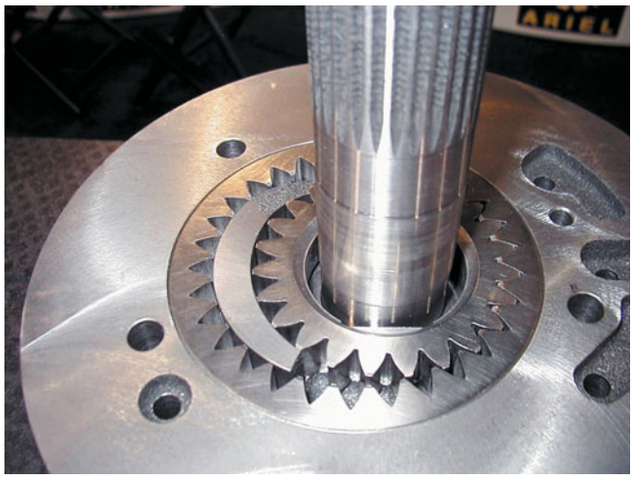
FIGURE 128–3 Engine coolant from the engine block flows through the passages in the cooler /warmer, and then out through the thermo valve to the upper radiator tank. The thermo valve uses a wax element–type valve to control the flow of engine coolant through the case-mounted cooler/warmer. The thermo valve improves the ATF warm-up times and maintains ATF temperature within the optimum operating range between 170° and 190°F (77° and 88°C).

PUMP

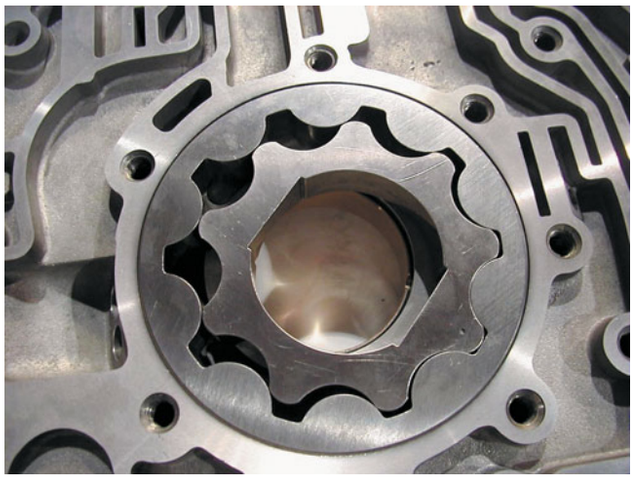
PURPOSE AND FUNCTION Every hydraulic system requires a *pump* to supply fluid flow and to pressurize the system. However, the pump itself does not develop pressure but instead pressure occurs when there is a resistance to flow. Initially, fluid flows freely when a hydraulic circuit is empty or partially filled. Once the circuit is completely full, there is a resistance to further flow. At this point, pressure begins to build up in the circuit as the pump continues to create flow.

PARTS AND OPERATION Most oil pumps mount directly behind the torque converter and are usually driven by the converter drive hub. This connects the pump to the engine and allows it to respond quickly to engine demand. This type of oil pump operates whenever the engine is running. ● **SEE FIGURE 128–4.**

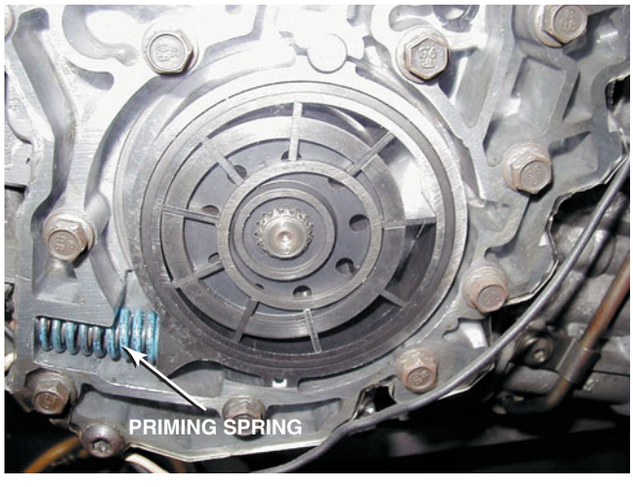
PRESSURE REGULATION Transmission oil pumps are capable of creating an excessive amount of pressure quickly; therefore, every transmission uses a **pressure regulator valve,** or *pressure control valve,* to control hydraulic pressure. This is usually a spool



(a)



(b)



(c)

FIGURE 128–4 (a) Gear-type pump. (b) Geroter-type pump. (c) Vane-type pump.

valve and spring combination. This regulated pressure, commonly known as *mainline pressure,* is the working pressure for the entire hydraulic system. Most pressure regulator valves balance pump pressure on one side of the valve against a preset spring force acting on the other side of the valve.

When hydraulic pressure is greater than the spring force, the valve moves in its bore far enough to uncover an exhaust port. ● **SEE FIGURE 128–5.**

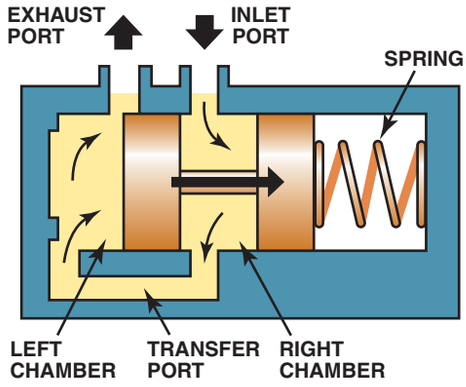


FIGURE 128–5 When pressure on the face of the pressure regulator valve overcomes spring force, the valve moves to open the exhaust port.

The exhaust port provides a low-pressure path to the transmission oil pan (sump) where excess ATF is stored. Excess pressurized fluid flowing through this port reduces system pressure. When hydraulic pressure drops below spring pressure, the regulator valve closes the port and pressure begins to build up again.

In operation, the opening and closing of the exhaust port occurs many times per second. This sequence of events achieves a steady pressure as the valve balances both the spring pressure and the hydraulic pressure. Because of this action, this type of valve is sometimes called a **balance valve.**

VARIABLE DISPLACEMENT PUMP

Many newer automatic transmissions and transaxles use a variable displacement pump to reduce the power needed to achieve fluid pressure to the amount required instead of being based on pressure alone. The use of a variable displacement pump helps improve fuel economy and reduce exhaust emissions. ● **SEE FIGURE 128–6.**

ELECTRONIC PRESSURE REGULATION

Electronic automatic transmissions/transaxles often regulate hydraulic system pressure using computer-controlled solenoids called any of the following:

- **Pressure control solenoids (PCS)**
- **Electronic pressure control (EPC)**
- **Pressure control (PC)**
- **Variable force solenoids (VFS)**
- **Force motors**

An onboard computer switches the solenoids on and off very quickly using pulse-width modulation (PWM). The solenoid pushes against an internal valve which opens and closes the hydraulic circuit it regulates. Electronic pressure control allows precise hydraulic system pressure regulation and can also be used to modify the timing and feel of transmission shifting. ● **SEE FIGURE 128–7.**

TYPICAL PRESSURES

Line pressure is controlled by the powertrain control module (PCM) or the transmission control module (TCM) to provide the specific pressure needed by the system based on input from the sensors such as vehicle speed and engine load. Line pressure is reduced to improve fuel economy because lowering pressure reduces draw on the engine which is driving the pump.

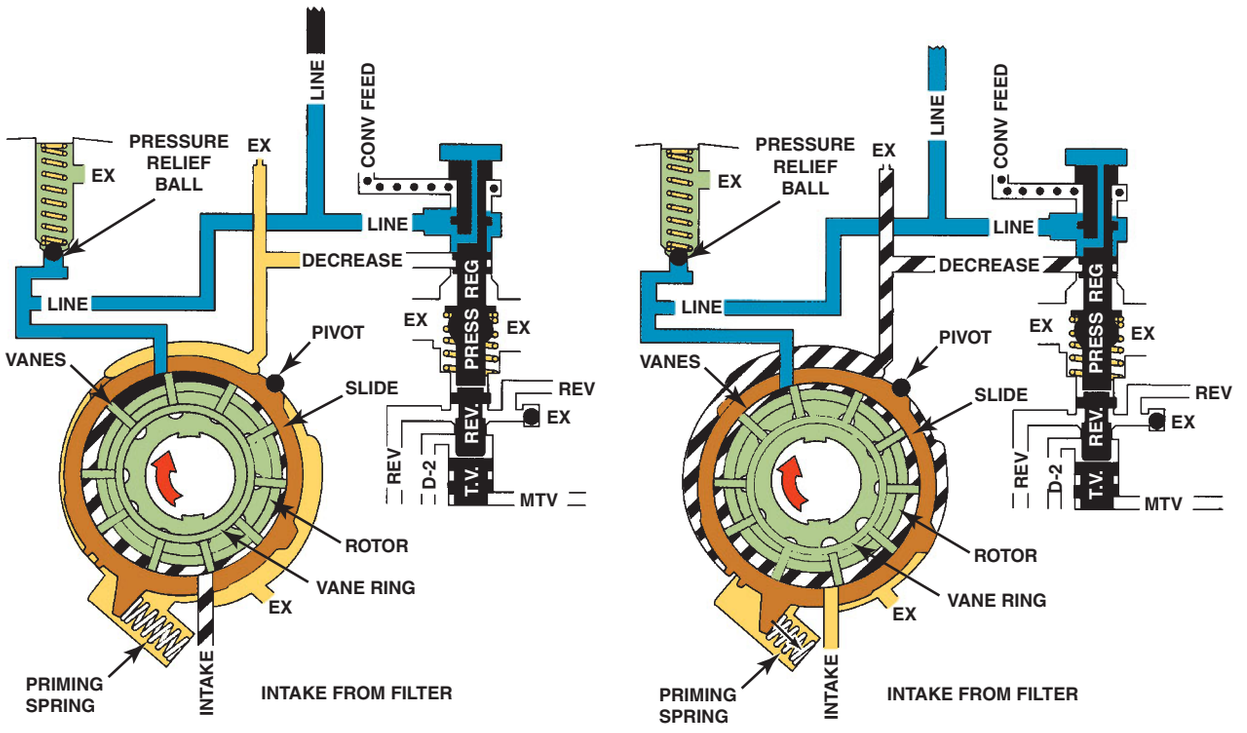


FIGURE 128–6 The variable pump is at the maximum output position until the regulator valve moves enough to decrease volume by rotating the slide against the force of the priming spring. The position of the pump constantly varies depending on the needs of the transmission/transaxle and the driving conditions.

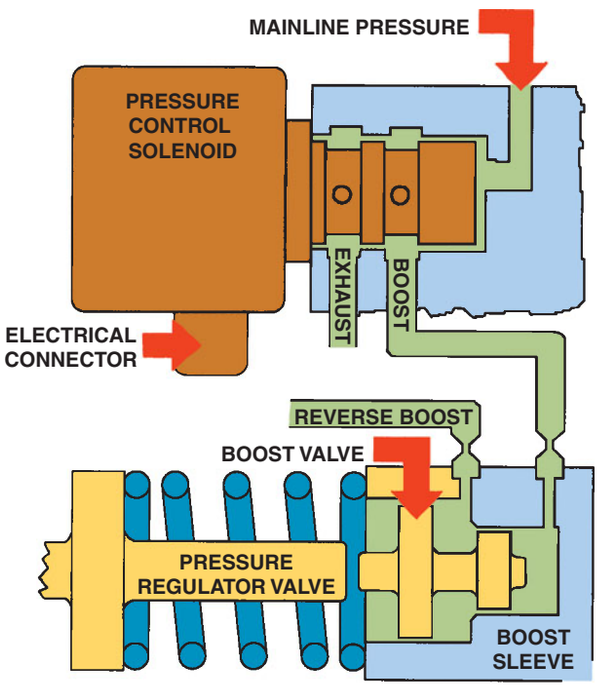


FIGURE 128–7 The pressure control solenoid controls the mainline pressure, which is in turn controlled by the powertrain control module (PCM) or the transmission control module (TCM), by applying pressure to the spring side of the pressure regulator valve.

Typical line pressures include:

- Normal line pressure = 60 to 120 PSI (414 to 830 kPa)
- The accelerator pedal pressed to wide open throttle (WOT) = 90 to 150 PSI (620 to 1,034 kPa)
- The gear selector in reverse or manual low (1) = 150 to 300 PSI (1,034 to 2,068 kPa)

Higher pressures are necessary in reverse because these apply devices are usually smaller and or have fewer clutch plates to ensure that the clutches are firmly applied, in order to avoid slippage when the engine is producing maximum torque.

APPLY OR HOLDING DEVICES

PURPOSE AND FUNCTION **Apply devices** or **holding devices** are the mechanical or hydraulic assemblies that provide the force to hold or drive members of a planetary gear set. Automatic transmissions typically use the following as apply devices.

- Transmission bands
- Multiple-plate clutches
- One-way clutches

BANDS

TERMINOLOGY Transmission bands are holding (braking) devices. The planetary gear set member held is known as a **reaction member.** A **transmission band** stops and holds one planetary gear set member so that another member can react against the held member and develop output motion. The reaction member has a control surface for the band to ride on, known as a drum. The band directly affects the drum, and the drum directly affects the planetary gear set member. ● **SEE FIGURE 128–8.**

The band provides a holding force around the outside of the drum, closing tightly to keep it from turning. To repeat, a transmission

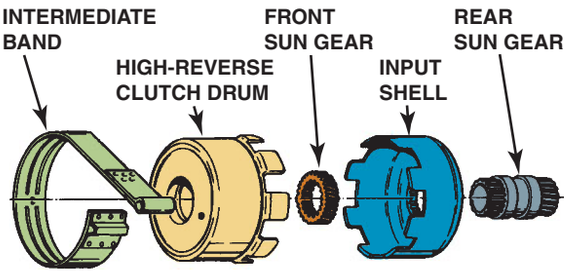


FIGURE 128–8 Gear set members are attached to a drum and are held stationary when the band applies.

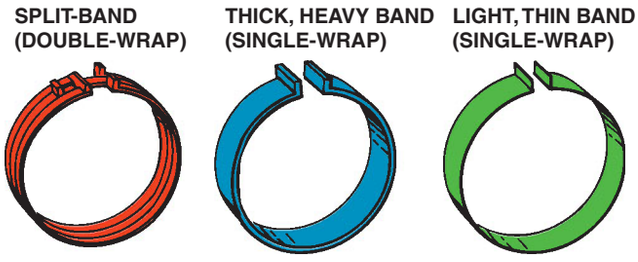


FIGURE 128–9 Transmission bands come in several designs and thicknesses.

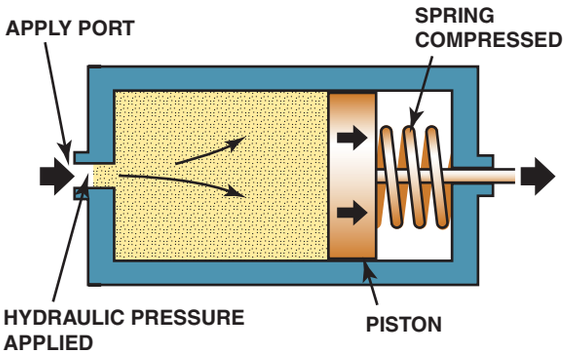


FIGURE 128–10 A servo uses hydraulic pressure to move a piston, which applies a band.

band is a holding device and is not capable of driving any member of the planetary gear set.

Transmission bands are made of cast iron or steel with friction material lining on the inside surface. Transmission design and component size dictate the type and size of band used. Bands fall into one of two categories:

- Single wrap
- Double wrap

The single-wrap band is a simple one-piece design, while the double-wrap band is a split band with overlapping ends. Bands may also be classified as either flexible or fixed, depending on how well they hold their shape when they are off the drum. ● **SEE FIGURE 128–9.**

HYDRAULIC SERVOS

A band is applied by using a hydraulically operated piston that travels inside a machined cylinder bore. This piston and cylinder assembly is known as a **servo.** ● **SEE FIGURE 128–10.**

A piston return spring normally holds the servo piston in its unapplied position. To apply the band, hydraulic fluid, under pressure,

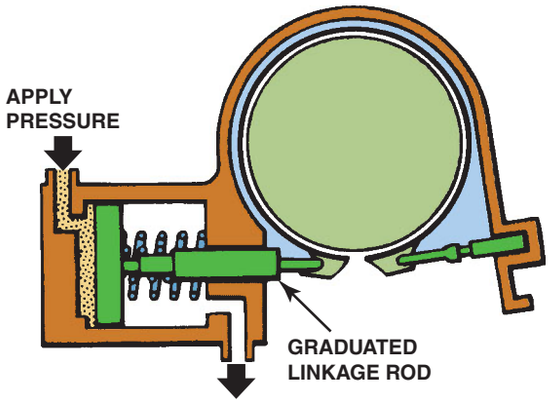


FIGURE 128–11 One end of a band is held stationary and the other end is attached to the servo.

enters the servo cylinder and acts on the piston. The piston begins moving once hydraulic pressure overcomes spring force.

SERVO LINKAGES

A mechanical rod, called a *strut,* and linkage attaches to the piston and connects it to the band. As the piston moves, the linkage applies the band by tightening it around the drum. Servo *rods* and *struts* transfer the servo apply force to the transmission band. Rods are round metal bars and struts are flat metal plates. These may be used at either or both ends of the band. Linkages connect the band to the servo or an anchor. One end of a band is often anchored to the transmission case and whenever the band is applied, the drum that the band wraps around is held from rotating. ● **SEE FIGURE 128–11.**

NOTE: Some bands have a provision for adjustment and may be adjusted in vehicle while others are adjusted or set during transmission assembly.

MULTIPLE-PLATE CLUTCHES

TERMINOLOGY

Like a transmission band, a multiple-plate hydraulic clutch is a type of apply device. Clutches have more friction area so they can develop more force and handle more torque than a band, and they are self-adjusting.

PARTS

The **multiple-plate clutch** consists of plates, a piston, drum (retainer), and snap ring. Hydraulic pressure acts upon the clutch piston which moves in the drum. The piston movement compresses the plates together to provide either a holding or driving function. When the pressure is released, the piston returns to an unapplied position via a return spring assembly. The entire assembly is commonly known as a **clutch pack.** ● **SEE FIGURE 128–12.**

The plates of a multiple-plate clutch assembly consist of a friction plate alternated with steel plates.

- A friction plate, also called simply a *friction,* has a rough surface friction material applied to both faces. The friction (clutch lining) material is made from a mixture of natural and man-made fiber. Natural fibers include cotton or wood (paper), and man-made fibers are aramid (Kevlar®) or carbon. The exact mixture is determined by the transmission engineer to provide the desired heat resistance and durability standards.

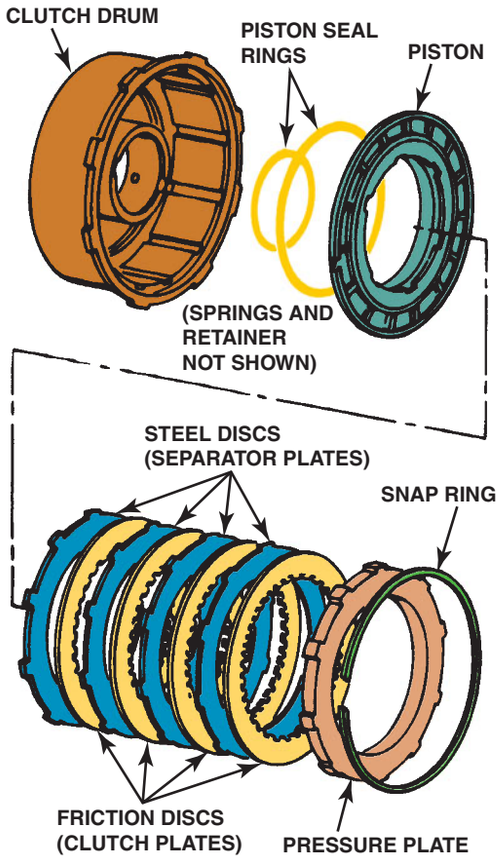


FIGURE 128–12 An exploded view of a multiple-plate clutch pack assembly.

- A steel plate, also called simply a *separator plate* or *steel,* has a smooth, flat surface finish with no friction material.
- Some transmissions may not have separate frictions and steels but rather combine them. One side of the plate will be coated with the frictional surface while the other side is flat metal like the steels.
- Collectively, the friction and steel plates are called clutch plates.

Generally, the steel plates have splines on their outer edge, while the friction plates have splines on their inner edge. Each set of splines engages matching splines on a:

- Shaft
- Drum
- Planetary gear set member or
- Transmission case

The piston compresses the clutch plates against a thicker reaction plate known as the **pressure plate.** Pressure plates may be used at one or both ends of the clutch pack and are available in selective (specific) sizes for adjusting clutch pack clearance. The pressure plate and clutch assembly components fit into either a **clutch drum** (retainer) or a machined bore in the transmission case. Snap rings retain all the clutch assembly components and are available in selective (specific) sizes for adjusting clearance. ● **SEE FIGURE 128–13.**

Some transmissions use a special wave-type spring to return the piston and cushion clutch applications. The piston returns to an unapplied position via a return spring assembly. These springs are designed to return the piston to the released position when apply fluid pressure is removed from the clutch pack. The two types of springs commonly used are the coil spring and the Belleville spring.

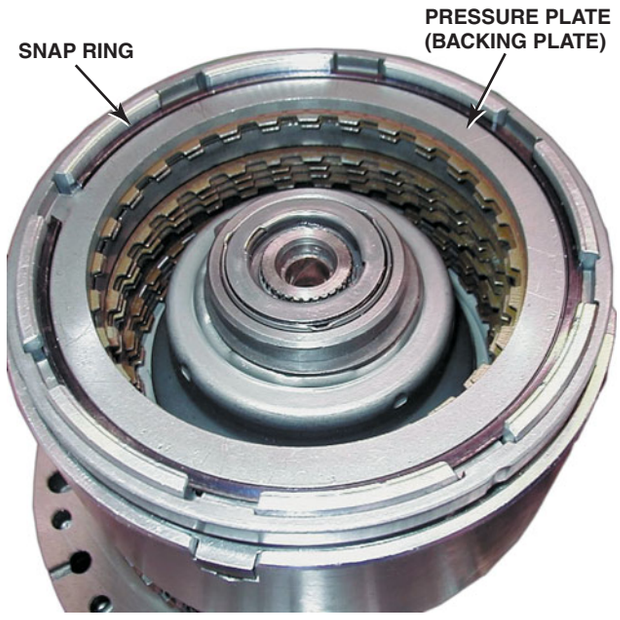


FIGURE 128–13 A typical clutch pack assembly.

CLUTCH OPERATION

To apply the clutch, pressurized fluid enters the drum through an internal passage in the input shaft. When the clutch applies, hydraulic pressure acting on the piston squeezes the two sets of plates together to mechanically connect the two components that engage the splines of the plates.

The fluid acts on the piston and moves it against return spring force to clamp the clutch plates together and hold them against the pressure plate. ● **SEE FIGURE 128–14.**

The friction between the plates then locks the clutch drum to the hub, causing them to turn as one unit.

To release the clutch, hydraulic fluid to the apply side of the piston is cut off and exhausted through an exhaust port. The piston return springs, which were compressed when the clutch was applied, are now free to expand and move the piston back, allowing the clutch plates to disengage.

TWO TYPES OF CLUTCHES

Although a multiple-plate clutch is an apply device similar to a transmission band, it differs from a band because it can also be used to drive members of planetary gear sets as well as hold them. There are two types of multiple-plate clutches.

1. **Holding (braking) clutches.** A clutch contains frictions discs which are splined to one member and the steel disc are splined to another member of a planetary gearset. When the clutch is applied, the friction surfaces are clamped or held together keeping whatever the clutch plates are splined to from rotating.

   ● **SEE FIGURE 128–15.**

2. **Driving clutches.** There are two types of multiple-plate driving clutches, and both types are commonly used in automatic transmissions. In one configuration, splines connect a set of friction plates to the transmission input shaft so that these plates function as the driving member. The alternating set of steel plates is splined to the inside of the clutch drum and serves as the driven member. When the clutch is released, the drive plate rotates with the input shaft, but they do not drive the driven plate that splines to the drum.

   When the clutch applies, the piston takes up clearance and forces both sets of plates firmly together. Now, the input

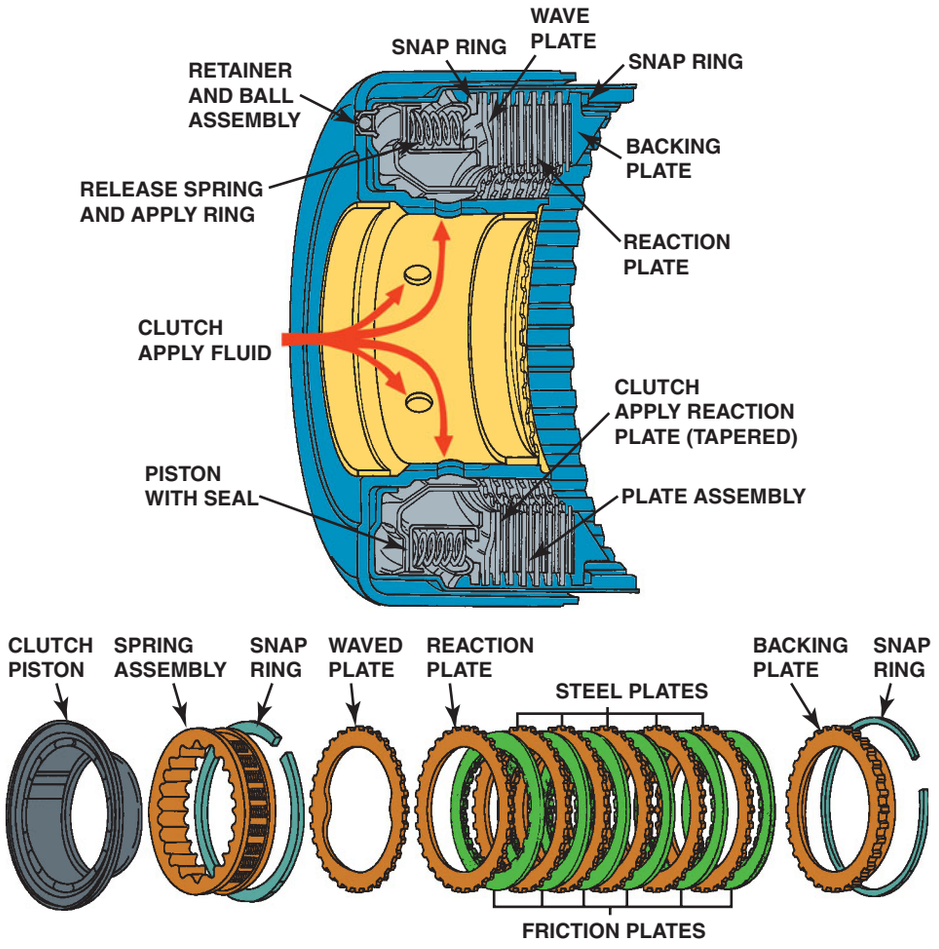


FIGURE 128–14 Hydraulic fluid under pressure enters the clutch housing and exerts a force on the clutch piston. The clutch piston forces the steel plates and the friction plates together, creating a shift.

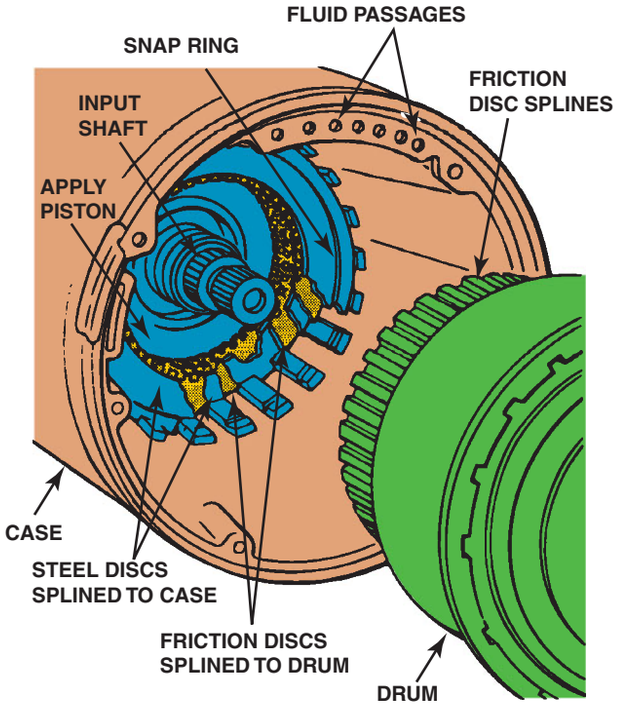


FIGURE 128–15 In a holding clutch, one set of discs engages splines on the transmission case and the other set engages splines on the drum.By applying the clutch, the drum is locked to the case.

shaft and drum rotate together at the same speed and torque transfers from one gear set member to another. A passageway carries fluid to the clutch apply piston.

With the second driving clutch configuration, the drum connects directly to the input shaft so the drum always rotates with the shaft. Splines connect the steel plate to the inside of the drum and the friction plate to the outside of a clutch hub. When the clutch applies, hydraulic pressure compresses the clutch pack to lock the drum and clutch hub together. The input shaft then drives the output shaft and both turn at the same speed.

ACCUMULATORS

PURPOSE AND FUNCTION An accumulator cushions or dampens the apply force during a shift. An accumulator reduces hydraulic pressure surges by temporarily diverting part of the fluid flow in a hydraulic circuit into a parallel circuit or chamber. Accumulators can be described as “hydraulic shock absorbers” because they absorb or reduce the shock of engagement of the clutch or band. The diversion allows pressure in the main apply circuit to increase gradually and provides a smooth engagement of the band or clutch.

Piston-type accumulators look and function much like servo pistons. In fact, some piston-type accumulators share a bore with

one of the transmission servos. This common bore design is known as an **integral accumulator.** ● **SEE FIGURE 128–16.**

OPERATION As hydraulic pressure enters both circuits, the clutch piston or band servo piston starts to move first. Once the clearance is taken up and resistance increases, the circuit pressure increases. This is when the accumulator piston starts to dampen the clamping force and time of the apply device. The accumulator piston area and spring are designed to absorb fluid during the clutch circuit pressure rise when the clutch piston stops moving. The result of this dampening action results in a slight increase in the clutch application. When the time is increased between the initial clutch application and complete application of the clutch, the result is a smoother shift.

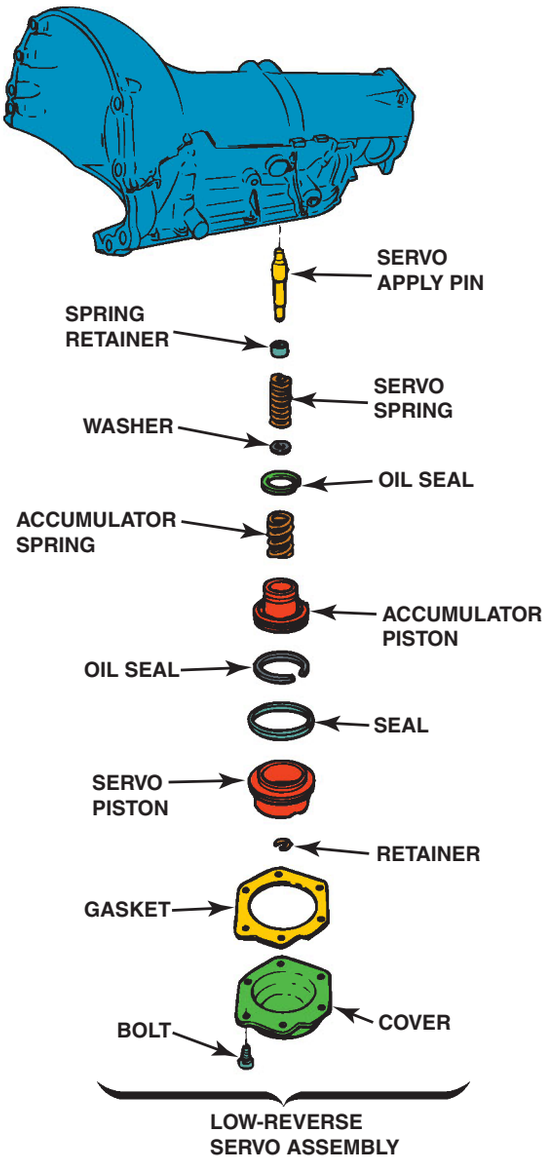


FIGURE 128–16 An integral accumulator is combined with a servo in a single bore in the transmission housing.

NOTE: Accumulators are disappearing in modern, electronic transmissions due to adaptive learning. The PCM or TCM measures the shift time and if it is too long or too short, it will raise or lower line pressure so shift time matches the programming.

ONE-WAY CLUTCHES

TERMINOLOGY Another common type of automatic transmission device is the **one-way clutch** (OWC), or overrunning clutch. Like a transmission band, a one-way clutch is always a holding device. One-way clutches are either roller or sprag clutches, although the roller clutch is more common.

ONE-WAY ROLLER CLUTCH A one-way roller clutch consists of a hub, rollers, and springs that fit inside a drum. The inner circumference of the drum has a series of machined ramps, or cam cuts, to accommodate the rollers and springs. Each ramp is narrower at one end than at the other.

If the drum is held while rotating the hub clockwise, the rollers will compress their springs and move toward the larger end of the ramps. This unlocks the clutch because there is enough clearance between the rollers and the drum for the hub to freewheel.

Rotate the hub counterclockwise while holding the drum. The rollers move toward the narrow end of the ramp, wedging themselves between the hub and drum to lock the clutch. With the rollers at the narrow end of the ramp there is no roller-to-drum clearance. Therefore, the hub cannot turn counterclockwise because the drum is being held. ● **SEE FIGURE 128–17.**

ONE-WAY SPRAG CLUTCH A **one-way sprag clutch** that consists of a hub and a drum separated by a number of figure-eight-shaped metal pieces called **sprags.** ● **SEE FIGURE 128–18.**

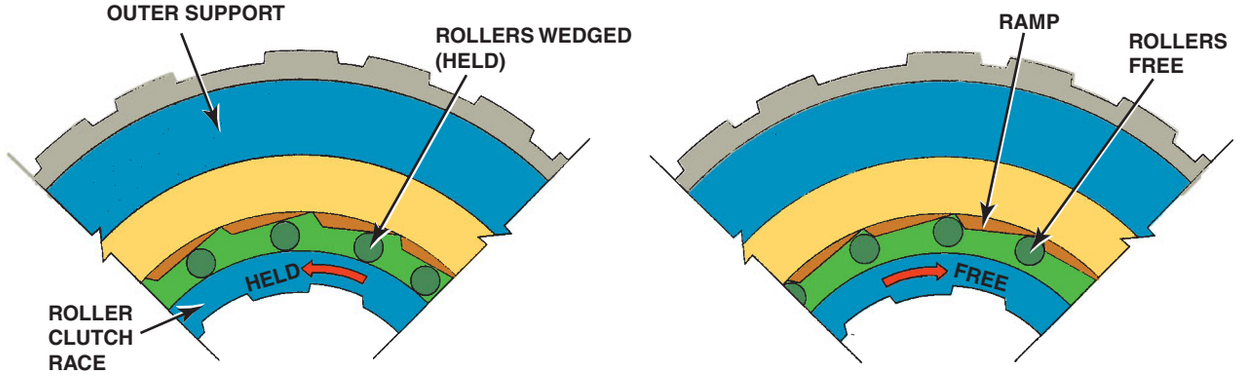


FIGURE 128–17 (a) Roller one-way clutch in the locked (held) position. Note how the rollers are wedged into the ramp that is machined into the outer support. (b) Roller one-way clutch in released (free) position. When the inner roller clutch race rotates faster than the outer support, the rollers move out of the wedge and are free to rotate, thereby unlocking the one-way clutch.

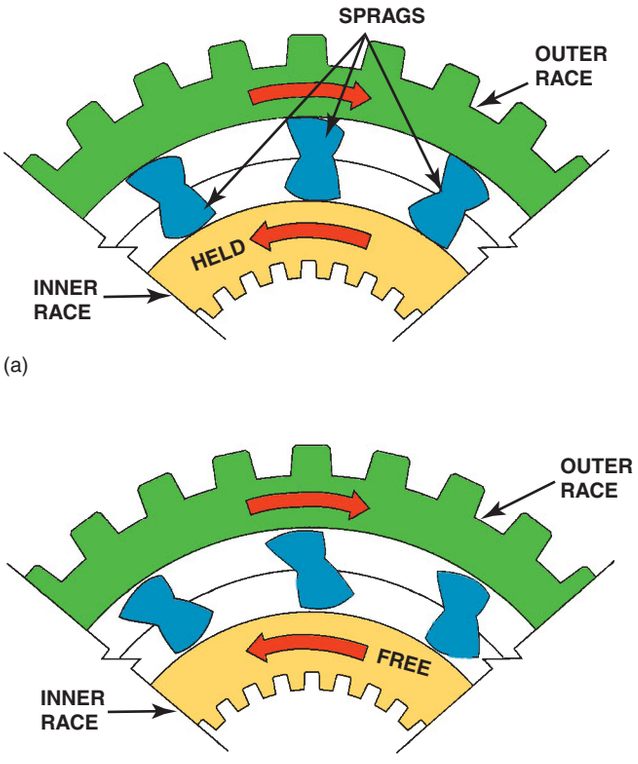


FIGURE 128–18 (a) The sprag in the holding (locked) position. Note how the long portion of the sprag is wedged between the inner and outer race. (b) The sprag in the released position. The inner race is free to rotate faster than the outer race.

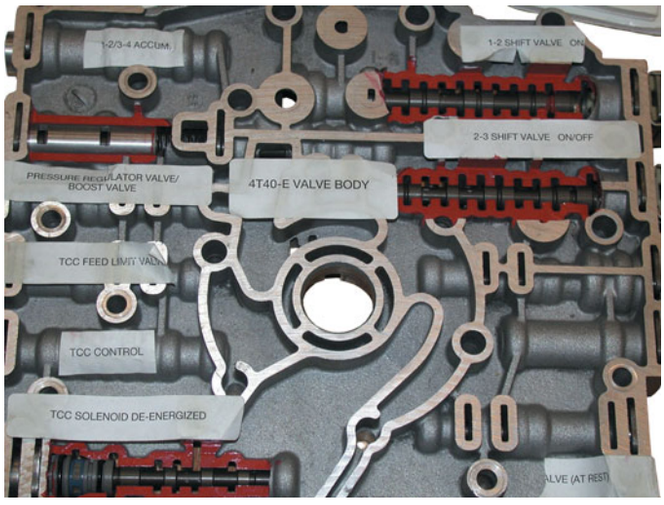


FIGURE 128–19 A partially cutaway valve body from a General Motors 4T40-E transaxle.

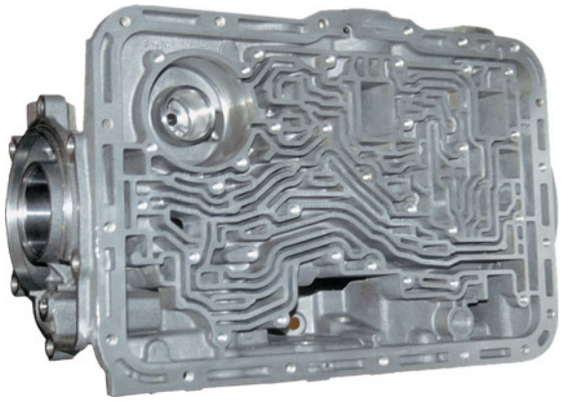


FIGURE 128–20 A typical upper valve body showing the fluid passages ("worm holes").

Sprags lock and unlock the clutch in a manner similar to the rollers in a one-way roller clutch. The shape of a sprag provides two effective working lengths. The direction the sprag tilts determines if working length is short or long.

NOTE: Some one-way clutches, either roller or sprag types, can be installed in a transmission or transaxle upside down by mistake. The transmission will not work correctly and will require that the unit be removed and disassembled again. Also check service information on how the one-way clutches should be installed.

VALVE BODY

PURPOSE AND FUNCTION A **valve body** is where most of the valves in a transmission are located, and is attached to the case with bolts. Valve bodies can be either cast aluminum or cast iron. The valve body in most rear-wheel-drive transmissions is located inside the oil pan at the bottom of the case. A transaxle valve body may be at the bottom of the case, on the backside of the torque converter housing, or on the top or side of the transaxle housing depending on the specific application. ● **SEE FIGURE 128–19.**

PARTS Valve bodies have many fluid passages for the various transmission hydraulic circuits cast into them. These are sometimes called **worm holes** or **worm tracks.** ● **SEE FIGURE 128–20.**

Some of these passages may be widened to form pockets that contain steel, nylon, or rubber check balls. Most valve bodies consist of two or more cast sections that bolt together with a flat metal separator plate between them. The upper section of the valve body is part of the transmission case casting. The **separator plate,** also called a *spacer plate,* provides rigidity and contains calibrated holes and openings that help manage fluid flow. Valve bodies contain specialized valves and circuits that are particular to a specific transmission. Electronic solenoids are used in place of some valves on electronically controlled transmissions/transaxles. Some transmissions/transaxles incorporate the TCM right on the valve body. This eliminates the wire harness between the TCM and the solenoids which in turn eliminates connector problems. ● **SEE FIGURE 128–21.**

FLOW DIRECTING VALVES Flow directing valves, or switching valves, control the direction and distribution of fluid flow in the hydraulic system. These valves may open or close passages, fill hydraulic circuits, apply or release clutches and bands, and control the direction of fluid flow from one passage or circuit to another.

ONE-WAY VALVES A **one-way valve** allows fluid to flow in one direction. The spring-loaded ball check valve is an example of a one-way valve. Valve operation is similar to that of a poppet valve. The spring holds the ball against its seat at the inlet port until fluid pressure overcomes spring force to push the ball from its seat. Fluid flows through the valve as long as hydraulic pressure exceeds the force of the spring.

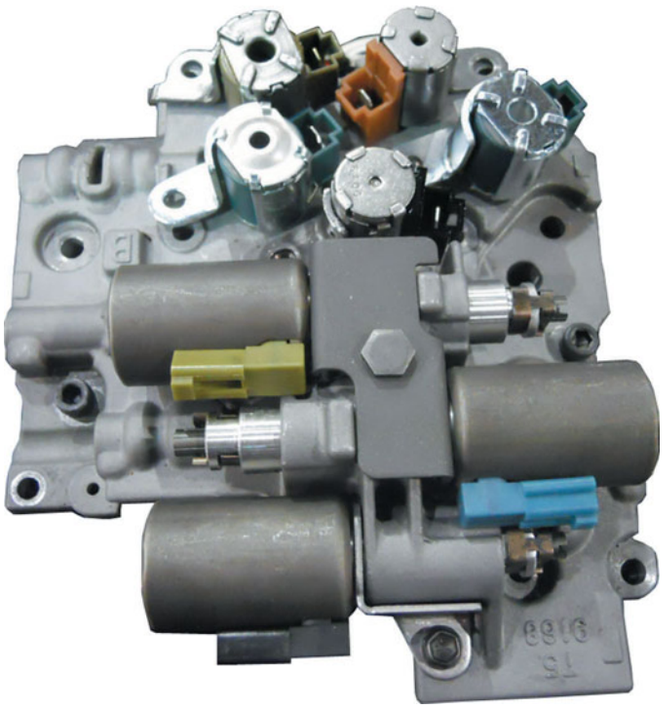


FIGURE 128–21 Electronically controlled automatic transmissions/transaxles use solenoids located in the valve body to control line pressure and to open and close passages in the valve body to control shifts.

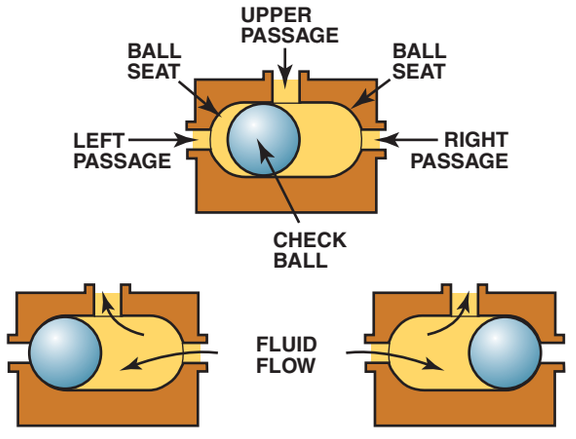


FIGURE 128–22 Check balls are used in the valve body to allow hydraulic circuits to share a common passage.

Spring-loaded ball check valves are used as pressure-relief valves, and work well on bypass circuits because they provide a fast apply rate with a slow release. A second type of one-way valve is a simple gravity valve, as commonly used in transmission valve bodies.

CHECK BALLS The **check balls** in these valves are usually made of steel, but they can be nylon, rubber, or some composite material as well. The type of material used depends on the manufacturer and application. Steel balls generally hold up better, but cause greater seat wear because of their hardness. The softer composite balls are easier on seats and they cannot be magnetized. ● **SEE FIGURE 128–22.**

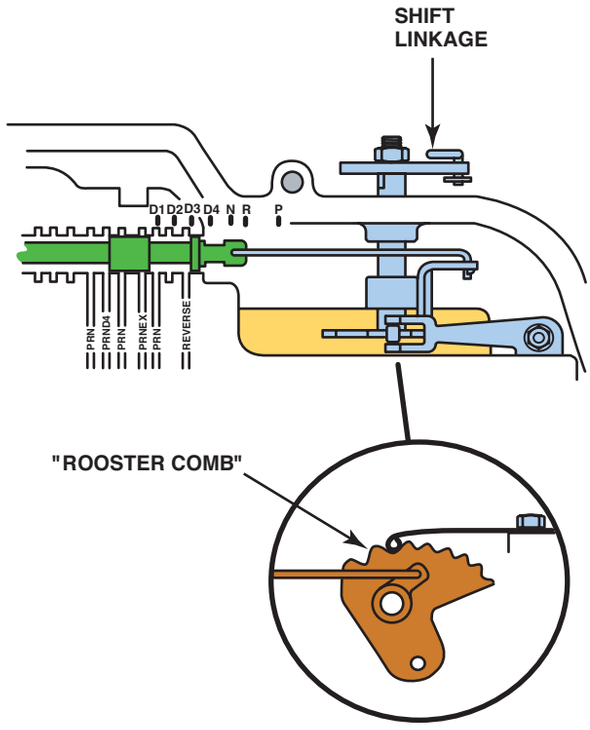


FIGURE 128–23 A rooster comb is the detent that helps retain the manual valve in the various positions in the valve body.

ORIFICES Orifices are holes in the separator plate and are used for several reasons, including:

- To control the rate of fluid movement and timing of clutch/accumulator application (shift feel)
- To separate hydraulic circuits inside the transmission, so a big leak in one circuit will not cause pressures to drop in the rest of the transmission as well

MANUAL VALVE The **manual valve** is the primary flow-directing valve in an automatic transmission. This valve connects to a shift lever in the transmission, which in turn connects to the gear selector lever through a mechanical linkage. The driver controls manual valve position through the gear selector and shift linkage.

Mechanical linkage physically positions the manual valve in its bore for the particular gear range selected. The part used to position the manual valve is commonly called the “rooster comb” because of its shape. ● **SEE FIGURE 128–23.**

The manual valve receives mainline pressure from the regulated pump output and distributes it to the hydraulic circuits uncovered by the valve lands.

HYDRAULICALLY CONTROLLED TRANSMISSION VALVES

PURPOSE AND FUNCTION Hydraulically controlled automatic transmissions/transaxles use valves to control when to shift instead of sensors that are used in electronically controlled transmissions/transaxles. These valves use mainline pressure to develop other hydraulic circuit pressures within the transmission. Pressure or control valves are normally spool valves that link to external components.

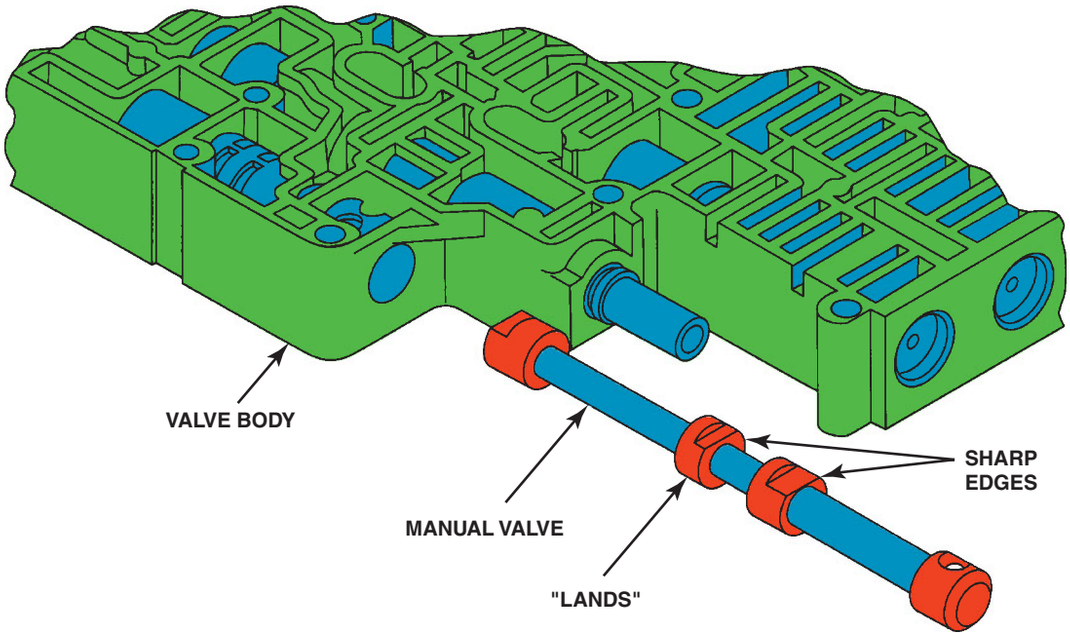


FIGURE 128–24 The manual valve is a spool valve that is moved by the shift linkage. All valves in the valve body have sharp edges on the lands. Any dirt in the valve body area can cause shifting problems due to the close tolerances between the valves and the bores in the valve body.

FREQUENTLY ASKED QUESTION

What Is a Spool Valve?

A spool valve is named after a spool of thread. A spool of thread is wooden and a spool valve used in an automatic transmission/transaxle is aluminum or steel. The ridges (larger diameter) of the spool valve fit closely into a smooth bore in the valve body and are used to direct the flow of automatic transmission fluid.

- The larger diameter sections of the spool valve are called *lands.*
- The smaller diameter sections of the valve are called *grooves* or *valleys.*
- The fluid is blocked by the lands and flows through the grooves or valleys.

● **SEE FIGURE 128–24.**

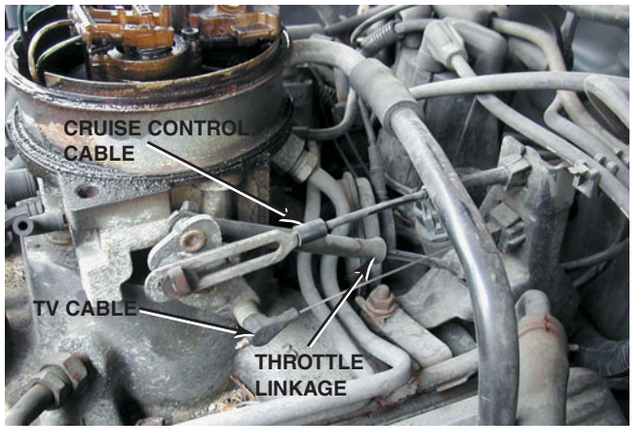


FIGURE 128–25 The throttle valve (TV) cable on a 4T-60.

THROTTLE VALVE The transmission throttle valve senses engine load and uses that operating signal to develop throttle pressure on hydraulically controlled automatic transmissions. Throttle valves have linkage that connects them mechanically to the throttle plates, and the throttle valve responds directly to engine load. ● **SEE FIGURE 128–25.**

Throttle valves are responsible for delaying the upshift points of the transmission based on the amount of load on the engine. A low engine load develops low throttle pressure while a higher load develops higher throttle pressure. The throttle position (TP) sensor has replaced the need for these valves in electronically controlled automatic transmissions/transaxles.

VACUUM MODULATOR VALVE A vacuum modulator is used to convert engine manifold vacuum into a signal pressure that increases as engine vacuum decreases. The modulator is connected to the intake manifold vacuum with a rubber hose or steel line. A vacuum modulator is used on hydraulically controlled transmissions/transaxles to help determine the shift point based on engine load. The purpose of the vacuum modulator is to delay the upshifting of the transmission based on the engine load. ● **SEE FIGURE 128–26.**

Consider, for example, the following:

- **Light engine load.** Manifold vacuum is high, shifts occur at lower speeds.
- **Heavy engine load.** Manifold vacuum is low, shifts occur at higher speeds.

The manifold absolute pressure (MAP) sensor or mass airflow (MAF) sensor and throttle position (TP) sensor serve in place of the vacuum modulator valve in measuring engine load on electronically controlled automatic transmissions/transaxles.

GOVERNOR VALVE The **governor valve** monitors vehicle road speed and uses that operating signal to develop governor pressure. The governor valve normally follows transmission output shaft rotation speed, which increases with vehicle speed. Mechanical governors contain "flyweights" that move in relation to centrifugal forces

caused by the speed of the output shaft. As the output shaft speed flyweights move outward, this in turn moves an internal valve which controls the output pressure. As the speed increases, governor pressure also increases. Governor pressure opposes throttle pressure at the shift valves to control upshifts and downshifts in relation to vehicle speed. ● **SEE FIGURE 128–27.**

Some electronic transmissions use the speed sensor signal to control a solenoid which produces a governor pressure and some do not use a governor pressure. Instead the speed signal is processed to control the shift valve solenoid directly.

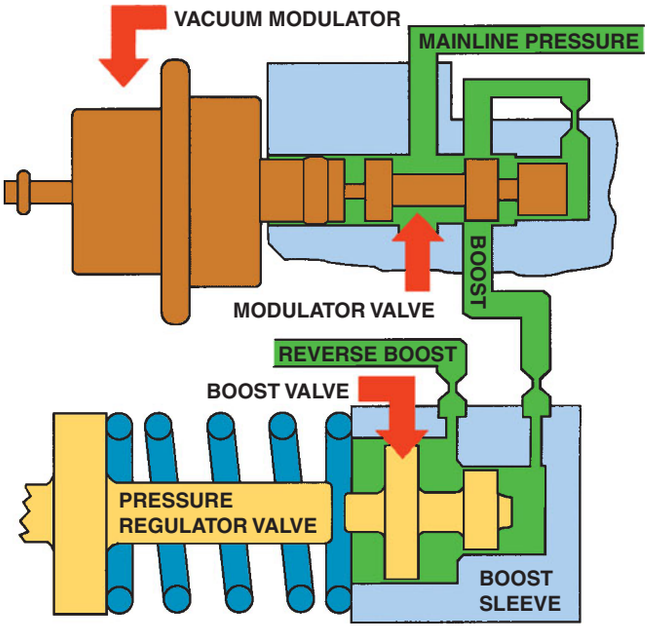


FIGURE 128–26 A vacuum modulator moves the modulator valve depending on the vacuum of the engine. A heavy load on the engine causes the vacuum to be lower than when the engine is operating under a light load. The spool valve applies mainline pressure to the boost sleeve of the pressure regulator valve which causes the mainline pressure to increase.

SHIFT VALVES

A **shift valve** is a spring-loaded spool valve that controls the transmission upshift and downshift circuits. Throttle pressure works against one side of the valve, while governor pressure works against the other side. When one pressure is greater than the other, the valve moves to the upshift or downshift position and the valve lands uncover the ports to the relative circuits. Transmission shift valves may be referred to as "snap valves" or "relay valves" because they shift almost instantly in response to pressure differential changes. Since these valves cause upshifts and downshifts, they are also known as "event-causing valves." There are only two positions for a shift valve:

- One end of the stroke or
- the other end of the stroke

Otherwise, hydraulic pressure could apply control devices for two gears at once and damage the transmission. ● **SEE FIGURE 128–28.**

In an electronically controlled automotive transmission/transaxle, solenoids control the pressure force which in turn controls the position of the shift valve.

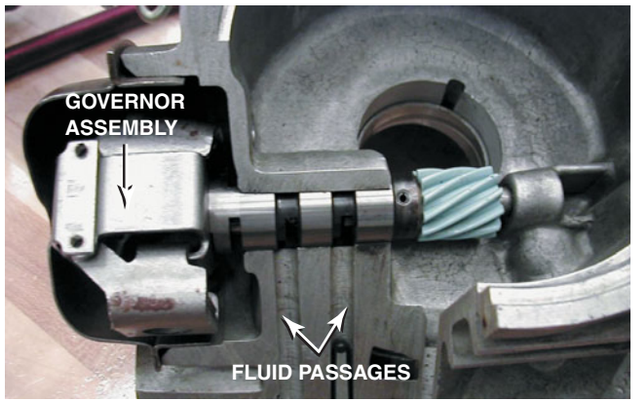


FIGURE 128–27 A governor assembly is used on older hydraulically controlled automatic transmissions/transaxles to control shift points based on vehicle speed.

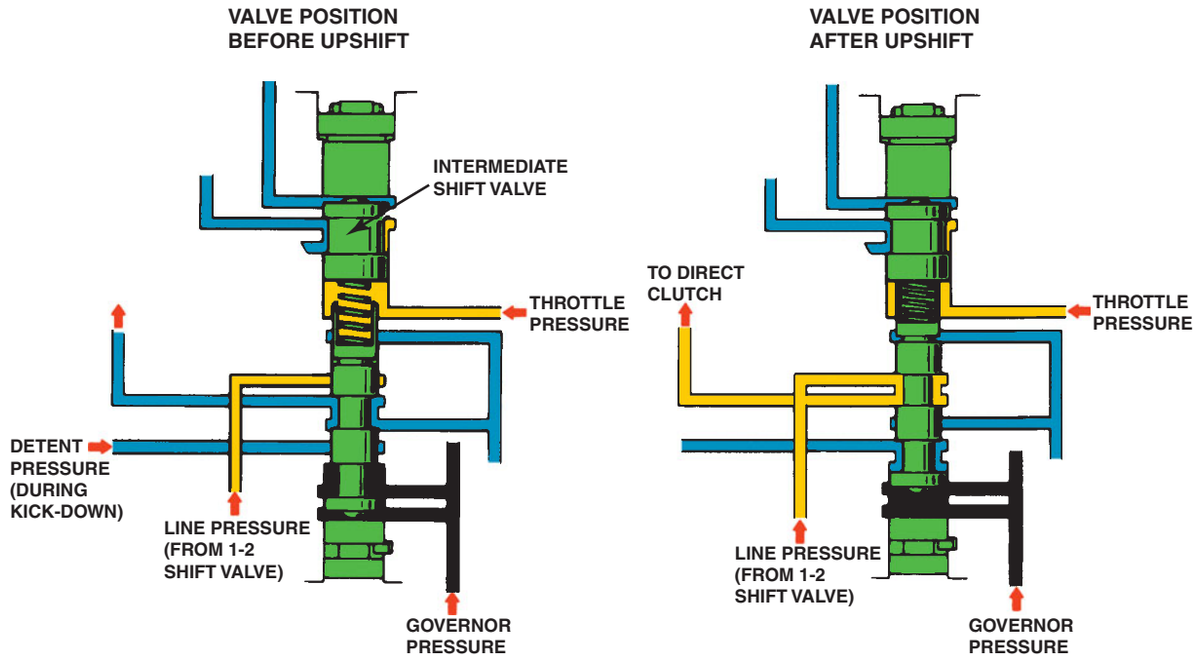


FIGURE 128–28 Shift valves move when there is a difference in pressure. In a hydraulically controlled automatic transmission/transaxle, the shift valves compare governor pressure force against throttle valve (TV) pressure force to determine when to upshift or downshift.

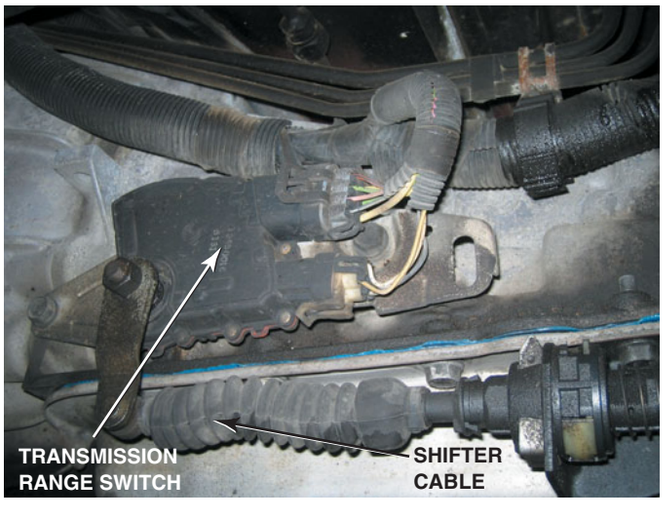


FIGURE 128–29 A transmission range switch on a rear-wheel-drive automatic transmission mounted directly to the side of the case of the unit and accessible from underneath the vehicle.

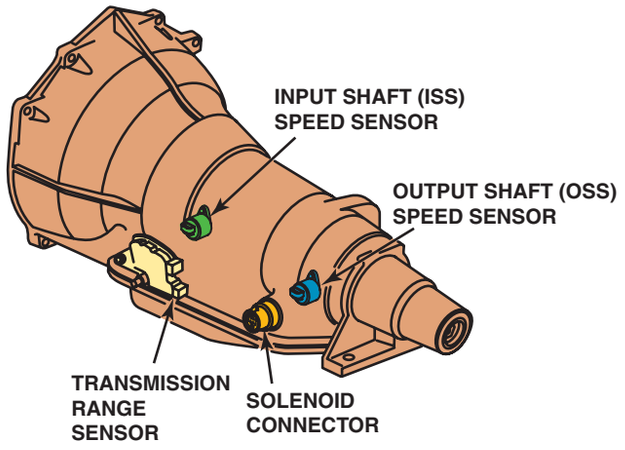


FIGURE 128–30 Speed sensors are used by the powertrain control module (PCM) or the transmission control module (TCM) to control shifts and detect faults such as slippage when the two speeds do not match the predetermined ratio for each gear commanded.

ELECTRONICALLY CONTROLLED TRANSMISSIONS

BACKGROUND Electronically controlled transmissions and transaxles have been used by most vehicle manufacturers since the early 1990s. Compared to hydraulically controlled units, using the powertrain control module (PCM) or the transmission control module (TCM) to operate and control shifting results in smoother operation. Also, the PCM or TCM can monitor the circuits and set a diagnostic trouble code if a fault is detected.

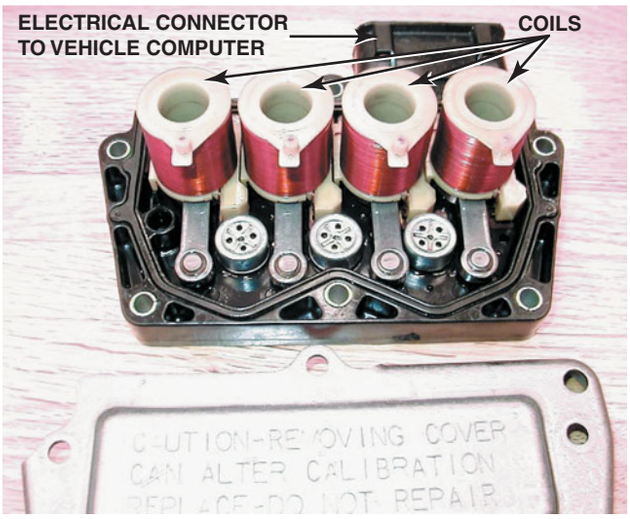
NOTE: All transmissions use hydraulic pressure and automatic transmission fluid to do the actual shifting. The difference between hydraulically controlled and electronically controlled automatic transmissions is the way that the shift points are controlled.

INPUTS Following are inputs to the powertrain control module (PCM) and their purposes.

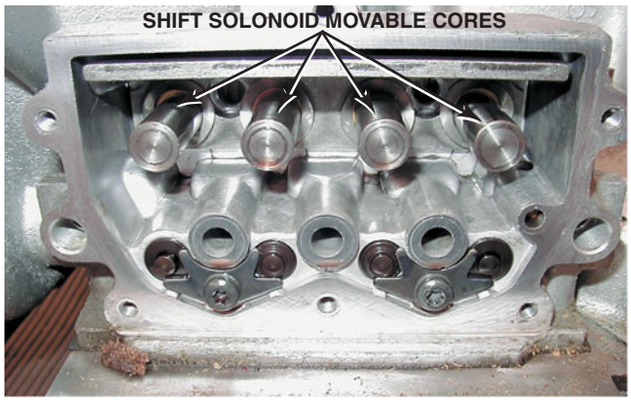
- **Transmission range switch.** This sensor is used by the PCM to detect the gear being commanded by the driver. If reverse or a manual forward gear is selected, then higher line pressure will be needed and the shifts will be delayed to provide more power being delivered to the drive wheels. ● **SEE FIGURE 128–29.**
- **Engine speed.** The speed of the engine has a direct relation to the amount of power the engine is developing. The engine speed information is taken from the crankshaft position (CKP) sensor and is used by the PCM or TCM to control shift points and to regulate line pressure.
- **Throttle position (TP) sensor.** This sensor is used by the PCM to detect the throttle opening being commanded by the driver. A higher throttle opening means that higher line pressure will be needed and the shifts will be delayed to provide more power being delivered to the drive wheels.
- **Manifold absolute pressure (MAP) sensor.** This sensor is used by the PCM to detect the amount of load on the engine. The greater the load, the more fuel that needs to be supplied, and the greater the amount of power the engine will create. This signal is used to determine the best shift points and to regulate line pressure.
- **Mass airflow (MAF) sensor.** This sensor is used by the PCM to detect the amount of air entering the engine. The greater the amount of air, the more fuel that needs to be supplied and, therefore, the greater the amount of power the engine will create. This signal is used to determine the best shift points and to regulate line pressure.
- **Speed sensors.** These sensors measure the speed of the input shaft and output shaft or sometimes other shaft speeds in the automatic transmission or transaxle. The output shaft speed sensor is often used to provide vehicle speed information to the PCM and for adaptive learning and self-diagnosis. ● **SEE FIGURE 128–30.**
- **Transmission fluid temperature (TFT) sensor.** This sensor is used by the PCM or TCM to detect the temperature of the automatic transmission fluid. This signal is used to determine the best shift points and to regulate line pressure. It will cause the PCM or the TCM to engage the torque converter clutch (TCC) sooner and disable overdrive, to help reduce the fluid temperature if it reaches higher than normal.

OUTPUTS Outputs to the powertrain control module (PCM) or transmission control module (TCM) and their purposes include the following:

- **Pressure control.** The PCM or TCM controls the line pressure by changing the signal to the pressure control solenoid. Using the input signal to detect the conditions that the vehicle is being driven, the specified line pressure is commanded to provide smooth shifts without slippage.
- **Shift control solenoids.** The PCM or TCM controls the shifting by applying power or ground to the correct control solenoid(s) at the right time.



(a)



(b)

FIGURE 128–31 An example of a solenoid valve installed in a valve body assembly.

- **Torque converter clutch (TCC).** The PCM or TCM controls the application of the torque converter clutch (TCC) by applying power or ground to the correct control solenoid at the right time.

  ● **SEE FIGURE 128–31.**

ADAPTIVE LEARNING Most late model electronically controlled automatic transmissions/transaxles use the PCM or TCM to monitor the time it takes to complete a shift. The PCM can determine this from the comparison between the engine speed and the output speed sensor data. When a shift is commanded, there should be a change in the speed of the output shaft. If the change in speed is longer than normal, which could indicate normal wear in the clutch pack, the PCM can learn from this and start the shift sooner to allow time for the clutch to be fully engaged.

SHIFT SOLENOIDS Solenoids used in electronically controlled automatic transmissions/transaxles are:

- **On-off solenoids.** These are can be normally open to fluid flow or normally closed to block fluid flow. They are commanded on or off by the PCM or TCM. The resistance of most on-off shift solenoids is 10 to 15 ohms.
- **Linear solenoids.** This type of solenoid can be varied by changing the amount of on time to precisely control the fluid flow through the solenoid valve. The variable power or ground applied to the linear solenoids is pulse-width modulated (PWM) and allows the PCM precise control over the shifting and the fluid pressure. The resistance of most linear (PWM) shift solenoids is about half of the on-off type and range from 4 to 6 ohms.

GENERAL MOTORS 4T60-E (FRONT-WHEEL-DRIVE TRANSAXLE)		
Gear Range	**Solenoid A**	**Solenoid B**
First gear	ON	ON
Second gear	OFF	ON
Third gear	OFF	OFF
Fourth gear	ON	OFF

CHART 128–2

In this example, the vehicle would start out and remain in third gear if there was a fault with the computer or wiring.

GENERAL MOTORS 4L80-E (REAR-WHEEL-DRIVE TRANSMISSION)		
Gear Range	**Solenoid A**	**Solenoid B**
First gear	ON	OFF
Second gear	OFF	OFF
Third gear	OFF	ON
Fourth gear	ON	ON

CHART 128–3

In this example, the vehicle would start out and remain in second gear if there was a fault with the computer or wiring.

TECH TIP

Parking Brake Before Parking Pawl

To prevent possible damage to the transmission/transaxle case or other internal components, most experts agree that the parking brake should be applied *before* placing the gear selector into the park position, especially when parking on a hill. This procedure keeps the weight of the vehicle from being exerted entirely on the parking pawl and makes it easier to move the gear selector out of the park position.

Shift solenoids control the pressure force which in turn controls the position of the shift valve. Shift solenoids may be labeled 1 and 2 or A and B. Using a combination of the two shift solenoids prevents the actuation of four forward gears.

A **default** (or **limp-in**) **gear** is the forward speed that is used if there is a failure in the electronic or computer system. If neither solenoid is engaged, then either second or third gear is actuated, depending on the exact make and model of the transmission or transaxle. ● **SEE CHARTS 128–2 AND 128–3** for examples of two General Motors transmissions.

RANGE	GEAR	SHIFT SOLENOIDS "A"	SHIFT SOLENOIDS "B"	2-4 BAND	REVERSE INPUT CLUTCH	OVERRUN CLUTCH	FORWARD CLUTCH	FORWARD SPRAG CL. ASSEMBLY	3-4 CLUTCH	LOW ROLLER CLUTCH	LOW REVERSE CLUTCH
Park		On	On								Applied
Reverse		On	On		Applied						Applied
Neutral		On	On								
	First	On	On				Applied	Holding		Holding	
Ⓓ	Second	Off	On	Applied			Applied	Holding			
	Third	Off	Off				Applied	Holding	Applied		
	Fourth	On	Off	Applied			Applied		Applied		
	First	On	On				Applied	Holding		Holding	
D	Second	Off	On	Applied			Applied	Holding			
	Third	Off	Off			Applied	Applied	Holding	Applied		
2	First	On	On			Applied	Applied	Holding		Holding	
	Second	Off	On	Applied		Applied	Applied	Holding			
1	First	On	On			Applied	Applied	Holding		Holding	Applied
	Second	Off	On	Applied		Applied	Applied	Holding			

CHART 128–4

The General Motors 4L60-E electronically controlled rear-wheel-drive transmission clutch, band, and solenoid application chart.

TYPICAL TORQUE FLOW

The General Motors 4L60-E can provide an example of how a typical electronically controlled rear-wheel-drive automatic transmission works. ● **SEE CHART 128–4.**

PARK AND NEUTRAL With the gear selector level in P or N, there is no torque flow through the gear set, even though the low-reverse clutch is applied in the 4L60-E. The clutch holds the reaction carrier stationary, but torque input to the gear set stops at the input housing.

The torque converter housing and impeller rotate clockwise at engine speed to hydraulically drive the turbine and mechanically drive the oil pump. The transmission input drum assembly rotates clockwise at turbine speed to drive the gear set. Turbine speed is slightly less than engine crankshaft speed. However, there is nothing connecting the input drum assembly to drive the gear sets and transfer torque at this time.

In neutral, the output shaft is free to rotate in either direction, and the vehicle can be pushed or towed. However, use caution because if the engine is not running, the pump is not providing lube fluid to components. In park, a mechanical pawl or finger engages one of many large notches cut into a gear mounted on the output shaft. In park to the transmission case, preventing the vehicle from moving in either direction.

OVERDRIVE FIRST With the gear selector lever in overdrive, the transmission starts off in first gear, and then upshifts into second, third, and fourth gears as the vehicle continues to accelerate. To engage first gear, the forward clutch applies, transferring engine torque from the input shaft to the input sun gear through the forward sprag clutch, driving the sun gear clockwise.

With the input sun gear turning clockwise, the input pinion gears spin counterclockwise in the stationary carrier and attempt to drive the input ring (internal) gear and reaction carrier counterclockwise. However, the forward sprag clutch is holding, so the pinions walk clockwise inside the ring (internal) gear, turning the input carrier clockwise. Then, the input carrier drives the output shaft clockwise in gear reduction. ● **SEE FIGURE 128–32.**

The reaction ring (internal) gear turns clockwise along with the output shaft and drives the reaction pinions clockwise on the stationary reaction carrier assembly. Pinion action drives the reaction sun gear counterclockwise. However, the reaction sun gear is not connected to a gear set member, so the reaction gear set simply freewheels. The low roller clutch prevents the reaction carrier from turning counterclockwise.

As long as the vehicle continues to accelerate in overdrive first, torque transfers through the gear set to the output shaft. During closed-throttle coasting, the clockwise torque load on the forward sprag clutch and the counterclockwise torque load on the low roller clutch are released. Both one-way clutches overrun so the gear sets freewheel on deceleration, and engine braking is not available.

OVERDRIVE SECOND As the vehicle continues to accelerate in the overdrive range, the transmission upshifts to second gear by applying the 2-4 band. The band holds the reverse drum, input shell, and reaction sun gear stationary. The forward clutch remains applied, while the input shaft drives the input sun gear clockwise through the forward sprag clutch. ● **SEE FIGURE 128–33.**

As in first gear, the input sun gear rotates clockwise and drives the input pinions counterclockwise. Since the 2-4 band is holding, the input pinions walk inside the internal gear, driving the input carrier and output shaft clockwise in gear reduction.

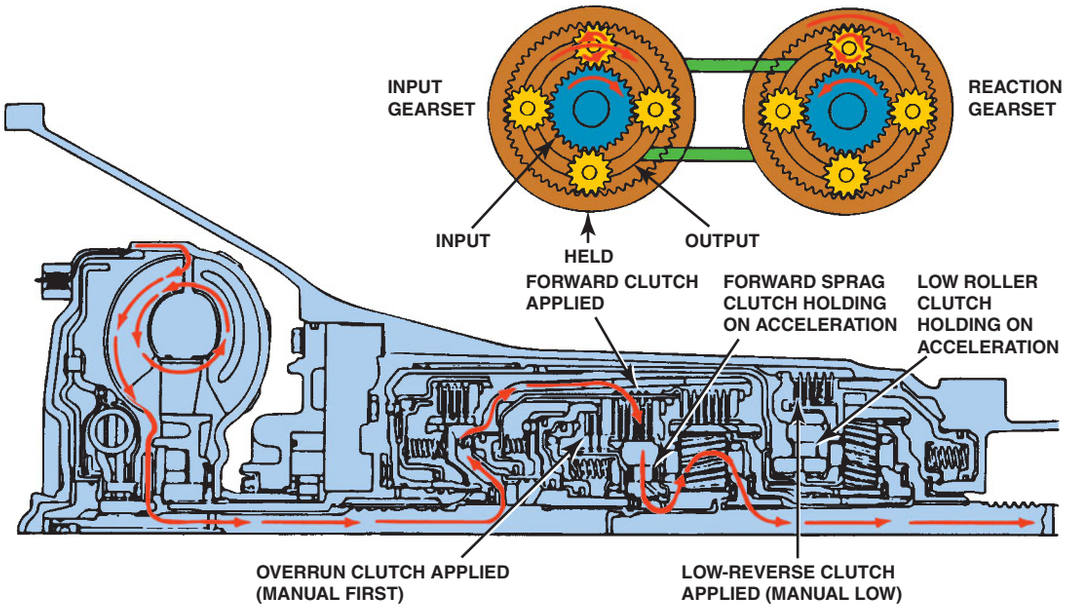


FIGURE 128–32 A GM 4L60-E torque (power) flow in overdrive first gear.

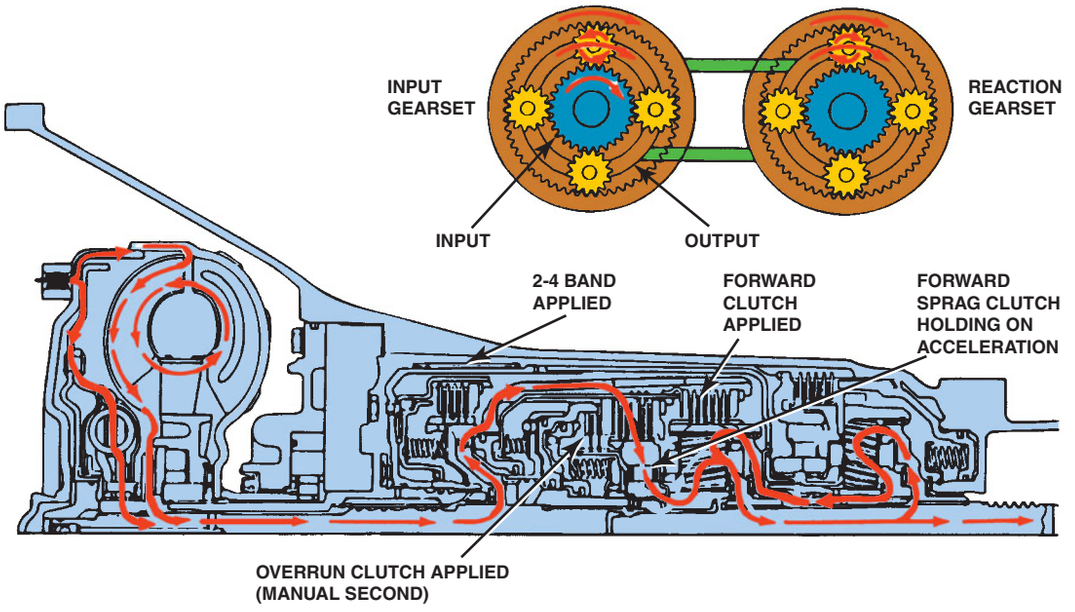


FIGURE 128–33 A GM 4L60-E torque (power) flow in overdrive second gear.

At the same time, the output shaft drives the reaction internal ring gear and pinion gears clockwise. With the reaction sun gear held, the pinion gears walk clockwise and drive the reaction carrier clockwise with them.

Clockwise rotation of the reaction carrier transfers to the input ring (internal) gear through the reaction carrier shaft. With the input ring (internal) gear turning clockwise, the input pinions spin counterclockwise and drive the input carrier clockwise. This removes the counterclockwise torque load from the low roller clutch so that it overruns at this time. There is no engine compression braking available in overdrive second because the forward sprag clutch overruns.

OVERDRIVE THIRD To automatically upshift into third gear as the vehicle continues to accelerate, the transmission releases the 2-4 band and applies the 3-4 clutch. Also, the forward clutch remains applied so the input shaft drives the input sun gear clockwise through the forward sprag clutch. ● **SEE FIGURE 128–34.**

Applying the 3-4 clutch connects the input shaft to the input ring (internal) gear, which drives the ring (internal) gear clockwise at turbine speed. Now that two members of the input gear set—the sun and ring (internal)—are being driven at turbine speed, the gear set provides direct drive as it locks up and turns as a unit.

As long as the vehicle is accelerating in overdrive third, torque transfers through the planetary gear set to the output shaft. There is no engine braking because the forward one-way clutch overruns and allows the input sun gear to freewheel.

OVERDRIVE FOURTH The transmission upshifts into fourth gear by applying the 2-4 band as the vehicle continues to accelerate in overdrive range. The 2-4 band holds the reverse drum and reaction sun gear stationary. Both the 3-4 and forward clutches remain applied, and the input drum continues to drive the input ring (internal) gear clockwise. ● **SEE FIGURE 128–35.**

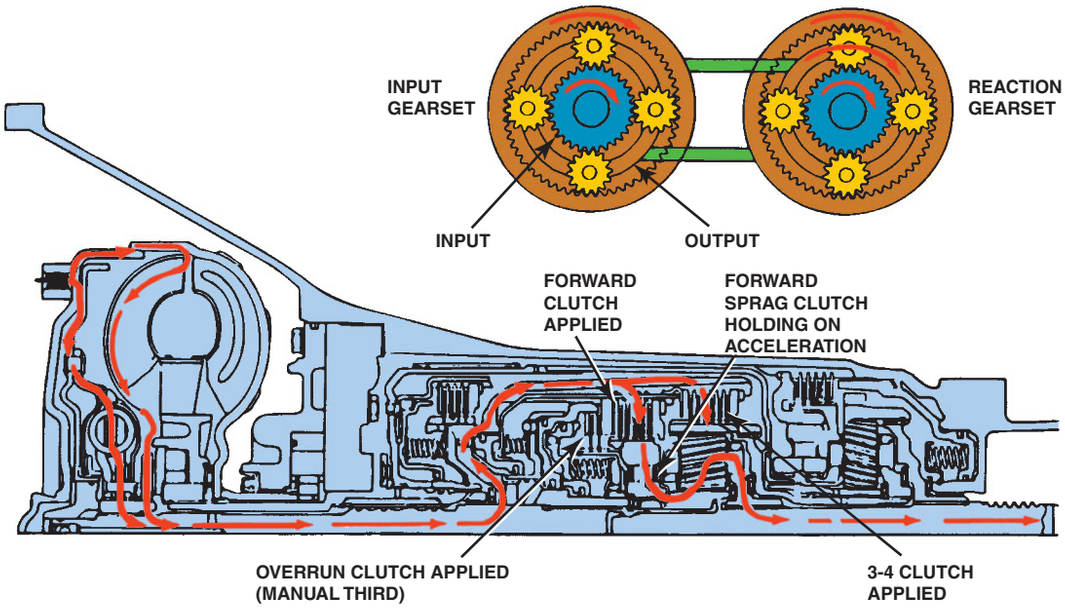


FIGURE 128–34 A GM 4L60-E torque (power) flow in overdrive third gear.

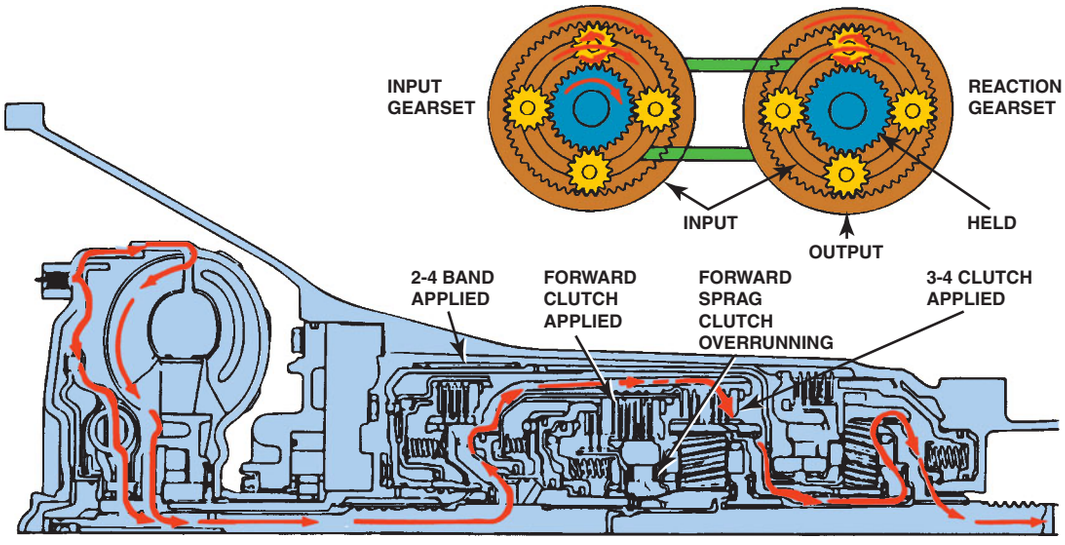


FIGURE 128–35 A GM 4L60-E torque (power) flow in overdrive fourth gear.

This drives the reaction carrier clockwise as well, since it is in common with the input ring (internal) gear. As the carrier turns, the reaction pinions walk clockwise around the stationary reaction sun gear. This drives the reaction ring (internal) gear and output shaft clockwise at an overdrive ratio.

In fourth gear, the input ring (internal) gear turns at input shaft speed, while the input carrier turns at a faster output shaft speed; both gears turn clockwise. As a result, the input pinions turn counterclockwise and drive the sun gear clockwise faster than input speed. This causes the forward sprag clutch to overrun and renders the forward friction clutch, which remains applied, ineffective.

When the transmission is operating in fourth gear, the input member, the reaction carrier, is being driven by a multiple-plate clutch, while a band prevents the held member, the reaction sun gear, from turning in either direction. Therefore, engine compression braking is available. However, due to the overdrive gear ratio, the braking effect is not noticeable to the driver.

REVERSE With the gear selector lever in reverse, the low-reverse clutch applies to drive the reaction sun gear clockwise with the input shaft. The reaction carrier and input ring (internal) gear are held stationary by the applied reverse input clutch. This turns the reaction pinions counterclockwise and drives the carrier counterclockwise in gear reduction. ● **SEE FIGURE 128–36.**

In reverse gear, the input ring (internal) gear is held, while the input carrier is driven counterclockwise. This causes the input pinions to rotate clockwise and drive the input sun gear counterclockwise.

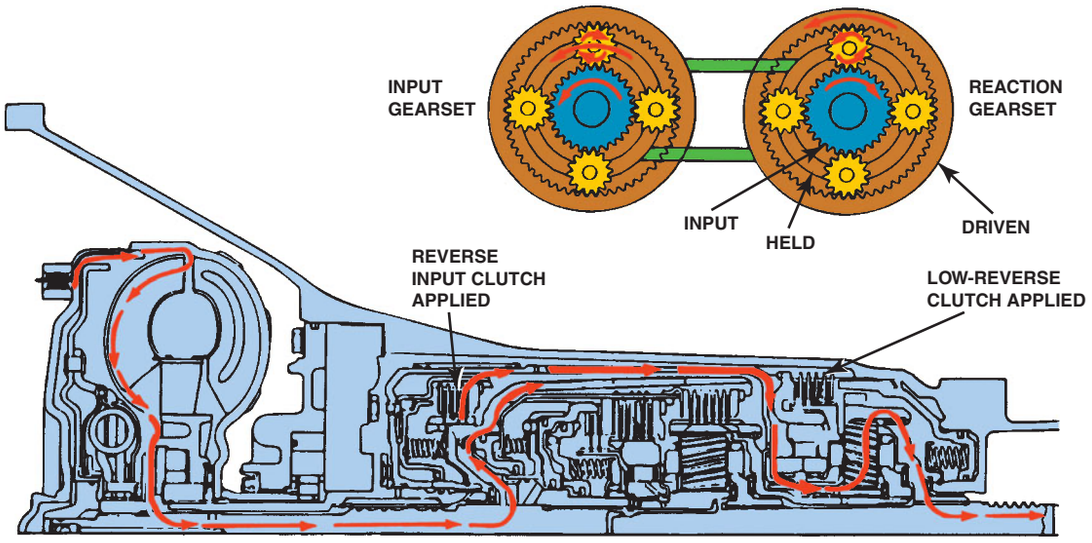


FIGURE 128–36 A GM 4L60-E torque (power) flow in reverse.

REVIEW QUESTIONS

1. What are three planetary gear set holding devices?
2. How are shift points achieved with a hydraulically controlled automatic transmission/transaxle?
3. How are solenoids used to control the shifting on electronically controlled automatic transmissions/transaxles?
4. What are the parts of a typical clutch pack assembly?
5. What are the solenoids used in a typical electronically controlled automatic transmission/transaxle?

CHAPTER QUIZ

1. Two technicians are discussing one-way clutches. Technician A says that a sprag and a roller are two types of one-way clutches. Technician B says that a one-way clutch could be installed upside down and cause the automatic transmission/transaxle to not function correctly. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
2. Two technicians are discussing automatic transmission/transaxle oil pumps. Technician A says that a vane-type pump is a positive displacement pump. Technician B says that the pump is driven by the torque converter. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. Which part controls mainline pressure in an electronically controlled automatic transmission/transaxle?
   a. Pressure control solenoid (force motor)
   b. Spool valve
   c. Boost valve
   d. Modulator valve
4. Technician A says that the automatic transmission/transaxle fluid (ATF) cooler is designed to cool the automatic transmission fluid.Technician B says that the cooler also warms the ATF when the fluid is cold. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
5. Technician A says that the mainline pressure is usually higher in manual first or manual second gear than it is when the gear selector is in the drive position. Technician B says that mainline pressure is higher in reverse than when the gear selector is in the drive position. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
6. What is the part of the planetary gear set called that is being held by a band?
   a. Reaction member **c.** Simple gear set
   b. Compound gear set **d.** Held member
7. What is the purpose and function of an accumulator?
   a. To apply a clutch
   b. To apply a band
   c. To cushion or dampen pressure surges
   d. Either a or b
8. The steel plates in a clutch pack are commonly called _____.
   a. Friction disks **c.** Friction members
   b. Reaction members **d.** Steels
9. Force motors are controlled by the computer by _____.
   a. Increasing/decreasing current (amperes)
   b. PWM
   c. Increasing/decreasing voltage
   d. Changing the resistance in the circuit
10. Check balls used in the valve body are constructed of _____.
    a. Steel **c.** Rubber
    b. Nylon **d.** All of the above

chapter 129

AUTOMATIC TRANSMISSION/ TRANSAXLE DIAGNOSIS AND IN-VEHICLE SERVICE

OBJECTIVES: **After studying Chapter 129, the reader will be able to:** • Prepare for ASE Automatic Transmission/Transaxle (A2) certification test content area "A" (General Transmission/Transaxle Diagnosis), content area "B" (Transmission/Transaxle Maintenance and Adjustment), content area "C" (In-Vehicle Transmission/Transaxle Repair), and content area "D" (Off-Vehicle Transmission/Transaxle Repair). • Describe what to look for regarding the operation of an automatic transmission or transaxle during a test drive. • Explain how to test an automatic transmission/transaxle using a scan tool. • Discuss how to locate automatic transmission fluid leaks. • Explain how to perform a system pressure test. • Describe how to replace or flush automatic transmission fluid. • Describe how to perform on-vehicle transmission adjustments.

KEY TERMS: Diagnostic trouble codes (DTCs) 1588 • Technical service bulletins (TSBs) 1590

TRANSMISSION PROBLEM DIAGNOSIS

VERIFY THE CUSTOMER CONCERN The first step is to verify the customer concern. The customer should be asked the following questions in an effort to determine as much about the problem as possible.

- What exactly seems to be the concern? (Ask the customer to be as detailed as possible.)
- When did the problem first appear?
- Under what conditions do the symptoms occur? (Do they occur first thing in the morning? After the vehicle has been driven for a while?)
- Describe under what driving conditions the problem is noticed, such as when accelerating or while coasting to a stop or some other condition.
- Has the vehicle been serviced recently, such as a fluid change?

FLUID CHECK The first step in diagnosing any problem is to test drive the vehicle and verify the customer complaint (concern). Before test driving the vehicle, check the level and condition of the automatic transmission/transaxle fluid. Follow the procedure for checking the level as published in the owner's manual or factory information. **SEE FIGURES 129–1 AND 129–2.**

The typical procedure for checking automatic transmission fluid level includes the following steps. (Check service information for the exact procedure to follow.)

STEP 1 Start the engine, except for Honda/Acura vehicles which specify that the ATF be checked with the engine off.

STEP 2 Be sure that the ATF is at normal operating temperature. This may require that the vehicle be driven for several miles.

STEP 3 Park the vehicle on a level surface. Start the engine and shift the transmission through each gear, allowing engagement in each gear.

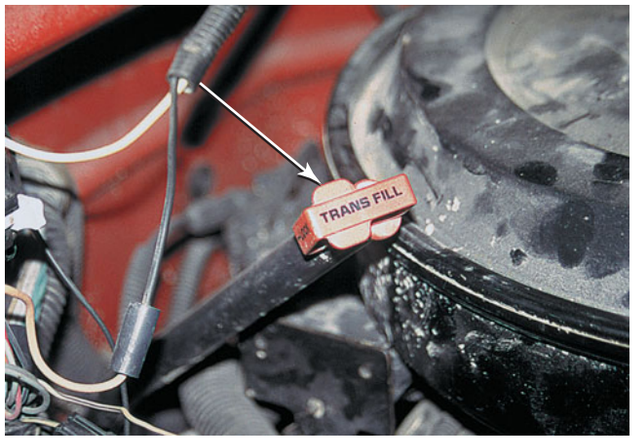


FIGURE 129–1 A typical automatic transmission dipstick (fluid level indicator). Many use a clip to keep it from being forced upward due to pressure changes inside the automatic transmission. A firm seal also helps keep water from getting into the fluid, which can cause severe damage to the clutches and bands.



FIGURE 129–2 The "add" mark on most automatic transmission dipsticks indicates the level is down 0.5 quart (0.5 liter). Always follow the instructions stamped or printed on the dipstick.

STEP 4 Clean the area around the dipstick to help prevent dirt from falling into the filler tube when the dipstick is removed.

CAUTION: Be sure any transmission filler cap, plug, or dipstick is installed tightly. Water contamination of the transmission fluid will eventually destroy frictional linings of apply devices.

STEP 5 Remove the dipstick and wipe it off with a shop cloth.

STEP 6 Reinsert the dipstick and then remove it again. Check the level. The "add" mark indicates that the level is a half quart (liter) low.

TECH TIP

Quick-and-Easy Automatic Transmission/ Transaxle Diagnosis

An experienced technician told the beginning technician that automatic transmission/transaxle diagnosis is often very easy. For example:

- **If the vehicle does not move in drive or reverse,** remove the transmission/transaxle for service because the problem is likely mechanical rather than hydraulic (valve body) or electrical (computer, solenoids, or sensors). If the unit will not power the vehicle, the unit will more than likely require removal for a thorough mechanical inspection and repair.
- **If the vehicle moves, but does not shift correctly,** the problem is likely electrical (computer, solenoid, or sensor) or hydraulic (valve body) rather than mechanical. This is usually true because if the vehicle is able to move forward and backward, the major mechanical components, though not in like-new condition, are at least able to function. Therefore, correcting the non-mechanical problem should be the technician's first consideration.

Results and possible causes include:

- If the fluid level is low, add the specified fluid until the proper level is achieved before test driving the vehicle.
- If the level is too high, this can cause the fluid to become aerated, meaning that the fluid becomes filled with air bubbles. When the fluid is aerated, the transmission or transaxle cannot shift properly. The fluid should be red, although some highly friction-modified ATFs are normally light brown which is normal and not a cause for alarm.
- If the color of the fluid is dark brown or black, then the fluid has been overheated.
- Smell the fluid. It should have a "clean petroleum" smell. If it smells "burned" or rancid, then this indicates that the fluid has been overheated and will require replacement.
- If the fluid is milky, this usually means that coolant has entered the fluid usually through a fault with the ATF cooler located in the radiator.

STEP 7 Insert the dipstick into the transmission/transaxle and remove. Allow a few drops to fall onto a paper towel. Then take the end of the dipstick and place it into a container of new ATF and allow the same number of drips to fall onto another section of the paper towel. Allow to sit for 10 minutes.

- If the fluid expands to the same size as the new fluid, then it has maintained it lubricity and viscosity.
- If the fluid fails to expand to the same diameter as the new fluid, this means that the fluid has lost some of its lubricity and has increased in viscosity. A fluid change would then be indicated.
- If a dark stain shows on the white paper towel, this means that it is contaminated with clutch material or varnish from oxidized fluid and requires further diagnosis.
- If the stain is a foamy pink, then this may indicate coolant in the transmission/transaxle.



FIGURE 129–3 Use all shift modes when diagnosing automatic transmission/transaxle concerns to help pinpoint the area where the fault is located.

STEP 8 Rub the fluid between your fingers. It should feel slick. If it feels gritty, then it is contaminated with friction material or other solid particles.

NOTE: Many newer transmissions/transaxles do not use a dipstick. The fluid level is usually checked similar to how the fluid in a manual transmission/transaxle is checked by removing a plug in the side of the case. In some vehicles the fluid level can be checked using a scan tool. Check service information for the exact methods to use to check ATF level.

TEST DRIVE

When test driving the vehicle, try to drive the vehicle under the same conditions that the owner noticed the problem.

To ensure a thorough diagnosis, the vehicle should be driven under a variety of conditions to see if it functions correctly, including the following:

1. **From a stop, and accelerated slowly until at highway speed.** This will check if all shifts are occurring and at the correct speeds.
2. **Note how the shifts feel.** The shifts may be too harsh or too soft. This could indicate a fluid pressure problem, or a worn clutch, bands, or accumulator.
3. **Note when the shifts occur.** The shifts may occur too early or too late.
4. **Use all gear selections.** Often a different element of clutch is used for manual gears compared to the same gear when the gear selector is in drive (D). Note any differences that may help in identifying the source of the problem. ● **SEE FIGURE 129–3.**

COMMANDING SHIFTS

Many automatic transmission test tools or scan tools can be used to actually cause the automatic transmission/transaxle to shift electrically. The tester is connected to the electrical connector at the automatic transmission/transaxle after disconnecting the factory connector. To perform this simple test, perform the following steps.

STEP 1 Safely hoist the vehicle.

STEP 2 Start the engine.

STEP 3 Place the gear selector in the drive position and use the tester or scan tool to command the various shift solenoids to actuate.

TRANSMISSION-RELATED DTCs			
P0703	Brake switch input circuit	P0741	Torque converter clutch system performance or stuck off
P0705	Transmission range sensor circuit problem (PRNDL input)	P0742	Torque converter clutch system stuck on
P0706	Transmission range sensor circuit range or performance	P0743	Torque converter clutch system electrical
P0707	Transmission range sensor circuit low input	P0745	Pressure control solenoid problem
P0708	Transmission range sensor circuit high input	P0746	Pressure control solenoid performance or stuck off
P0710	Transmission fluid temperature sensor problem	P0747	Pressure control solenoid stuck on
P0711	Transmission fluid temperature sensor range or performance	P0748	Pressure control solenoid electrical
P0712	Transmission fluid temperature sensor low input	P0750	Shift solenoid A problem
P0713	Transmission fluid temperature sensor high input	P0751	Shift solenoid A performance or stuck off
P0715	Input or turbine speed sensor circuit problem	P0752	Shift solenoid A stuck on
P0716	Input or turbine speed sensor circuit range or performance	P0753	Shift solenoid A electrical
P0717	Input or turbine speed sensor circuit no signal	P0755	Shift solenoid B problem
P0720	Output speed sensor circuit problem	P0756	Shift solenoid B performance or stuck off
P0721	Output speed sensor circuit range or performance	P0757	Shift solenoid B stuck on
P0722	Output speed sensor circuit no signal	P0758	Shift solenoid B electrical
P0725	Engine speed input circuit problem	P0760	Shift solenoid C problem
P0726	Engine speed input circuit range or performance	P0761	Shift solenoid C performance or stuck off
P0727	Engine speed input circuit no signal	P0762	Shift solenoid C stuck on
P0728	Gear 6 incorrect ratio	P0763	Shift solenoid C electrical
P0730	Incorrect gear ratio	P0765	Shift solenoid D problem
P0731	Gear 1 incorrect ratio	P0766	Shift solenoid D performance or stuck off
P0732	Gear 2 incorrect ratio	P0767	Shift solenoid D stuck on
P0733	Gear 3 incorrect ratio	P0768	Shift solenoid D electrical
P0734	Gear 4 incorrect ratio	P0770	Shift solenoid E problem
P0735	Gear 5 incorrect ratio	P0771	Shift solenoid E performance or stuck off
P0736	Reverse incorrect ratio	P0772	Shift solenoid E stuck on
P0740	Torque converter clutch system problem	P0773	Shift solenoid E electrical

CHART 129–1

Transmission/transaxle-related diagnostic trouble codes (DTCs). For transmission-related diagnostic trouble codes for vehicles older than 1996, check service information on how to retrieve and read the codes.

RESULTS: If the shift occurs when commanded, the hydraulic system is functioning. If the tester commands a shift to occur and a shift does not occur, the service technician knows that the problem is either in the solenoid itself or the hydraulic system that actuates the clutch or band to accomplish the shift. ● **SEE FIGURE 129–4**.

CAUTION: A scan tool or special tester can be used to command shift while an assistant is driving the vehicle instead of on a hoist as stated above. If commanding a shift when driving, use extreme care as some shift may be harsh and damage to the vehicle could occur if the commanded shift occurs at too high a vehicle speed.

CHECK DIAGNOSTIC TROUBLE CODES

If there are any **diagnostic trouble codes (DTCs)** stored in the memory of the vehicle computer, then a problem has been detected that should be corrected before further testing. ● **SEE CHART 129–1** for transmission-related diagnostic trouble codes.

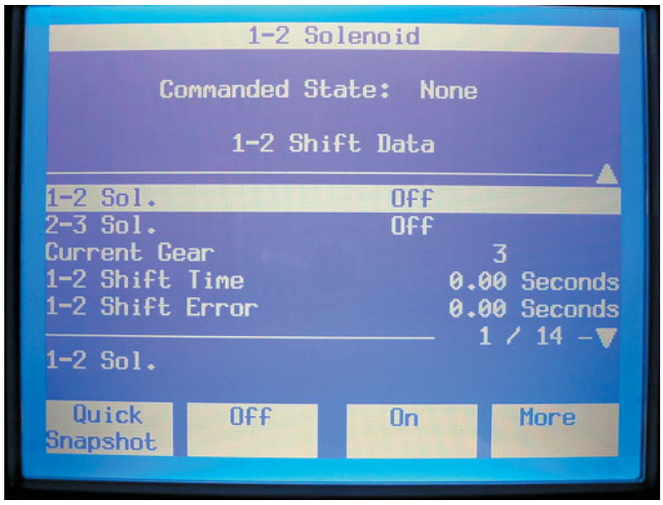


FIGURE 129–4 Most factory or factory-level scan tools are capable of bidirectional control of the automatic transmission or transaxle.

A weak or missing engine cylinder can cause the vehicle to lack power, jerk, and hesitate. These symptoms are often blamed on an incorrectly shifting or slipping automatic transmission/transaxle. If a P0300 diagnostic code (random engine misfire code) is set, repair the cause of the misfire before trying to diagnose the transmission. Other misfire codes include:

P0301	Cylinder 1 misfire detected
P0302	Cylinder 2 misfire detected
P0303	Cylinder 3 misfire detected
P0304	Cylinder 4 misfire detected
P0305	Cylinder 5 misfire detected
P0306	Cylinder 6 misfire detected
P0307	Cylinder 7 misfire detected
P0308	Cylinder 8 misfire detected
P0309	Cylinder 9 misfire detected
P0310	Cylinder 10 misfire detected
P0311	Cylinder 11 misfire detected
P0312	Cylinder 12 misfire detected

SCAN DATA A scan tool can display information about the various sensors and components that can assist the service technician in determining the cause of many automatic transmission/transaxle problems.

A properly operating engine should display the following readings with the engine at idle and operating in closed loop.

- **Engine coolant temperature (ECT)**—between 180°F and 215°F (82°C and 102°C)
- **Throttle position (TP) sensor**—usually between 0.5 volt and 4.5 volts and varying directly with throttle movement
- **Accelerator pedal position sensor (APPS)**—usually two or more sensors on differing scales (0.4 volt to 4.6 volts) and varying with accelerator pedal movement
- **Fuel injector pulse width**—1.5 to 3.5 ms
- **Upstream oxygen sensor (O2S)**—voltage varying between 200 and 800 mV
- **Air-fuel ratio sensor(s) (if equipped)**—scan tool to read fairly low and steady
- **Transmission fluid temperature**—less than 275°F (135°C)
- **Brake switch**—scan data to show a change when brake pedal is pressed and released
- **Manifold absolute pressure (MAP) sensor**—with the engine idling in park or neutral, the voltage should be within 0.88 volt and 1.62 volts or between 102 and 109 Hz for a Ford MAP sensor.
- **Mass airflow sensor (MAF)**—warm engine in park with no load typically reads grams per second within 20% of the engine's liters of displacement, a 3.5 liter engine will show fairly close to 3.5 g/s of airflow at idle
- **Vehicle speed (VS) sensor**—source can vary: derived from ABS wheel speed sensors, output speed sensor of transmission, or a dedicated sensor on transmission or transfer case
- **Idle speed**—check for normal idle speed; vehicles with electronic throttle control are usually 2% to 3% open at warm idle in park and vehicles with IAC (idle air control) valves are typically 10 to 30 steps if stepper motor type or 250 to 400 milliamps if linear
- **Shift solenoids**—check for the proper voltage and current of the shift solenoids using a factory or factory-level scan tool.

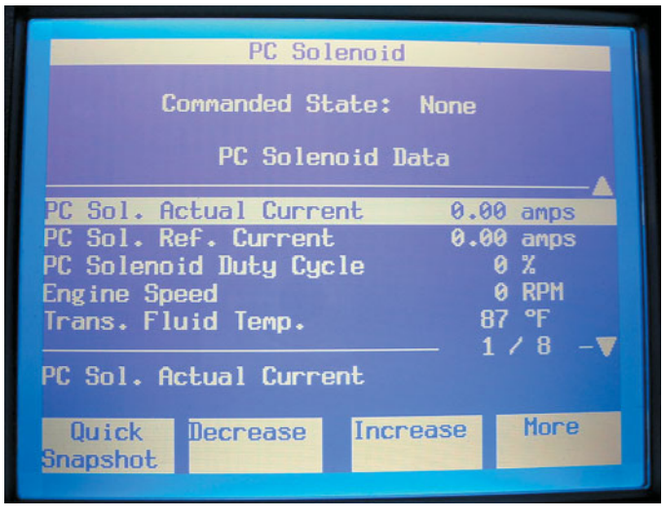


FIGURE 129–5 A Tech 2 scan tool is able to display shift solenoid current. Use this information and check service information for the specified current to help diagnose shift solenoid-related faults.

INPUT SENSOR	TYPICAL VALUE
Throttle position (TP) sensor	0.5 to 4.5 volts (0% to 100%)
Mass airflow (MAF) sensor	3 to 7 grams per second at idle
Oxygen sensor (O2S)	200 to 800 mV and changing rapidly
Turbine shaft speed (TSS) sensor	Should be the same as the engine speed
Transmission fluid temperature (TFT) sensor	−40°F to 300°F (−40°C to 150°C)
Transmission range (TR) sensor	P, N, R, D, L (or 2, 1)
Overdrive switch (if equipped)	On or Off
Barometric pressure (BARO) sensor	Varies with weather and altitude
Accelerator pedal position (APP) sensor	0% to 100%
Brake pedal position (BPP) switch	On or Off

CHART 129–2

Typical automatic transmission/transaxle sensor values as displayed on a scan tool.

Observe the operation of the command for the shift solenoids and the TCC solenoid while driving the vehicle. This information confirms that the computer is commanding the operation; it does not mean that the solenoids are working correctly. Therefore, if the scan data indicates that a particular solenoid is being commanded on and nothing occurs, then the problem could be caused by a defect with the following:

1. Hydraulic component (clutch, band, etc.)
2. Solenoid
3. Fault in the wiring to the solenoid or from the solenoid to the PCM or TCM

● **SEE FIGURE 129–5.**

Use a scan tool to check the engine operation values and inputs that could affect transmission operation. ● **SEE CHART 129–2.**

TECH TIP

You'd Ask a Friend, Wouldn't You?

If you were stuck on a difficult transmission problem, you would probably ask a technician friend for ideas. Think of the service information as a friend with some inside information. It is written by the people who know how the system works in detail.

Such advice is available in service information. If the technician follows the recommended steps, chances are excellent of finding the problem—just like getting the advice of an experienced technician. ● **SEE FIGURE 129–6.**



FIGURE 129–6 Checking service information for how to perform diagnosis on an automatic transmission fault is a wise step.

TECH TIP

Quick-and-Easy Automatic Transmission/Transaxle Diagnosis

An experienced technician told the beginning technician that automatic transmission/transaxle diagnosis is often very easy. Assuming that the fluid level has been checked and is at the specified level, consider the following examples.

- **If the vehicle does not move in drive or reverse,** then remove the transmission/transaxle for service because the problem is likely mechanical rather than valve body or electrical (computer, solenoids, or sensors). If the unit will not power the vehicle, the unit will more than likely require removal for a thorough mechanical inspection and repair.
- **If the vehicle moves, but does not shift correctly,** then the problem is likely electrical (computer, solenoid, or sensor) or hydraulic (valve body) rather than mechanical. This is usually true because if the vehicle is able to move forward and backward, the major mechanical components, though not in like-new condition, are at least able to function. Therefore, correcting the nonmechanical problem should be the technician's first consideration.

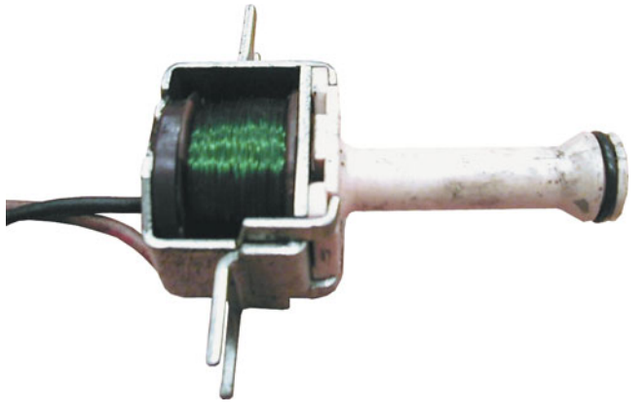


FIGURE 129–7 A torque converter clutch (TCC) solenoid. This TCC can be replaced on a General Motors vehicle without having to remove the transmission/transaxle from the vehicle.

REAL WORLD FIX

The Stalling Impala

The owner of a Chevrolet Impala complained that the vehicle would occasionally stall when slowing to a stop. The problem only occurred after at least 20 miles and occurred more frequently in warm weather. The owner also indicated even though this vehicle was equipped with an automatic transmission it felt like the clutch not being depressed on a manual transmission. Thankfully, the service technician was aware of this common problem and installed a new torque converter clutch solenoid.

When the original solenoid got hot, it became stuck in the applied position. Even though the voltage was removed from the solenoid when the brakes were applied, the solenoid and the torque converter clutch (TCC) remained applied. ● **SEE FIGURE 129–7.**

CHECK TECHNICAL SERVICE BULLETINS

According to studies performed by automobile manufacturers, as many as 30% of the vehicles can be repaired following the information, suggestions, or instructions concerning replacement parts found in a **technical service bulletin (TSB).** Before an accurate search of a TSB can be performed, the technician must know the following information about the vehicle under service.

- Make, model, and year of the vehicle
- Engine size and VIN
- Transmission type
- Federal, high-altitude, or California emissions
- Build date (sometimes)
- Current hard codes
- History or soft codes
- PCM/TCM part number for applicable module flash

Diagnostic trouble codes must be known before searching for TSBs because bulletins often include information on solving problems that involve a stored code.

TRANSMISSION/TRANSAXLE IDENTIFICATION

The identification of the transmission/transaxle can sometimes be a

REAL WORLD FIX

The Rough Idle Story

The owner of a Chevrolet pickup truck equipped with a V-6 engine complained of a rough idle. The idle was smooth when the transmission was in park or neutral, but became rough when the gear selector was placed in any drive gear position. The service technician could not find the cause of the problem but did notice that the engine seemed to be under a heavy load at idle speed due to the MAP sensor reading. The customer was questioned again about the possibility of a previous repair that may have had an effect on the idle. The customer said that the automatic transmission had been replaced recently but didn't think that could have an effect on the rough idle problem. A quick check of the stall speed indicated a much lower stall speed than normal—1400 RPM versus 1850 RPM normal stall speed. Obviously, either the torque converter was defective or a torque converter for a V-8 was installed in the V-6 truck. After returning to the transmission shop and getting a replacement torque converter installed, the rough idle problem was solved.

challenge. Check service information to determine the identification of the unit based on one or more of the following:

- Vehicle identification number
- Engine (transmissions can vary internally based on engine size)
- Regular production option (RPO) code
- Transmission/transaxle identification plate information
- Pan shape and/or number of bolts used on the pan

STALL TESTING THE TORQUE CONVERTER A stall test is often performed to verify the proper operation of the torque converter.

CAUTION: Some vehicle manufacturers do not recommend performing a stall test because it can be dangerous if the brakes were to fail during the test and it places stress on the engine. Always follow the manufacturer's recommended service procedures.

Performing a stall test includes the following steps.

STEP 1 Drive the vehicle until normal operating temperature is achieved.

STEP 2 Check the stall speed specifications for the vehicle being serviced and connect a tachometer to the engine.

STEP 3 With your left foot firmly applied to the brake pedal, move the shift selector in the drive position and depress the accelerator pedal to the floor. Observe the maximum engine speed. This engine speed is the stall speed.

● **SEE FIGURE 129–8.**

STEP 4 Release the accelerator as soon as possible to avoid the possibility of overheating the automatic transmission fluid. Repeat the test with the gear selector in reverse.

NOTE: Checking the stall speed in reverse is just a double check. This is done because the line pressure is higher in reverse and as a result, the higher pressure will hold clutches better and keep them from slipping. A slipping forward clutch could cause the engine speed to be higher than normal and would affect the recorded stall speed.



FIGURE 129–8 This 4-cylinder General Motors vehicle has a stall speed of about 2350 RPM. Notice that the gear selector is in drive and the speedometer is reading zero.

STEP 5 Compare results with the specifications.

- *If the engine speed is higher than specifications,* then a holding clutch or band is slipping.
- *If the engine speed is lower than specifications,* then the torque converter is defective (one-way clutch or stator is slipping) or the engine is not producing normal power output.

Both conditions can result in reduced vehicle performance and slow acceleration.

NOTE: There are many other possible causes of poor performance or sluggish acceleration besides a fault with the automatic transmission/transaxle. The stall test is just one test that can be performed to help narrow the problem to the root cause.

FLUID LEAK DIAGNOSIS

VISUAL INSPECTION To locate a leak from an automatic transmission/transaxle, the first step is to perform a thorough visual inspection. Start by checking the fluid level.

- If too high, then the fluid loss could be caused by it being overfilled and forced out of the vent opening located at the top of the unit.
- If too low, a fluid leak is the most likely cause and should be corrected as soon as possible to prevent damage, wear, or harm to the transmission/transaxle parts due to low fluid level.

Perform a visual inspection using the following steps.

STEP 1 Use a trouble light and start the visual inspection under the hood and look for signs of fluid leakage on the top of the unit. Because fluids flow downward due to gravity, the fluid will be most likely seen from underneath the vehicle; however, the source could be at or the near the top.

STEP 2 Hoist the vehicle safely and look for the highest and most forward place where fluid is seen. Due to gravity and the forward movement of the vehicle, leaking fluid will travel downward and toward the rear. ● **SEE FIGURE 129–9.**

DYE TESTING Often the exact location of a fluid leak is difficult to locate. Using a dye designed for ATF and a black light is an

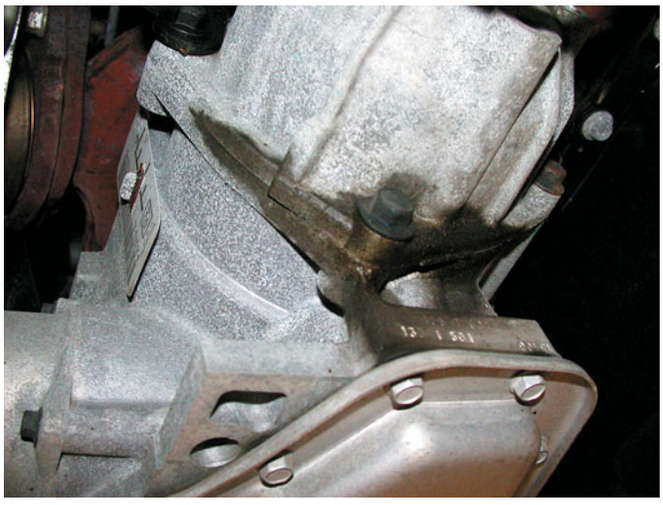


FIGURE 129–9 Sometimes the location of a transmission fluid leak is easy to see, but with others it can be difficult to find the exact location. Look closely at places where O-rings or gaskets are used, as these are the most common areas where fluid leaks occur.



FIGURE 129–10 A black light being used to locate the source of an automatic transmission fluid leak.

TECH TIP

Vibration—Engine or Transmission?

A vibration is often difficult to diagnose. One method is to separate (unbolt) the torque converter from the engine drive flex plate. Push the torque converter as far toward the transmission/transaxle as possible, then start the engine. If the vibration is gone, the problem is due to a fault in the torque converter, pump assembly, or other component that is constantly rotating with the engine running. If the vibration is still present, then the cause is due to an engine or accessory problem.

TECH TIP

Look at the Command and the Engine Speed

Using a scan tool is very helpful when diagnosing automatic transmission problems. However the display often shows when the shift has been commanded and may not show if the shift or the TCC engagement actually occurred. To help ensure that the shifts have in fact occurred, also watch the engine speed. Many factory or enhanced scan tools can also display the engagement speed. A slow engagement is usually caused by worn clutches. Check service information for the exact parameters and range of proper operation for the vehicle being diagnosed.

effective method to locate ATF leaks. To check for leaks using a dye, perform the following steps.

STEP 1 Add a small bottle of dye that is designed for use in ATF into the dipstick tube using a transmission funnel.

CAUTION: Do not use dye designed for use in coolant or air-conditioning systems or severe harm can occur to the automatic transmission/transaxle.

STEP 2 Drive the vehicle until the fluid has reached normal operating temperature.

STEP 3 Safely hoist the vehicle.

STEP 4 Using a black light, look for the highest and most forward place where a greenish stain appears. This is the source of the leak.

SEE FIGURE 129–10.

TORQUE CONVERTER CLUTCH DIAGNOSIS

The torque converter clutch is usually applied above 30 MPH (48 km/h) when the automatic transmission/transaxle is in second, third, or overdrive gear, depending on the vehicle speed and the throttle position. It is often difficult to distinguish between a normal shift and the application of the torque converter clutch. The torque converter clutch (TCC) may not even be applying due to a fault in the computer sensors, wiring, or the TCC solenoid.

NOTE: If the torque converter clutch does not apply, a drop in fuel economy of 3 to 4 miles per gallon is commonly reported. If the TCC fails to apply on an automatic transmission/transaxle, the automatic transmission fluid is likely to become overheated due to the torque converter slip. The higher fluid temperature can cause the automatic transmission/transaxle to fail.

To test for proper operation of the torque converter clutch, simply drive the vehicle and watch either the tachometer on the dash or connect a scan tool to observe the engine RPM.

STEP 1 Drive the vehicle until the engine has reached normal operating temperature.

STEP 2 Drive the vehicle on a flat, level road away from any traffic about 50 MPH (80 km/h).

STEP 3 While maintaining constant speed with your right foot on the accelerator, gently apply the brake pedal with your left foot to open the electrical circuit for the torque converter clutch through the brake switch. The TCC will disengage and the RPM should increase about 150 to 250 RPM and then drop back when the brake pedal is released. This RPM change is evidence that the TCC is, in fact, working. If the torque converter clutch is not operating, consult the factory information for the exact procedures to follow.

RANGE	GEAR	2-4 BAND	REVERSE INPUT CLUTCH	OVERRUN CLUTCH	FORWARD CLUTCH	FORWARD SPRAG CL. ASSEMBLY	3-4 CLUTCH	LO-ROLLER CLUTCH	LO-REV. CLUTCH
Park-Neutral									
Overdrive	First Gear		Holding		Applied	Holding		Holding	
	Second Gear	Applied	Third Gear		Applied	Holding			
	Third Gear		Applied		Applied	Holding	Applied		
	Fourth Gear	Applied	Applied		Applied		Applied		
Drive	First Gear		Holding	Applied	Applied	Holding		Holding	
	Second Gear	Applied	Applied	Applied	Applied	Holding			
	Third Gear			Applied	Applied	Holding	Applied		
Manual 2Nd	First Gear			Applied	Applied	Holding		Holding	
	Second Gear	Applied		Applied		Holding			
Manual 1St	First Gear			Applied		Holding		Holding	Applied
Reverse	Reverse		Applied						Applied

CHART 129–3

This typical range chart shows the forward clutch is applied in all forward gears. Notice that if the low-reverse clutch were to fail, it would prevent the vehicle from moving in both reverse and forward.

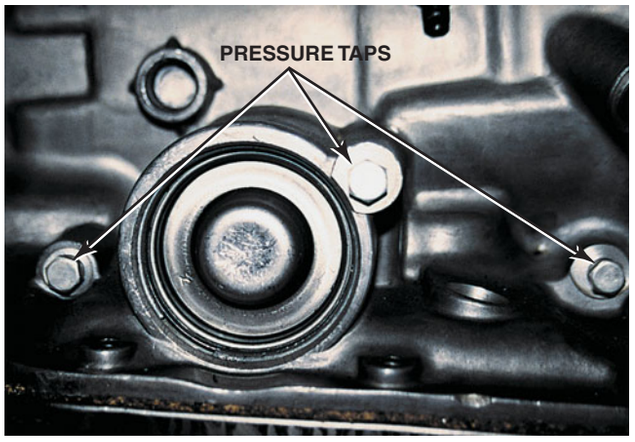


FIGURE 129–11 The locations (taps) for connecting a pressure gauge to measure the pressure of the various hydraulic circuits are usually found on the side of the automatic transmission/transaxle. Check service information for the exact locations for the vehicle being tested.

GEAR SELECTION	IDLE (PSI)	WIDE OPEN THROTTLE (WOT) (PSI)
Park (P)	54–60	54–60
Reverse (R)	100–105	250–300
Neutral (N)	54–60	54–60
Drive (D)	54–87	240–250
Low (L)	84–87	240–250

CHART 129–4

A pressure chart for the Ford 6F50N/GM 6T70 transaxle.

NOTE: If the temperature of the automatic transmission fluid (ATF) is too high, the computer will modify the shift pattern (usually disabling overdrive) and engage the TCC at slower speeds in an attempt to drop the temperature of the ATF to less harmful temperatures. Also if the temperature is too low, the PCM may not allow lockup and may limit the number of forward gears available until the transmission fluid warms up. This computer control of the shifting may be noticeable to the driver as a fault.

RANGE CHARTS

All vehicle manufacturers publish range charts that indicate which holding device is used for each gear selection. Knowing which component is being used for each gear helps the service technician determine the cause of a failure or problem. ● **SEE CHART 129–3.**

PRESSURE TESTING

Pressure testing involves connecting a pressure gauge to pressure taps located on the outside of the automatic transmission/transaxle. ● **SEE FIGURE 129–11.**

After connecting the pressure gauge(s) to the transmission/transaxle, start the engine and select the gear being monitored. Check service information for the specified pressures.

● **SEE CHART 129–4** for a typical pressure chart.

If the pressure is not within specifications, then the technician knows that the fault is internal and usually involves either removing the valve body, or in many cases, removing the automatic transmission/transaxle from the vehicle. ● **SEE FIGURE 129–12.**

TRANSDUCERS

Pressure switches are used to verify that solenoids and/or valves have done their job. They do not read actual pressure as they are usually controlled by a spring rated at a certain number of pounds. A transducer-equipped vehicle will usually provide an actual pressure reading on a scan tool. Many vehicles with variable line pressure will have a transducer.

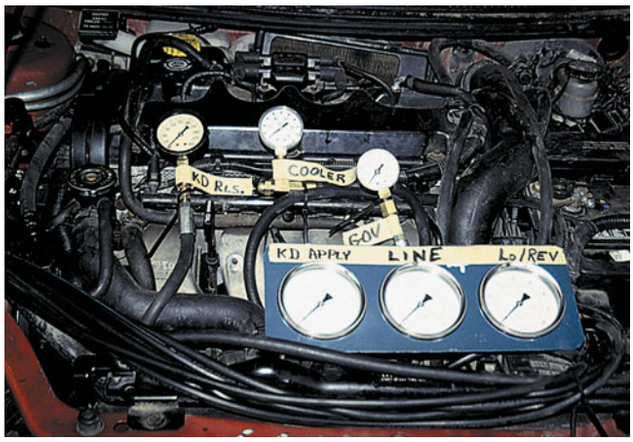


FIGURE 129–12 Six pressure gauges are installed on this vehicle to show students how the pressures vary and how the gauges can be used to find faults or possible problem areas before the unit is removed and disassembled.



FIGURE 129–13 Draining the fluid from an automatic transaxle by allowing the fluid to flow into a container after most of the retaining bolts have been removed.

REAL WORLD FIX

The Customized Van Story

The owner of a customized General Motors van equipped with an electronically controlled automatic transmission (4L80-E) complained that the automatic transmission downshifted into second gear and stayed in second gear whenever the headlights were turned on. The transmission shifted okay when the headlights were turned off. After hours of troubleshooting, including the replacement of the vehicle computer (which did not help), the technician discovered that 4 volts DC were on the one wire leading from the vehicle speed (VS) sensor to the vehicle computer whenever the headlights were turned on. Obviously, there was a short to voltage between a light wire and the sensor wire. Instead of totally disassembling the van, the technician decided to replace the wire with a new one, and the problem was solved. The 4 volts DC apparently shut down the computer. When the computer stopped controlling the shifts, both A and B solenoids were shut off. With both solenoids A and B off, the transmission was in second gear. This is the default gear or the limp-in-mode gear for this transmission. After replacing the wire, the automatic transmission returned to manual operation, allowing the driver to drive at night and in the daytime.

FREQUENTLY ASKED QUESTION

What Is Wrong When My Automatic Transmission Does Not Upshift?

The following examples can cause the automatic transmission/transaxle to fail to upshift.

- A *defective governor* (if so equipped) will often not allow any automatic transmission/transaxle to shift out of first gear or stuck in high gear.
- A *defective vacuum modulator* (if so equipped) or misadjusted *throttle valve* will often delay the shift until a very high speed is achieved.
- A *fault in the PCM, TCM, or a speed sensor* on electronically controlled automatic transmissions/transaxles will occur when one gear, usually second or third, is selected and the unit will not shift out of that gear.

IN-VEHICLE SERVICE

PAN REMOVAL Check service information for the exact procedure to follow when removing the pan. Some transaxles are equipped with a side pan that either may nor may not be needed to be removed when serving the assembly. The usual procedure includes the following steps.

STEP 1 Hoist the vehicle safely.

STEP 2 Place a large drain pan under the transmission/transaxle pan.

STEP 3 Loosen all of the fasteners except for those at one end. Allow the pan to drop down slightly at one end allowing fluid to drain into the drain pan.

● **SEE FIGURE 129–13.**

STEP 4 After the fluid has stopped flowing from the pan, carefully remove the last retaining bolts, slowly lower the pan, and allow any remaining fluid to flow into the drain pan.

STEP 5 Dispose of or recycle the used automatic transmission fluid according to state or local laws.

STEP 6 Remove all of the oil pan bolts except for two at one end. This will allow the pan to drop and empty most of the ATF into the drain container without falling. After most of the ATF has drained, remove the remaining bolts and remove the pan.

STEP 7 Inspect the inside of the pan for excessive friction material and wear metals (such as lead and copper from bushings). Use a magnet to check for steel particles, which would indicate serious wear to major components. ● **SEE FIGURE 129–14.**



FIGURE 129–14 This is a normal amount of wear material in the bottom of an automatic transmission pan.

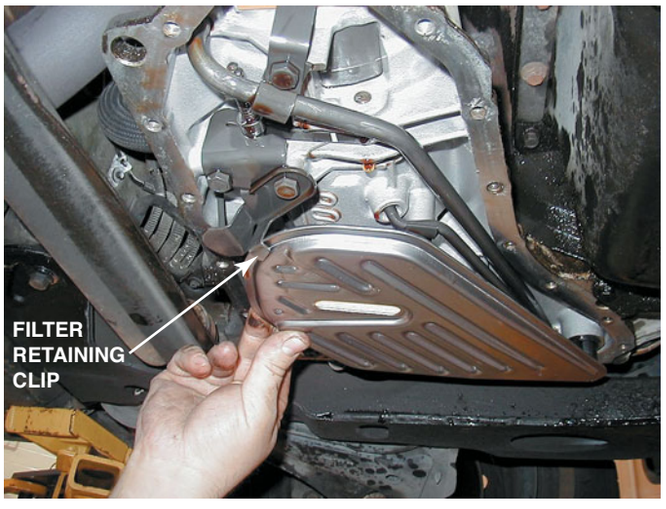


FIGURE 129–15 Always check that the filter is secured by a clip or other fastener to keep it from dropping out of location.

NOTE: The presence of metal particles in the pan of an automatic transmission/transaxle does not necessarily mean that a part(s) has failed or needs to be replaced. Some wear is normal. If there are a lot of metallic particles in the pan, then this may be an indication of severe gear failure that may require replacement. Use a magnet to check for steel particles. Ask the advice of an experienced transmission expert, if in doubt, about whether the wear should be considered "normal."

WARNING

The automatic transmission fluid may be hot enough to cause personal injury. Wear protective clothing and avoid contact with the hot fluid.

FILTER REPLACEMENT

Check service information for the exact procedure to follow when replacing the filter. Most are retained by a clip or a bolt. ● **SEE FIGURE 129–15.**

CAUTION: Extra or missing O-rings on filter necks and/or cracked or mispositioned filter filler necks cause many problems. The pump may intermittently ingest air, leading to transmission or driveability complaints such as rough idle or an engine stalling condition.

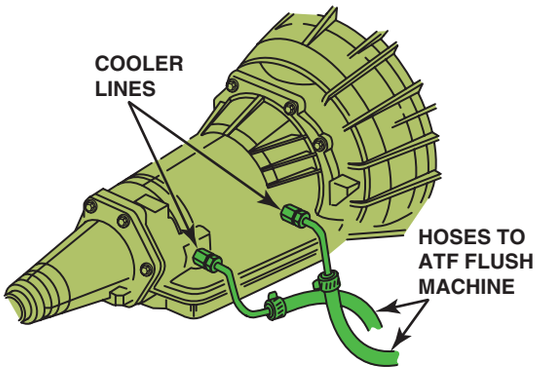


FIGURE 129–16 A fluid exchange machine uses the engine and the transmission pump to force the fluid into the machine where the old fluid is used to push against a diaphragm, which then forces new fluid back through the transmission. A sight glass is used to show the technician the fluid, so the process can be stopped when only clean, new fluid is seen flowing through the cooler line.



FIGURE 129–17 In this case, the cork-rubber gasket is glued to the pan and is ready to be installed. The retaining bolts need to be tightened in sequence, but be aware that overtightening will cause a leak. Also, some manufacturers recommend using only an RTV sealer, but never use an RTV sealer and a gasket together.

FLUSHING ATF

The following are ways to flush automatic transmission fluid.

1. Connect the cooler lines to a machine that exchanges the old fluid with new fluid. ● **SEE FIGURE 129–16.**
2. Use a machine to draw out the old fluid though the filler tube and then refill it with clean fluid.
3. Use a machine that attaches to the pump inlet after the pan and filter have been removed. The machine uses its own pump to force all of the old fluid from the transmission or transaxle.
4. Drain and refill. Using this method, recommended by Honda and Acura, means that about 3 quarts are being replaced. The vehicle should be driven and the drain and refill formed another two times.

Most experts recommend that the filter be replaced, so the pan should be removed (except for Honda and Acura) and the filter replaced after any of the above methods are used. ● **SEE FIGURE 129–17.**

FREQUENTLY ASKED QUESTION

How Is a Vacuum Modulator Tested?

A vacuum modulator is used on many hydraulically controlled automatic transmissions/transaxles. Most vacuum modulators affect shift points, so if shift timing is delayed on most units that have a vacuum modulator, then it should be tested. Higher engine loads (lower vacuum to the vacuum modulator) result in a firmer shift occurring later than normal; and at light engine loads, the shift is softened and will occur earlier.

To check for proper operation of the vacuum modulator, follow these steps:

STEP 1 Hoist the vehicle safely and locate the vacuum modulator (if equipped).

STEP 2 Remove the vacuum hose from the vacuum modulator. If automatic transmission fluid drips out when the hose is removed, the vacuum modulator is defective and must be replaced.

STEP 3 Use a hand-operated vacuum pump to apply vacuum to the vacuum modulator. If the modulator is okay, the vacuum reading will hold steady and not drop. If the vacuum modulator will not hold vacuum, the modulator should be replaced.

STEP 4 Connect a vacuum gauge to the vacuum line from the intake manifold and have an assistant start the engine. The vacuum reading at the vacuum modulator should be 17 to 21 in. Hg with a minimum vacuum reading of 15 in. Hg to assure proper shifting of the automatic transmission/transaxle.

NOTE: A defective vacuum modulator can cause automatic transmission fluid (ATF) to be drawn by engine vacuum into the intake manifold. When ATF burns, it produces white smoke. The white smoke is often confused with steam. Therefore, the smart technician should check if the vehicle is equipped with a properly functioning vacuum modulator before continuing the diagnosis for steam coming from the tailpipe.

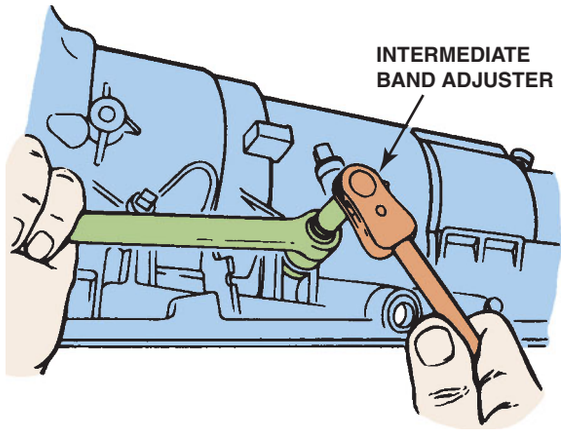


FIGURE 129–18 Adjusting the intermediate band on a Ford A4LD transmission.

BAND ADJUSTMENT Some automatic transmissions/transaxles allow the technician to adjust the clearance between the band and the drum inside the unit. The procedure usually involves tightening the adjustment nut or bolts to a specified torque reading and then backing off the adjustment nut or bolts a specified number of times. Some bands are adjustable external to the transmission and others require dropping the pan. ● **SEE FIGURE 129–18.**

TECH TIP

Use Old Headlights to Check Wiring

The proper operation of any electronically controlled automatic transmission/transaxle depends on having electrical power available to operate the solenoids. Before removing the unit from the vehicle, use a headlight to check if there is enough current being sent to the unit. Unplug the electrical connection that supplies 12 volts, usually from the ignition switch. Use a headlight and attach wires to the ground and the bright filament terminals.

Attach one test lead from a headlight to the terminal that supplies 12 volts to the unit. Attach the other lead from the headlight to a good clean chassis or transmission ground such as the case. Turn ignition key on, engine off (KOEO) and observe the headlight.

- If the headlight is dim, there is a voltage drop between the source (battery) and the transmission feed. Check the wires directly leaving the ignition switch or transmission control relay. If the headlight is still dim, replace the ignition switch or transmission feed relay. ● **SEE FIGURE 129–19.**
- If the headlight is off, then there is an open circuit between the battery and the transmission/transaxle. Follow electrical troubleshooting procedures to find and repair the open circuit.
- If the headlight is bright, there is enough voltage and current being supplied to the transmission/transaxle to correctly operate all of the solenoids. ● **SEE FIGURE 129–20.**



FIGURE 129–19 A dim headlight indicates excessive resistance between the battery and the electrical connector to the automatic transmission/transaxle.



FIGURE 129–20 A bright headlight indicates that there should be sufficient current flow available at the automatic transmission/transaxle to operate all the solenoids correctly.

Some bands are adjusted using selective length push rods and some bands are not adjustable at all. The band(s) should be adjusted whenever the fluid is changed or when recommended by the vehicle manufacturer.

LINKAGE ADJUSTMENT The linkage between the shift selector and the automatic transmission should be checked for proper adjustment whenever there is a transmission-related problem. The linkage may need to be adjusted to compensate for worn linkage components. Before adjusting the linkage, check the engine and transmission/transaxle mounts carefully, because a defective mount is a common reason for needing a linkage adjustment.

REVIEW QUESTIONS

1. What tests can be performed on an automatic transmission/transaxle to determine any faults while the unit is still in the vehicle?
2. How does a defective torque converter clutch solenoid cause the vehicle to stall when the vehicle is slowing to a stop?
3. How does automatic transmission fluid reach the intake manifold of the engine and be burned in the engine?
4. How do you perform a test of the mainline and other pressures of an automatic transmission/transaxle?

CHAPTER QUIZ

1. Technician A says that the apply and hold units are usually the same as for first gear when the gear selector is in manual first. Technician B says that a defective vacuum modulator could cause the automatic transmission to delay shifting until a higher-than-normal speed is achieved. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
2. Two technicians are discussing what could be wrong with a hydraulically controlled automatic transmission/transaxle that does not shift out of first gear regardless of vehicle speed. Technician A says that a defective governor could be the cause. Technician B says that a weak pump could be the cause. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
3. Two technicians are discussing an automatic transmission that will not go into any forward gear or reverse. Technician A says that a defective PCM or TCM could be the cause. Technician B says that a defective or worn pump could be the cause. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
4. A General Motors vehicle is being tested using a scan tool. The input speed and the output speed sensor read the same when at highway speed. Technician A says that the transmission/transaxle is in a gear where the ratio is 1:1. Technician B says that the torque converter clutch must be defective and not working. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
5. An electronically controlled overdrive automatic transmission is equipped with a transmission fluid temperature sensor. Technician A says that the shifts may be changed if the fluid temperature is too high. Technician B says that overdrive may be disabled if the transmission fluid temperature is too high. Which technician is correct?
   a. Technician A only **c.** Both Technicians A and B
   b. Technician B only **d.** Neither Technician A nor B
6. A scan tool can be used to _____.
   a. Check for stored diagnostic trouble codes
   b. Command a shift
   c. Check for transmission-related sensor information
   d. All of the above
7. Fluid exchange can be performed using _____.
   a. Drain and refill three times
   b. A machine that replaces the ATF through the cooler lines
   c. A machine that forces the old fluid out, using a pump inside the machine that is attached to the fluid inlet after removing the transmission pan and filter
   d. All of the above
8. Caution should be used when performing a stall test because _____.
   a. It could increase the temperature of the ATF
   b. It could be hazardous if the brakes fail
   c. It puts a strain on the engine
   d. All of the above

9. An electronically controlled automatic transmission operates okay in reverse, but the vehicle does not shift at all when moving forward. Technician A says that a defective torque converter is the likely cause. Technician B says that a defective shift solenoid could be the cause. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

10. Two technicians are discussing inspection of the transmission pan. Technician A says that some friction material at the bottom of the pan is normal. Technician B says that if any metal parts stick to a magnet then further investigation is needed to determine the cause. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

chapter 130 AUTOMATIC TRANSMISSION/ TRANSAXLE UNIT REPAIR

OBJECTIVES: **After studying Chapter 130, the reader will be able to:** • Explain how to identify the transmission/transaxle. • Discuss how to disassemble an automatic transmission/transaxle. • Describe what repairs can be done with the transaxle in the vehicle. • Explain how to properly install and check clutch packs. • Describe how to flush the cooler. • Explain how to properly reassemble an automatic transmission/transaxle. • List the steps necessary to follow when removing an automatic transmission/transaxle assembly. • Describe how to properly remove and install an aluminum pump in an automatic transmission/transaxle. • Discuss how to assemble an automatic transmission/transaxle. • Explain how to flush an automatic transmission fluid cooler. • Describe how to install an automatic transmission into a vehicle.

KEY TERMS: Air pressure check 1604 • Holding fixture 1600 • Tag number 1599

VERIFY THE NEED FOR UNIT REPAIR

VERIFY THE FAULT It is not unusual for a transmission or transaxle to be removed from the vehicle when the fault could have been repaired with the unit still in the vehicle. Or the fault could be due to an electrical or engine-related fault outside the transmission/transaxle. Check with all of the following to be sure that the unit needs to be removed from the vehicle.

- A knowledgeable technician
- The archives at www.iatn.net
- A hotline service provider, such as Identifix (www.identifix.com)

Use these resources to verify that the fault is inside, not outside, the unit.

IN-VEHICLE REPAIRS Not all mechanical faults require that the automatic transmission/transaxle be removed from the vehicle. Faults that can usually be repaired with the unit still in the vehicle include any valve-body-related concerns.

● **SEE FIGURE 130–1.**

Depending on the transmission/transaxle, it may be possible to disassemble and repair many mechanical components of the unit while it remains in the vehicle. Parts and components that may be replaced with the transmission/transaxle still in the vehicle include:

- Pressure switches
- Transmission range switch
- Turbine and output speed sensors
- Extension housing gasket
- Drive axle seals
- Valve body replacement

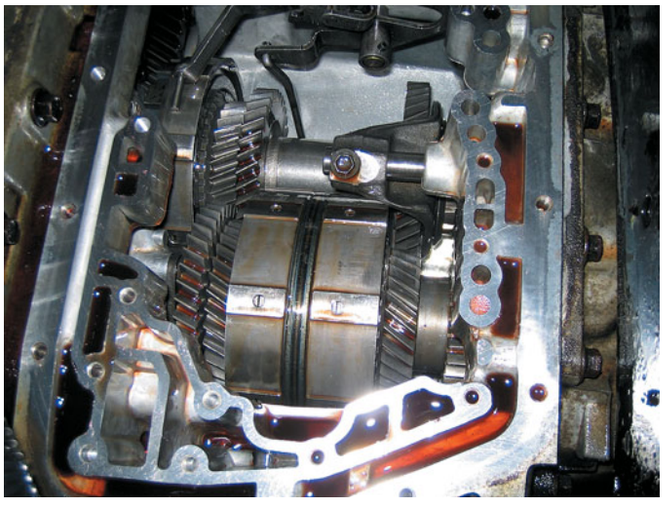
Check service information for details on what can be replaced with the unit in the vehicle.

IDENTIFY THE UNIT Before removing the transmission/transaxle for replacement or repair, be sure that the unit is properly identified. This identification is critical because of the following:

1. The final drive ratio in transaxles can vary depending on the application; and using the wrong unit can cause shifting and other issues such as gear ratio–related diagnostic trouble codes.
2. The internal gear ratios can vary depending on exact application of the unit.



(a)



(b)



(c)

FIGURE 130–1 (a) This Saturn did not shift correctly and one technician was ready to replace the unit; however, another technician thought that the problem could be due to a fault in the valve body. (b) Removing the valve body shows the nonplanetary gears used in the Saturn automatic transaxle. (c) The valve body was disassembled and a broken pressure regulator spring was found to be the cause of the customer concern.

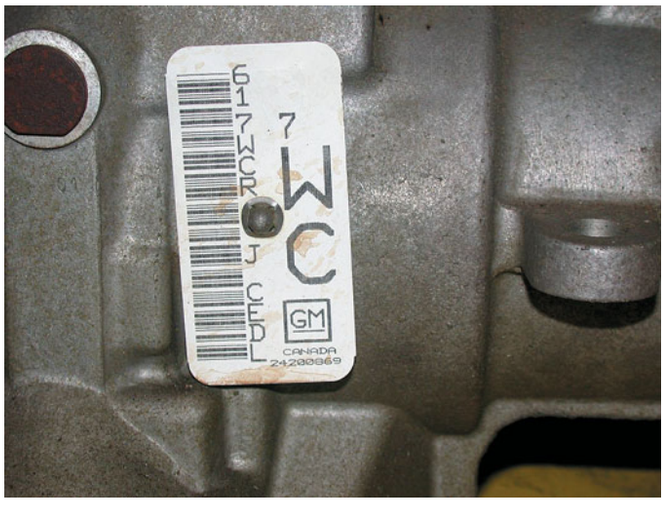


FIGURE 130–2 A transmission identification number on the side of the unit. The information on this tag is needed when ordering parts, as there are often several versions of the same transmission used in similar vehicles and the differences could affect the parts needed.

3. Sometimes the vehicle identification number (VIN) is needed to obtain the correct parts, but more often the transmission/transaxle identification number, also called the **tag number,** is the identification needed to be assured of ordering and receiving the proper parts.

   ● **SEE FIGURE 130–2.**

REMOVING THE AUTOMATIC TRANSMISSION/TRANSAXLE FOR SERVICE

STEPS INVOLVED Removing an automatic transmission/transaxle from a vehicle includes many steps to avoid doing damage to the vehicle or personal harm. Always follow the vehicle manufacturer's recommended procedures. Most procedures include the following steps.

STEP 1 Disconnect the negative (−) battery cable from the battery. This prevents the possibility of an accidental short circuit that could damage the vehicle or cause a spark that could start a fire.

STEP 2 Hoist the vehicle safely and drain the fluid from the unit.

STEP 3 Disconnect the driveshaft or drive axle shafts.

STEP 4 Disconnect all cooler lines, linkage, and electrical connections. Be sure to label each to ensure proper reinstallation. Also be sure to label all electrical connectors so that they can be reinstalled in the proper location.

STEP 5 Disconnect the torque converter from the flex (drive) plate of the engine.

STEP 6 Support the engine before disconnecting the automatic transmission/transaxle. ● **SEE FIGURE 130–3.**

STEP 7 Remove the transmission/transaxle mounting fasteners.



FIGURE 130–3 A chain and holding fixture being used on this front-wheel-drive vehicle to support the engine when the transaxle is removed.

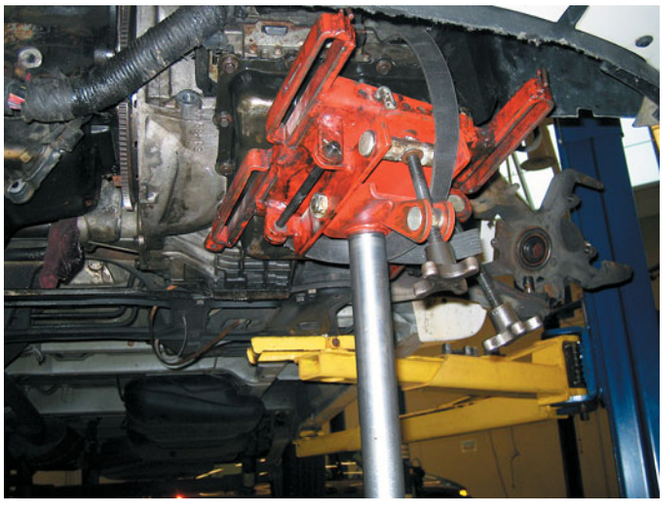


FIGURE 130–4 A transaxle being supported by a transmission jack prior to removal of the unit from underneath the vehicle.

STEP 8 Support the transmission/transaxle on a jack and remove the attaching bolts at the bell housing of the engine. ● **SEE FIGURE 130–4.**

STEP 9 Remove the transmission/transaxle from the vehicle.

AUTOMATIC TRANSMISSION/ TRANSAXLE DISASSEMBLY

MOUNT TO HOLDING FIXTURE For best results, the automatic transmission/transaxle should be attached to a **holding fixture** that allows the unit to be rotated yet properly supported during disassembly and reassembly. ● **SEE FIGURE 130–5.**

TORQUE CONVERTER CHECKS Remove the torque converter and drain the fluid by tipping it so the fluid runs out into a suitable container. Check the torque converter for the following:

- Visually check for wetness that could indicate a leak such as at the welded seam.
- Check for damage to the pump drive tags.

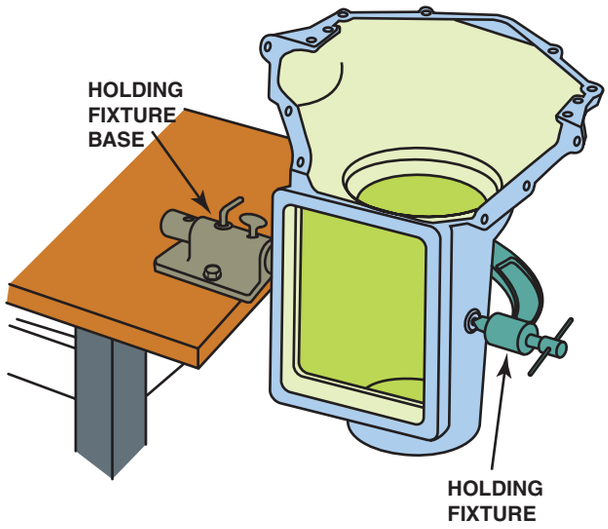


FIGURE 130–5 A holding fixture makes working on a transmission easier.

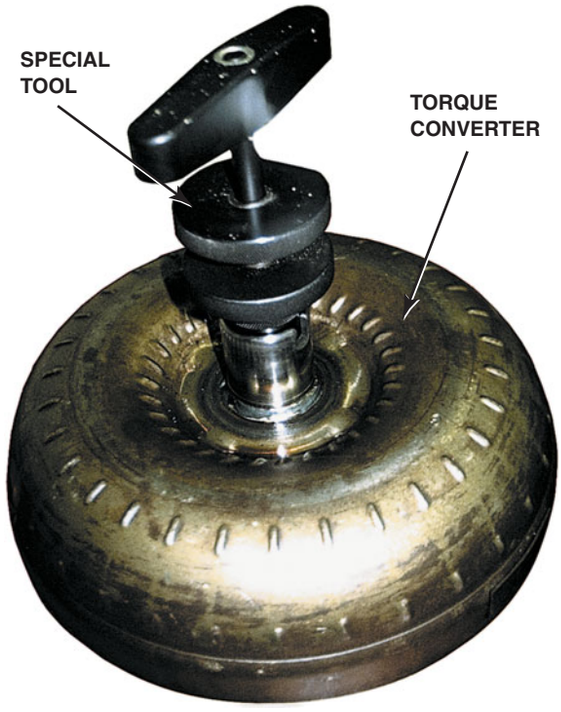


FIGURE 130–6 A special tool being used to check the end play of the stator inside the torque converter.

TECH TIP

Check the Flex Plate

After removing the transmission or transaxle, carefully inspect the flexplate for the following faults.

1. Cracks
2. Warpage
3. Stripped starter ring gear teeth

- Inspect the hub for seal and wear.
- Check that the one-way clutch of the stator is working.
- Check for end play of the stator. ● **SEE FIGURE 130–6.**

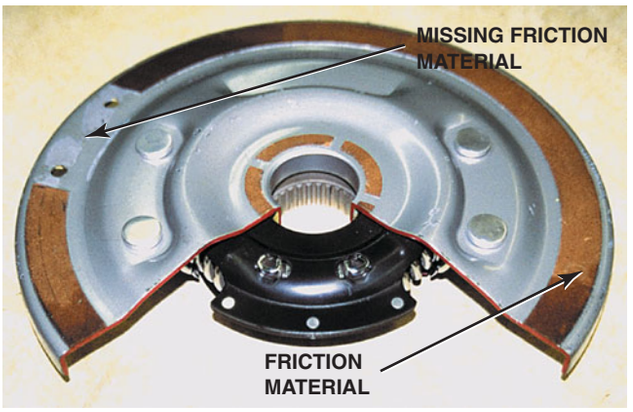


FIGURE 130–7 A cutaway of the torque converter clutch showing the paper-thin friction material.



FIGURE 130–8 A typical separator plate. Check holes over check balls to make sure that the metal balls have not caused damage to the separator plate during operation.

TECH TIP

Replace the Torque Converter

Many automotive transmission/transaxle experts recommend that the torque converter be replaced when the automatic transmission is rebuilt or replaced. This is because the torque converter is generally considered to be the "garbage pit" of the entire unit in that it often collects wear particles from the clutches and bands that can cause future problems. According to remanufacturers of torque converters, the majority of the torque converters being returned as cores have little, if any, friction material remaining for the torque converter clutch. ● **SEE FIGURE 130–7.**

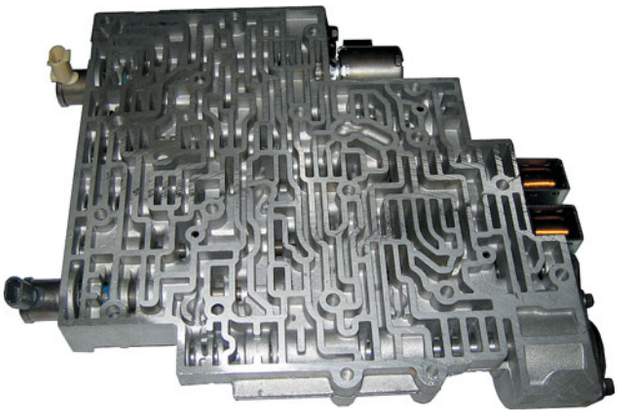


FIGURE 130–9 Check that all valves are free to move, and look for signs that the valves have caused wear to the valve bore. This causes fluid to leak around the valves, which can also cause shifting problems. If the bore is found to be worn, then the valve body will require repair using specialized tools or replacement.

TECH TIP

The Valve Body Cardboard Trick

To help remember where each bolt goes in the valve body, draw an outline of the valve body on cardboard and then stick the bolts through the cardboard in the position where they were removed. Often the lengths of the bolts are different, so this method saves time and helps prevent possible harm to the valve body of the case of the transmission/transaxle when reassembling the unit.

VALVE BODY Remove the valve body and the internal electronic components found in many units. Before the valve body fasteners are removed, the following items need to be performed or checked.

1. Disconnect the manual valve linkage and "rooster comb."
2. Carefully loosen the valve body bolts starting from the outside and working toward the center or help prevent distortion.
3. Remove the lower part of the valve body.
4. Remove the separator plate. ● **SEE FIGURE 130–8.**
5. Check and note the location of all check balls in the upper valve body.
6. Carefully check the operation of all shift valves by using a plastic tool or compressed air to move the valves in their bores. All valves should be free to move and should return to the home position by spring pressure.

● **SEE FIGURE 130–9.**

To service a valve body, disassemble all the parts, identify them for reassembly, and check the valve body with a precision straightedge.

PUMP ASSEMBLY Remove the pump assembly using the proper removal tool to avoid damaging it. ● **SEE FIGURES 130–10 AND 130–11.**

Check the pump for wear by checking service information for the recommended procedure and specifications. ● **SEE FIGURE 130–12.**

UNIT DISASSEMBLY Before disassembly, measure input shaft end play. Some transmissions require the measurement of output shaft end play. Always check service information for the specified procedures to follow.

The usual disassembly procedure includes:

1. Removal of snap rings
2. Compressing of clutch pistons most often using special tools

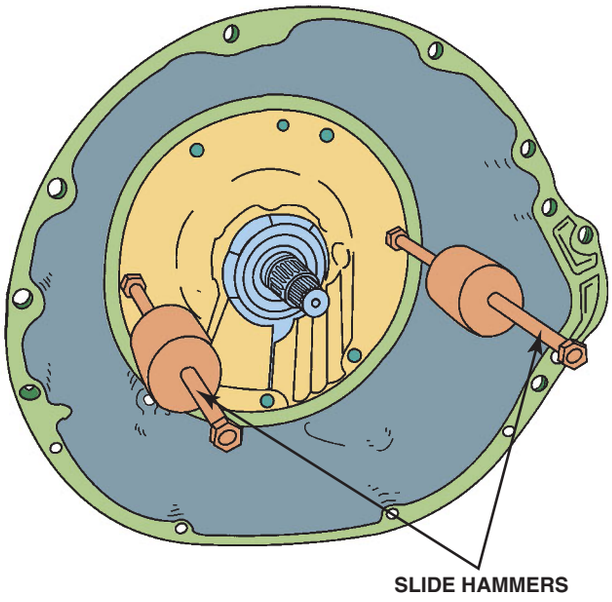


FIGURE 130–10 Two slide hammers are often used to remove a pump from older automatic transmissions.

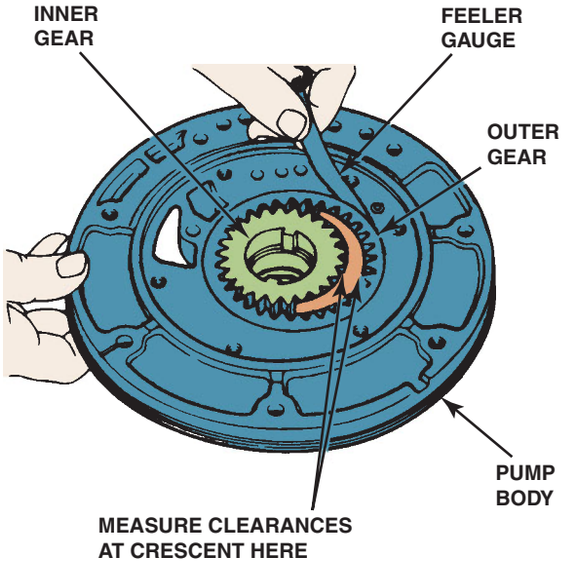


FIGURE 130–12 Checking a transmission pump assembly for wear using a feeler gauge. Compare the reading to factory specifications.

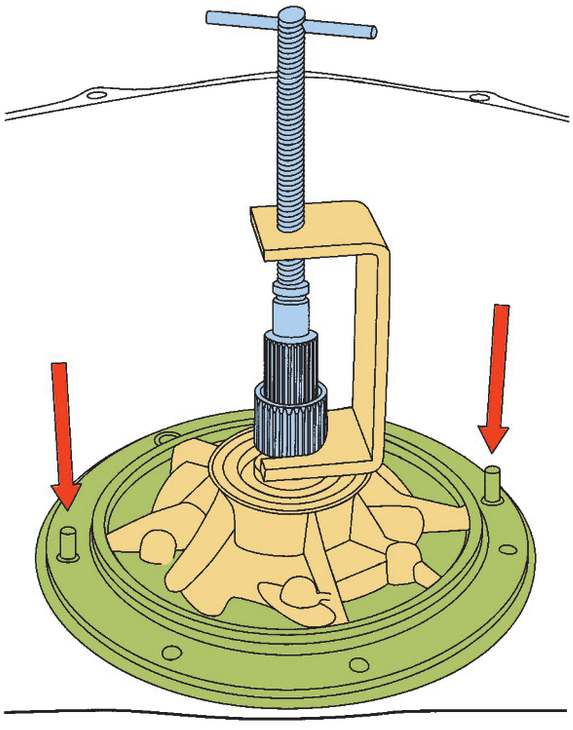


FIGURE 130–11 A special puller is usually specified to remove aluminum pumps from automatic transmission/transaxles. Alignment pins (arrows) are used to properly align the gasket and pump on the case during reassembly.

3. Removal of bands (if equipped)
4. Removal of solenoids
5. Disconnecting and labeling of all interior wiring

Note the condition of all of the following so that any parts needed can be ordered.

- One-way clutches
- Clutches and bands (if used)
- Accumulators and springs

TECH TIP

A Picture Is Worth a Thousand Words

During disassembly, note items such as direction of snap rings front and back and clock position of the snap ring openings. Instead of taking numerous detailed notes, use a digital or phone camera and take pictures as the unit is being disassembled. Then the photos can be reviewed during reassembly to be sure that everything is installed in the same position as it was when it was disassembled.

- Trust washers
- Snap rings
- Servos and springs
- Planetary gear sets
- Final drive assembly on transaxles
- Shift and pressure control solenoids

Save the old gaskets to match with the new ones. Clean all parts in a solvent that removes all gum, varnish, dirt, and grease. Rinse clean parts in hot, running water, and then immerse them in clean mineral spirits or a similar solvent to separate water from the parts. Finish cleaning by blow drying with low-pressure, filtered, compressed air. Once clean, inspect the valve body and its components for the following:

- Scored, cracked, or burred plugs and valves
- Broken, bent, or worn springs
- Scored or rusted bores
- Plugged or restricted fluid passages
- Bent or rusted separator plates
- Stuck check valves
- Bent manual valves
- Cracked castings and distorted or nicked mating surfaces.

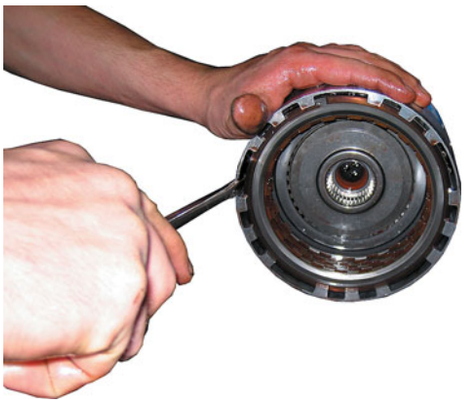


FIGURE 130–13 A straight-blade screwdriver can help remove the snap ring that is used to retain the frictions and steels in the clutch pack.

Shiny areas on valve lands indicate friction between the spool valve and body. On steel valves, these areas can be polished carefully with 400- to 600-grit wet or dry sandpaper, crocus cloth, or polishing stone. Take care not to round off the edges of the valve lands while polishing. Aluminum valves cannot be polished. If a valve needs polishing, the bore it rides in also requires servicing. Polish the valve bore by inserting and turning loosely rolled wet or dry sandpaper or crocus cloth. Attach a piece of crocus cloth to a slotted dowel rod or bent welding rod to reach the bottom of a deep bore. Rewash and dry any valves and bores that are polished.

After polishing and washing, lubricate the spool valve with ATF and slide it into its bore to check fit and operation. The valve should slide back and forth freely of its own weight.

CAUTION: Do not use cloth shop cloth as lint can cause a sticking shift valve.

CLUTCH PACKS Begin disassembling a clutch pack by removing the snap ring that holds the discs in the housing. Remove the snap ring from most clutches by prying one end of it free from its groove with a small screwdriver. Then, slide the screwdriver around the drum and the snap ring removes easily. ● **SEE FIGURE 130–13.**

FRICTION DISC INSPECTION Wipe each friction disc with a dry, lint-free cloth and inspect for the following:

- Excessive wear
- Cracks in the lining material
- Charred, burned, or glazed lining surface
- Pitting, flaking, or scoring
- Chips or particles embedded in the lining
- Scoring or burns on disc serrations
- Distortion and/or warping

Friction discs tend to discolor in use, which is normal. However, if any friction disc shows signs of one or more of the defects above, replace the entire set. Replace the set of friction discs if they do not fit freely in the clutch hub serrations (grooves) or if there is wear or damage to their splines.

STEEL DISC INSPECTION Clean steel discs by wiping with a dry, lint-free cloth and, once clean, inspect each disc for the following:

- Uneven heat discoloration
- Surface scuffing or scoring
- Drive lug damage
- Distortion and/or warping

Replace the entire set of steels if you note a rough surface or there is uneven or spotty discoloration on any of the discs. Also replace steel discs if they do not fit freely into the clutch drum tang notches.

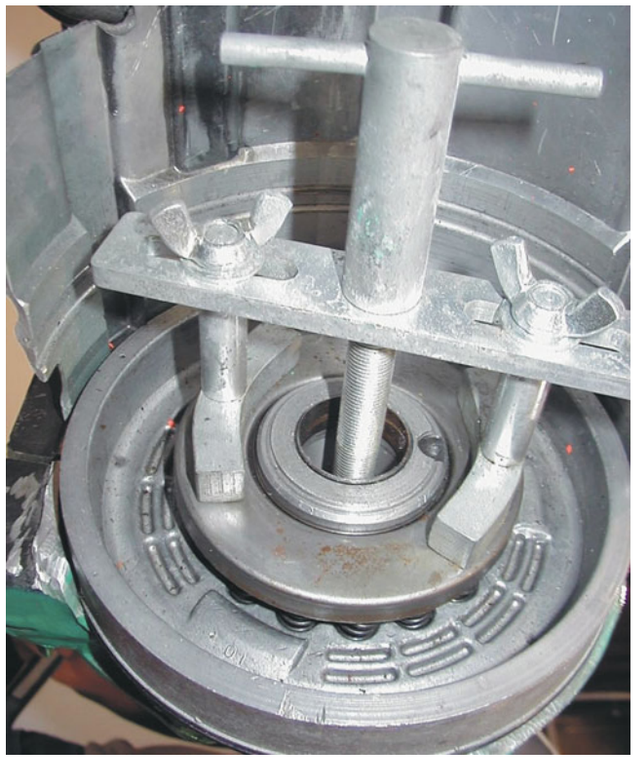


FIGURE 130–14 A compressor tool is usually necessary to compress the springs of the clutch piston to remove the snap ring.

TECH TIP

Smooth Is In; Rough Is Out

It used to be common practice in the automatic transmission business for the rebuilder to use sandpaper to "roughen up" the surface of the steel discs to achieve a good clutch apply. This is not true now. Sanding creates grooves and sharp peaks that decrease the oil film between the paper on the friction plate and the steel plates. There should be a thin oil film between the paper and the steel to create a holding bond and make it possible for a clutch pack to apply and release thousands of times without wear. Therefore, for consistent shifts and a long-lasting transmission/transaxle, do not sand the steel discs. Steels are often replaced with new steels along with new friction discs during an overhaul.

CLUTCH PISTON REMOVAL AND INSPECTION To remove the snap ring holding the clutch piston in place, compress the piston return springs using the proper compressor tool. Always check service information for proper procedure. ● **SEE FIGURE 130–14.**

Tightening a nut onto the shaft draws the fingers of the tool down, compressing the spring, and allowing the snap ring to be removed. After removing the snap ring, release and remove the spring compressor, then remove and inspect the return springs.

RETURN SPRING INSPECTION Coil springs should be straight and provide proper pressure. Check for broken, distorted, or collapsed springs. If one or more of the springs requires replacement, discard them all and install a complete set of new springs.

NOTE: Individual return springs are often colored coded as to their location. Make note of the color and number of return springs for ease of reassembly.

Some coil springs are permanently attached to their retaining collar and can only be serviced as a set. There will be vacant spring seats in some applications. This allows the manufacturer to use the same piston but vary the number and location of springs to precisely match spring return rate to the requirements of a particular vehicle. In these cases, reinstall return springs in exactly the same location.

CLUTCH PISTON INSPECTION Remove the clutch piston from the hub. The drag of the piston seal can make it hard to remove the piston from its bore. Should this be the case, apply low-pressure compressed air through the hydraulic apply hole in the housing to force the piston from its bore.

CAUTION: Always use care when using compressed air, as it can be very dangerous. Use regulated air pressures set to a maximum 35 PSI (240 kPa) and a rubber-tipped nozzle. Always wear safety glasses when checking valves and actuators using compressed air.

Do not use high air pressure and be careful to avoid pinching your hand or dropping the piston as it pops from its bore. Once you remove the piston, check for the following:

- Cracks or scoring in the piston bore
- Nicks, scores, burrs, or signs of wear on the piston
- Seal damage
- Fluid passage obstructions or restrictions

If the piston contains a check valve, make sure it is functional. Remove and discard seals.

HUBS, DRUMS, SHELLS, AND PLANETARIES Clutch hubs, drums, and shells transfer the torque load to the various combinations of planetary gear set members to provide different gear ratios. Hubs, drums, shells, and planetaries are *hard parts* that do not wear out under normal conditions, so they can be reused unless they are damaged. **SEE FIGURE 130–15.**

Carefully check drums and shells for cracks before reusing. Wash with solvent, dry with compressed and filtered air, and then inspect. Planetary gear sets should be checked for proper pinion gear end play and compared to factory specifications. **SEE FIGURE 130–16.**



FIGURE 130–15 The ring gear has damaged gear teeth. This entire planetary gear set must be replaced because the damage also affected the gear teeth of the planetary pinion gears and the sun gear.

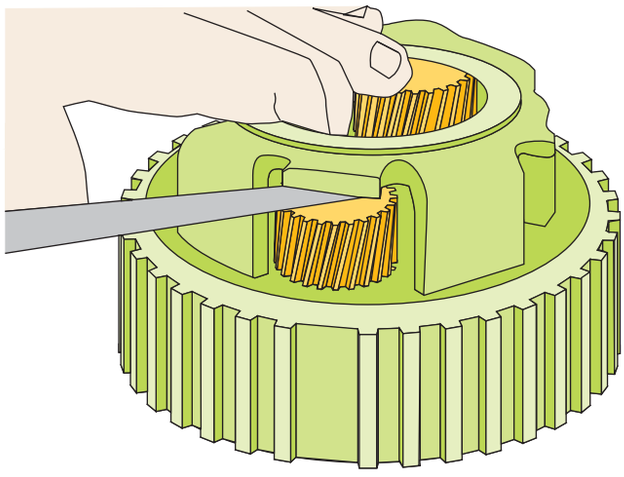


FIGURE 130–16 Pinion gear end play can be checked using a feeler gauge.

REASSEMBLING AN AUTOMATIC TRANSMISSION/TRANSAXLE

CLUTCH ASSEMBLY Before assembling a clutch assembly, soak all friction plates in automatic transmission fluid (ATF). This should be done for as long as possible to allow the friction material to absorb the automatic transmission fluid. Check service information for the exact order of assembly and assemble each clutch pack.

AIR PRESSURE CHECKS Reassembly of an automatic transmission/transaxle involves assembling the various subassemblies, such as a clutch pack clearance, before final assembly is completed. **SEE FIGURES 130–17 AND 130–18.**

If the clutch pack clearance is not correct, often one clutch pack component is a selective member. The selective component could be any of the following:

- Reaction plate
- Pressure plate
- Thrust washer
- Snap ring

After making the needed changes, the clearance should be rechecked to be sure it is within factory specifications.

An **air pressure check** uses air to apply clutches and/or bands to verify that components such as clutch packs perform correctly. The air takes the place of the ATF under pressure when it is being used in the vehicle. Air checking a unit includes the following steps.

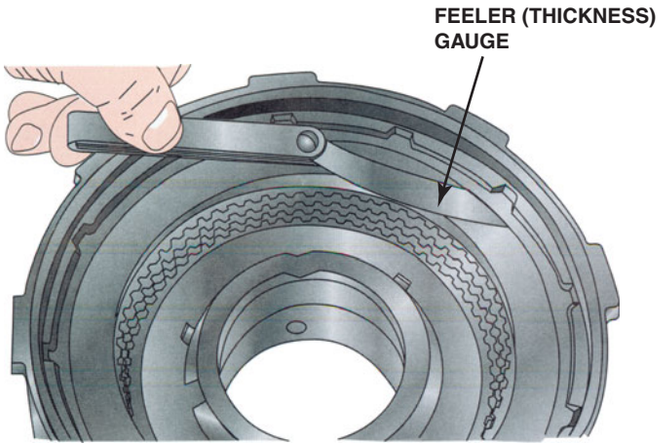


FIGURE 130–17 All clutch packs should be checked for proper clearance. Here, a feeler (thickness) gauge is used to check the clearance to make sure it is within factory specifications.

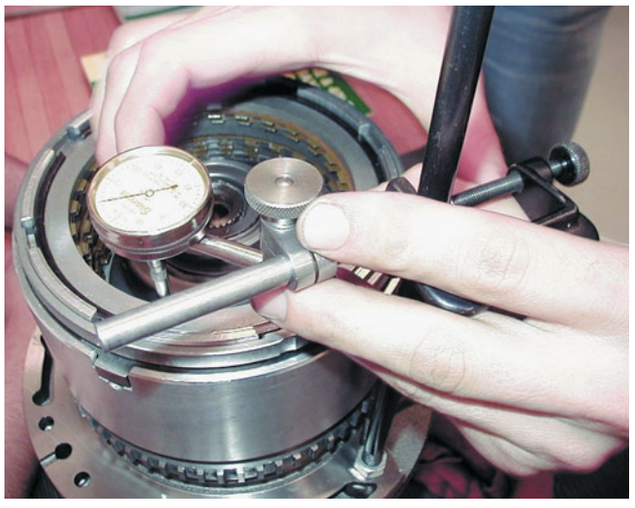


FIGURE 130–18 Checking clutch pack clearance using a dial indicator. This method is used when a feeler gauge cannot be inserted to check for proper clearance.

STEP 1 Use the factory service information regarding where to air check and what the results should be.

STEP 2 Use a rubber-tipped air nozzle and regulate the air supply to about 35 PSI (240 kPa).

STEP 3 A typical result is a dull thud or clunk heard when air pressure is applied to a clutch pack or servo piston. ● **SEE FIGURE 130–19.**

STEP 4 When the air pressure is removed, the unit should release. If there is a seal leak, air can usually be heard hissing from around the seal.

● **SEE FIGURE 130–20.**

BUSHINGS All bushings should be inspected and replaced if necessary. ● **SEE FIGURE 130–21.**

ONE-WAY CLUTCHES Always double check that all one-way roller clutches are installed correctly. The transmission will not work correctly if the one-way clutch is installed upside down. Check service information for the exact method to use to ensure that they are installed correctly. ● **SEE FIGURE 130–22.**

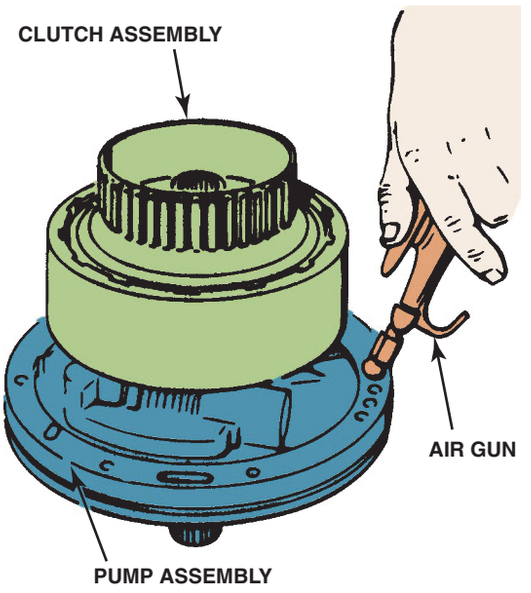


FIGURE 130–19 Air testing a clutch pack before installing it into an automatic transmission or transransaxle.

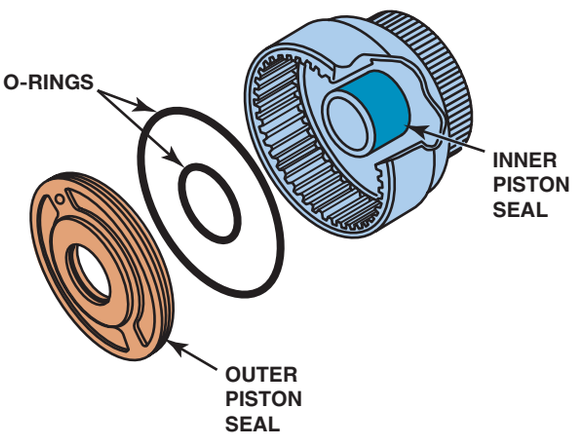


FIGURE 130–20 Both the inner and outer seals are checked when air testing a clutch pack assembly.



FIGURE 130–21 A typical brass bushing used in an automatic transmission.

SPECIAL TOOLS Special tools are often specified by the vehicle manufacturer. These tools allow the service technician to disassemble and reassemble the transmission/transaxle more easily without harming the unit. ● **SEE FIGURE 130–23.**

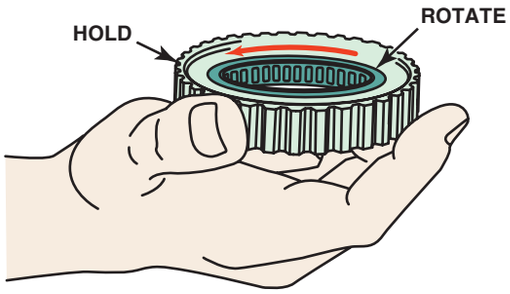


FIGURE 130–22 Service information states that this one-way roller clutch should be installed as shown. Check by holding the outer race so that the inner race is free to rotate counterclockwise as shown.

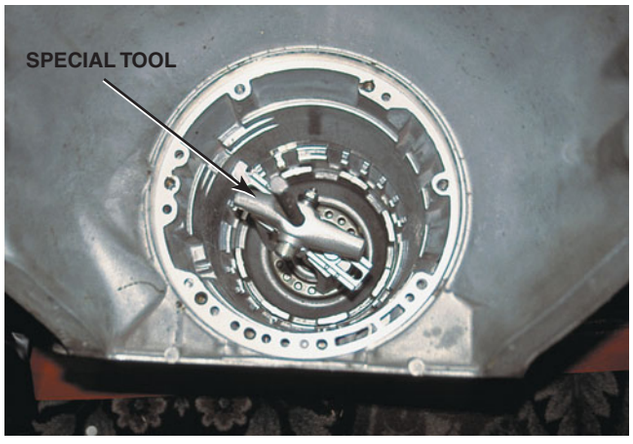


FIGURE 130–23 A special clamp makes removal and reinstallation of this clutch pack easier.

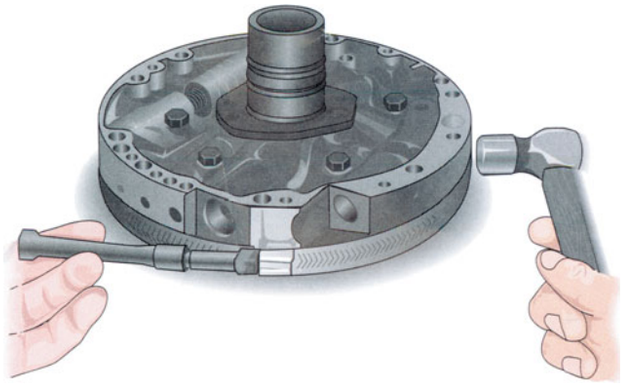


FIGURE 130–24 Using an alignment clamp to assemble both pump halves. To ensure proper alignment, many experts recommend lightly tapping the outer edges of the pump while tightening the clamp.

PUMP ASSEMBLY Follow the vehicle manufacturer's recommended procedures. For example, a special clamp is often necessary to properly assemble a pump. ● **SEE FIGURE 130–24.**

END PLAY CHECKS Perform all end play checks during assembly to ensure that the unit was properly assembled and that the proper internal clearances are achieved. ● **SEE FIGURE 130–25.**

VALVE BODY CHECKS The valve body can be checked using a tester especially designed for this purpose. Adapters are available for all commonly serviced automatic transmissions/transaxles, and the pressure gauges that are part of the tester are used to monitor the movement and flow through the valve body. This unit also heats the automatic transmission fluid so that the valve body is being tested under the same conditions as will be occurring in the

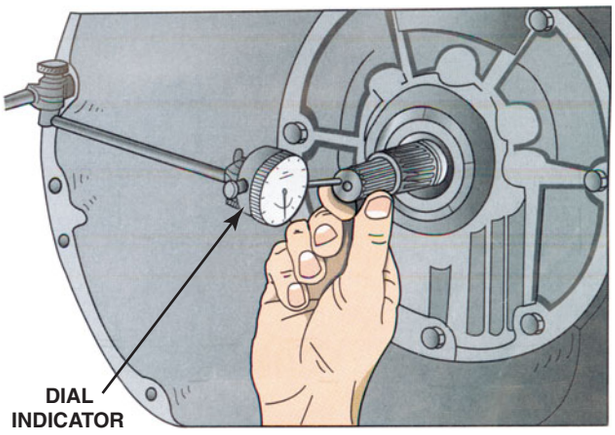


FIGURE 130–25 A dial indicator being used to measure the end play of an input shaft. If the end play is not within factory specifications, the unit may not have been assembled correctly.



FIGURE 130–26 Blue assembly lube.

TECH TIP

Avoid Using Red Assembly Lube

Assembly lube is used during the reassembly of automatic transmissions. If red assembly lube is used on seals, it may look like an automatic transmission fluid leak when the transmission gets hot and the lube melts. If you use blue, green, brown, or clear assembly lube, then the color will immediately identify it as assembly lube. ● **SEE FIGURE 130–26.**

Many transmissions have been disassembled because the service technician thought that the red liquid dripping from parts of the transmission was automatic transmission fluid when, in fact, it was only assembly lube that melted and ran when the transmission reached normal operating temperature.

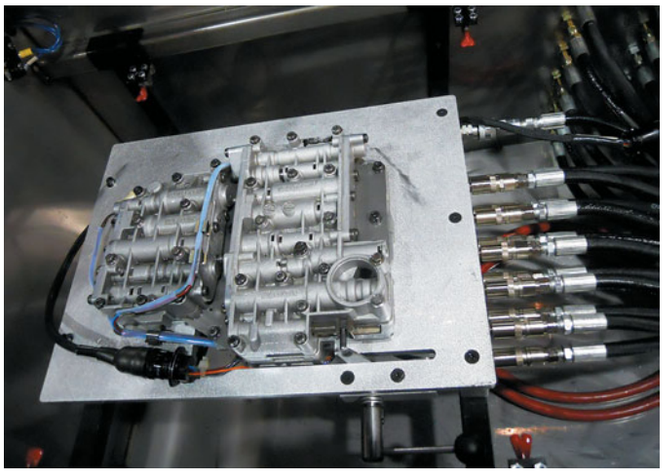


FIGURE 130–27 A valve body being tested on a valve body tester. While it takes some setup time to adapt each valve body to the proper hoses, this type of machine can find valve body problems before the transmission/transaxle is installed in the vehicle.

TECH TIP

Change the Bolts and Washers

When reassembling an automatic transmission, always replace the pump bolts and sealing washers to avoid the possibility of a leak. A leak in the area of the pump can cause quite a headache for the technician because the entire assembly must be removed from the vehicle again to fix it.

vehicle. It is easier to repair a fault with the valve body than wait until the valve body and the transmission are installed in the vehicle. ● **SEE FIGURE 130–27.**

CAUTION: It is critical that the valve body be torqued in the proper sequence to the correct specification to avoid warpage which could cause a sticking valve.

FLUSHING THE COOLER AND TORQUE CONVERTER

PURPOSE All vehicle manufacturers recommend that the automatic transmission fluid cooler be checked for proper flow and, if not, then it should be replaced whenever a replacement or overhauled automatic transmission/transaxle is installed in a vehicle. Most vehicle manufacturers are recommending to NOT flush the cooler. The major reason is because most manufacturers have gone to the "flat" tube design, so the passages are too small for flushing. In addition, some coolers have internal thermostats which would be closed during flushing. Instead, manufacturers recommend replacement with either a new radiator or cooler (if remotely mounted).

COOLER-OUT LINES

TRANSMISSION	COOLER-OUT LINE ON THE TRANSMISSION/TRANSAXLE
GENERAL MOTORS	
125 (3T40)	Bottom
THM-180	Bottom
THM-200/200-4R	Top
THM-325/325-4L	Bottom
THM-350	Bottom
THM-400 (4L80)	Bottom
THM-440-T4 (4T60)	Bottom
THM-700-R4 (4L60)	Bottom
FORD	
A4LD	Bottom
AOD	Top
ATX	Bell housing end
AXOD	Top
C3, C4, C5, C6	Front
CHRYSLER	
904, 727	Front
42RLE	Bottom is one to cooler
41TE	Right side is one to cooler
62TE	One farther from bell housing is one to the cooler
IMPORT BRANDS	
Honda	Over the bell housing
Jatco (RWD) (Various Makes and Models)	Front
Mitsubishi	Inner
Renault	Top
Nissan RL3F01A	Top
Nissan RL4F02A	Front
Subaru	Top of the differential
Toyota FWD	Top
Toyota RWD	Front

CHART 130–1

The location of the cooler-out lines varies by vehicle and transmission/transaxle. Check service information for location of the cooler lines on the vehicle being serviced.

NOTE: At least 2 quarts (liters) of ATF should flow through the cooler every 30 seconds or the cooler and/or the lines are restricted. ● SEE CHART 130–1 for the placement of the cooler-out lines on common transmissions/transaxles.

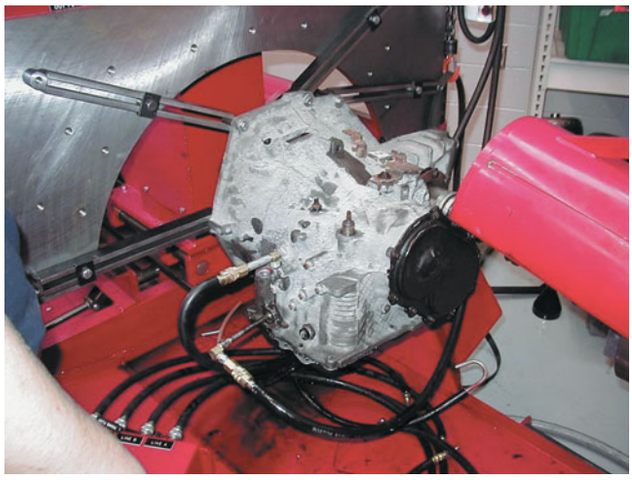


FIGURE 130–28 An electric motor-driven dynamometer being used to check the operation of a 41 TE transaxle.

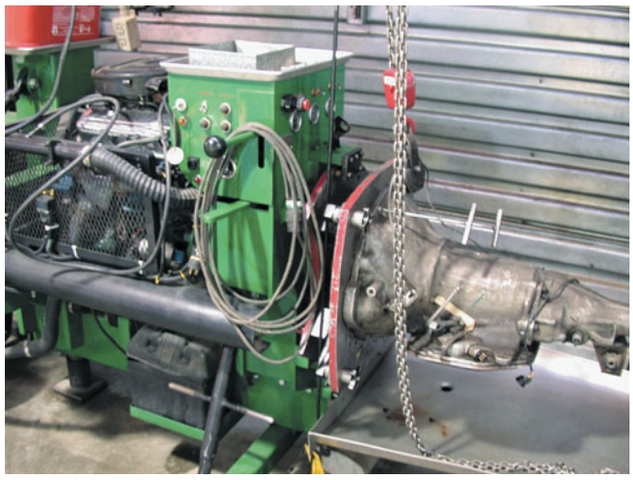


FIGURE 130–29 A gasoline-powered dynamometer being used to test a rear-wheel-drive automatic transmission.

DYNAMOMETER TESTING THE AUTOMATIC TRANSMISSION/TRANSAXLE

A rebuilt automatic transmission/transaxle can be tested on a dynamometer powered by:

- An electric motor (● **SEE FIGURE 130–28.**)
- A gasoline engine (● **SEE FIGURE 130–29.**)

Most dynamometers are equipped with pressure gauges to provide a load so the operation of the unit can be checked before being installing in the vehicle.

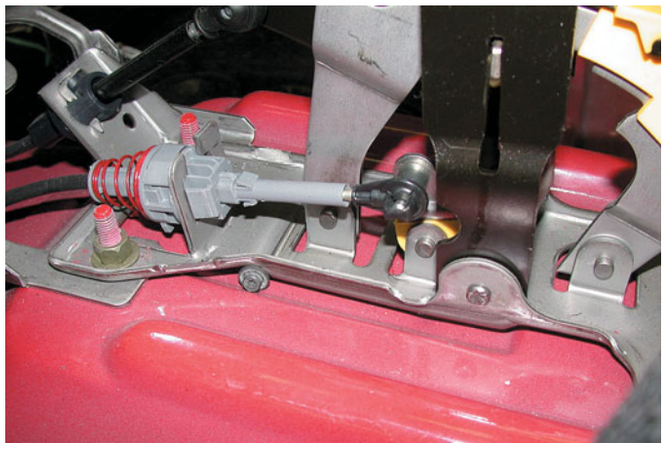


FIGURE 130–30 Check the linkage for proper adjustment so that the shift interlock works correctly and the PRNDL is aligned with the transmission range switch.

REINSTALLING THE AUTOMATIC TRANSMISSION/TRANSAXLE

DOUBLE CHECK END PLAY After the unit has been reassembled and all end play checks indicate that the unit is properly assembled, reinstall the automatic transmission/transaxle in the vehicle. Many experts recommend that new transmission/transaxle mounts be installed to assure proper driveshaft/drive axle shaft angles.

NOTE: New mounts are particularly important if the unit was leaking automatic transmission fluid (ATF). The ATF can soften and deteriorate the rubber used in the mounts.

TORQUE CONVERTER INSTALLATION Before installing the unit into the vehicle, flush the torque converter with clean ATF. Carefully install the torque converter onto the input shaft being sure to fully engage the following:

- Pump gear
- Stator splines
- Turbine splines

TRANSMISSION/TRANSAXLE INSTALLATION Check service information for the exact procedure to follow when installing an automatic transmission/transaxle. Following are the steps often specified.

- Carefully install the unit and use a torque wrench to torque the bolts to the bell housing.
- Attach the torque converter to the flex (drive) plate.
- Reattach all electrical connections, linkages, and cooler lines. ● **SEE FIGURE 130–30.**
- Lower the vehicle and add enough ATF to properly fill the unit. Consult factory information for the recommended amount, to avoid under- or overfilling.

ROAD TEST

FAST LEARN THE PCM/TCM Start the engine and check the level of the ATF. For an electronic transmission/transaxle to operate correctly, a "fast learn" or a "quick learn" should be performed with a scan tool before the vehicle is driven. This action will get the

adaptive settings close to what they should be and will help prevent damage to the unit if this procedure is not done.

In addition, Chrysler has a torque converter burnishing mode that can be activated on the scan tool for some models.

ROAD TEST PROCEDURE Carefully test drive the vehicle, checking for proper operation and shift points. Hoist the vehicle and check for any possible ATF leaks before returning the vehicle to the customer.



FIGURE 130–31 An auxiliary automatic transmission fluid cooler installed on a Chevrolet pickup truck used to haul a car trailer.

TECH TIP

Install a Transmission Cooler

An auxiliary transmission fluid cooler is recommended by most experts to help keep the temperature from becoming excessive, especially when towing or performing other heavy-duty vehicle operation. ● **SEE FIGURE 130–31.**

Most experts recommend that the cooler be connected so that the hot fluids travel through the auxiliary cooler and then through the factory cooler and return to the transmission/transaxle. Using this method of plumbing allows the radiator to warm the transmission fluid in cold weather as well as provide additional cooling of the fluid when the fluid temperature is high.

.TECH TIP

If the Torque Converter Is Dropped, Replace It

Torque converters include plastic thrust plates which are very strong under the compressive forces of normal torque converter operation. However, if a torque converter is dropped, even from a distance of less than 6 inches (15 cm), the thrust washer can easily break, ruining the torque converter. Even though torque converts look strong and feel heavy, handle them as if they are glass.

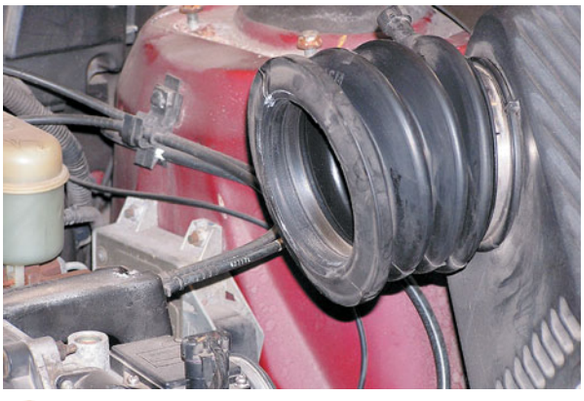
TRANSAXLE REMOVAL



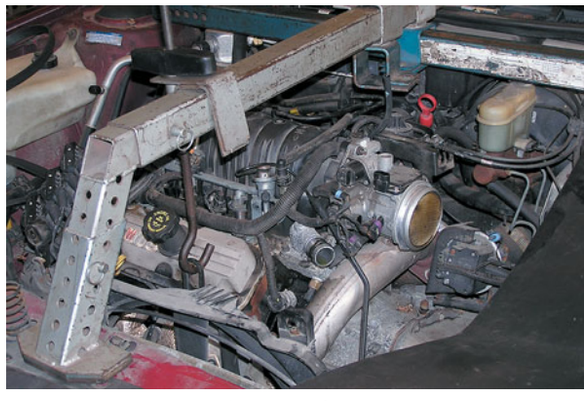
1 For safety purposes, remove the negative battery cable before starting the removal procedure.



2 Remove engine bay cross members that may interfere with access to the transaxle fasteners.



3 Remove the air intake and air filter assembly, which is covering the transaxle in this vehicle.



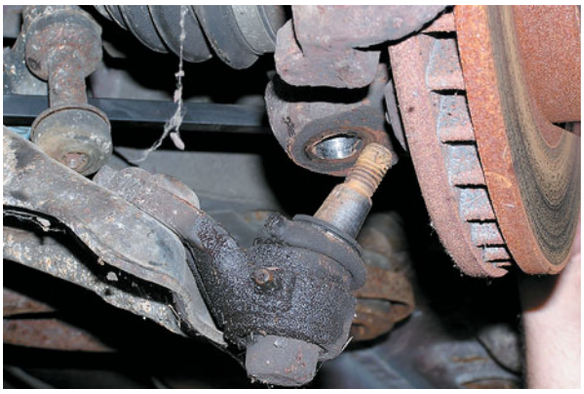
4 Install a support for the engine.



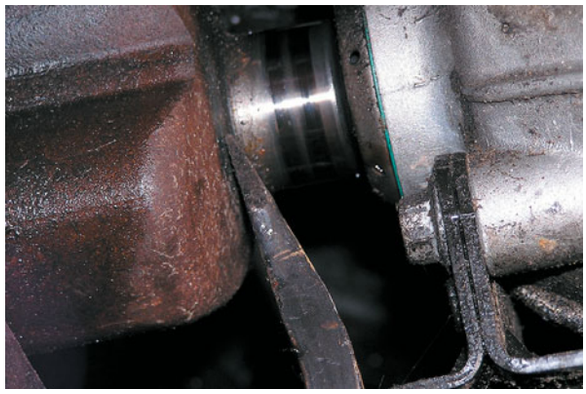
5 Safely hoist the vehicle and remove the wheels.



6 Remove the retaining nut from the drive axle shaft.



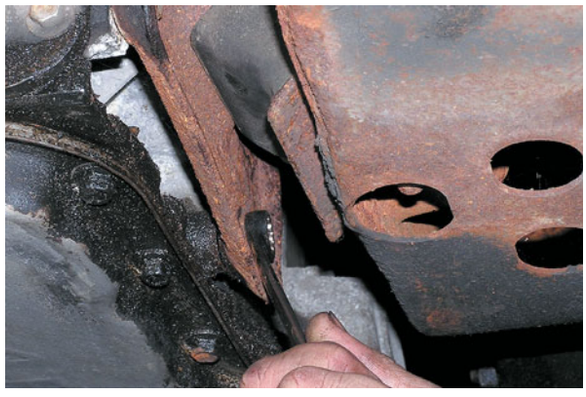
7 Disconnect the lower ball joint on the front-wheel-drive vehicle to allow removal of the drive axle shaft.



8 Remove the drive axle shaft from the transaxle using a pry bar.



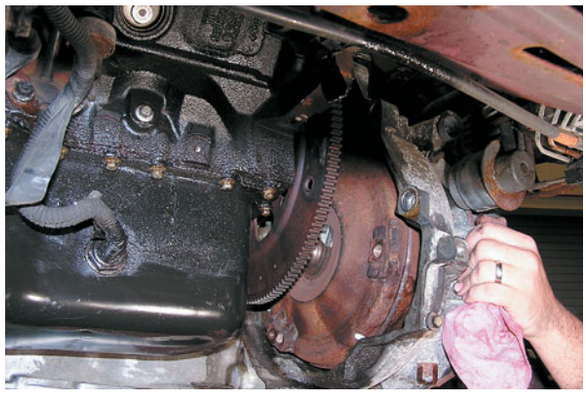
9 Disconnect the cooler lines from the transaxle using a line wrench.



10 Unbolt the torque converter from the flexplate, then remove the transaxle mounts.



11 With the transaxle supported on a transmission jack, remove the retaining bolts from the bell housing.



12 Carefully remove the transaxle from the vehicle.

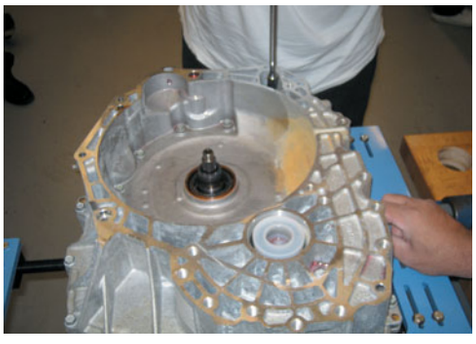
6T70 TRANSAXLE DISASSEMBLY AND ASSEMBLY



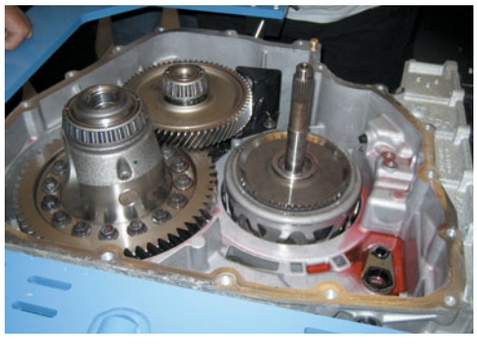
1 The GM 6T70 6 forward speed transaxle was a joint venture with Ford and therefore is similar to the 6F50.



2 A unique thin torque converter is used to help reduce the overall length of the transaxle.



3 After removing the torque converter, the housing is being removed.



4 The final drive assembly is exposed after the housing has been removed.



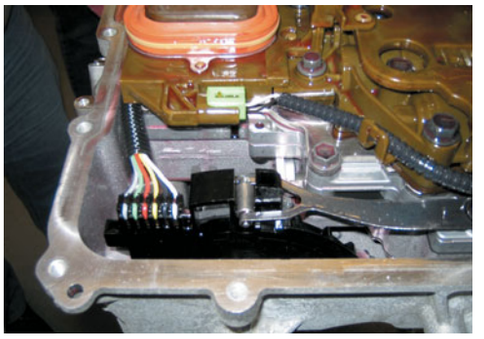
5 The final drive is easily lifted out after the housing has been removed.



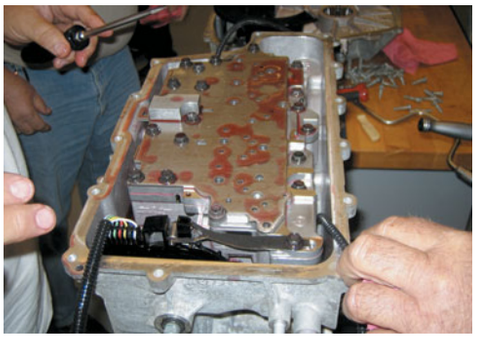
6 Note the tapered roller bearing used in the final drive assembly component.



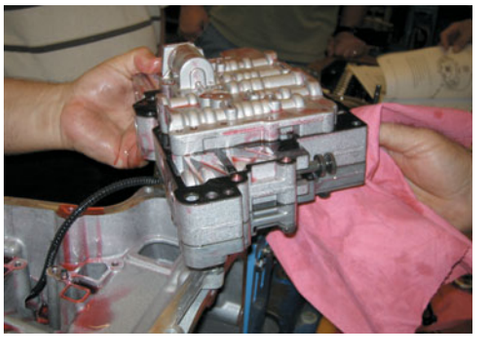
7 The transaxle is rotated and the plastic side cover is removed.



8 Under the side cover is the valve body and integrated solenoid assembly.



9 Under the plastic electrical solenoid assembly is the valve body assembly.



10 Removing the valve body assembly.

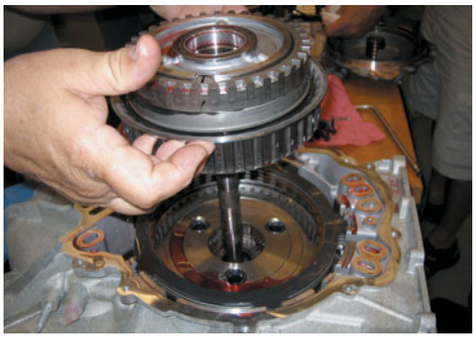


11 Turning the assembly around, showing the end cover.



12 Removing the end cover shows the clutch packs and planetary gear set.

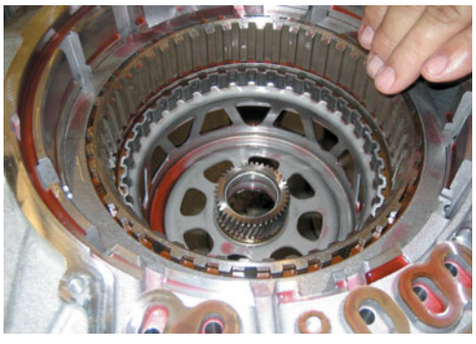
CONTINUED ▶



13 Removing the first of five clutch packs (two driving and three holding).



14 A typical clutch pack in a 6T70 showing the selective thickness steel used to determine clutch pack clearance.



15 A view down into the case where multiple clutch packs are found.



16 The output planetary gear set with four pinions used on 6T70 units. The 6T75 version uses a five pinion carrier and a reinforced case.



17 Reassembly of the clutches. Check service information for specified clutch pack clearance.



18 Notice that the final drive is equipped with tapered roller bearings and this means that the preload must be adjusted.



19 A special set of spacers and blocks used to determine the preload needed. A feeler gauge is then used to measure the clearance.



20 Following the procedure in service information, the designated thickness of shim is selected, which is placed under the bearing race in the bearing packet.



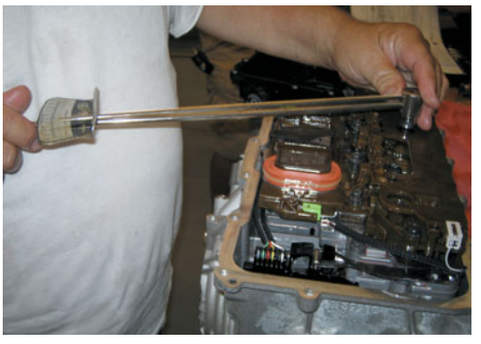
21 The selective shim and race before the race is driven into position.



22 Driving the race into position using the specified driver.



23 Reassembly of the valve body being sure that all fasteners are tightened to factory specifications.



24 The solenoid assembly is replaced as an assembly only if defective and all the fasteners need to be torqued to factory specifications.

REVIEW QUESTIONS

1. What are the typical operations needed when disassembling an automatic transmission/transaxle?
2. What are two methods of checking a clutch pack?
3. Why is it important to perform an end play check of an automatic transmission/transaxle during the reassembly process?
4. Why is it important to flush the automatic transmission fluid cooler when a rebuilt or replacement automatic transmission/transaxle is being installed in a vehicle?

CHAPTER QUIZ

1. Technician A says that the torque converter should be separated from the flex (drive) plate before removing the automatic transmission/transaxle. Technician B says that the clutches should be installed "dry" when replacing the frictions and steels in a clutch pack. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. Air pressure checking is used to test _____.
   a. Clutch packs
   b. TV adjustment
   c. Vacuum modulators
   d. Governors
3. Technician A says that all friction and steel plates in a clutch pack should be replaced during an overhaul. Technician B says that the automatic transmission fluid cooler should always be flushed when a unit is rebuilt or replaced. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. Slide hammers or special pullers are used to remove what component?
   a. Extension housing
   b. Filter
   c. Pump
   d. Rear seal
5. What part must be replaced if dropped?
   a. Pump
   b. Torque converter
   c. Extension housing
   d. Pan
6. Technician A says that the sharp edges of spool valves should be rounded, using 400 grit sandpaper. Technician B says that all valve body parts should be cleaned and then dried using low-pressure, filtered compressed air. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. Clutch pack clearance can be changed if not correct by using selective _____.
   a. Piston
   b. Pressure plate
   c. Snap ring
   d. One of the above depending on the unit
8. Friction discs should be _____ before being installed.
   a. Sanded
   b. Soaked in ATF
   c. Surface roughed up
   d. All of the above
9. How much transmission fluid should flow through the cooler?
   a. 2 quarts every 30 seconds
   b. 1 quart per minute
   c. 2 quarts per minute
   d. 2 pints per minute
10. Why should red assembly lube be avoided?
    a. Can harm friction disks
    b. Too slippery
    c. Clogs filters
    d. Looks like an ATF leak when it melts

INDEX

A

A-arm suspension, 1313
Aboveground oil storage, 51
Aboveground storage tanks (AGST), 51
Abrasive cleaning, 44
  safe use, 44
Abrasive pads or discs, 272
  Scotch Brite® pad, 273
Abrasive wheel, 287
ABS (antilock brake system)
  false trouble code, 507
  fault, warning light, 627
ABS (antilock braking system)
  functional failure, 1020
  historical background, 2
  hydraulic service, 1067–1069
  laws of physics, 1210
  limitations, 1210
  operation, 1210–1211
  overview, 1018–1019
  schematic, 1212
  system configurations, 1211
  traction, 1208–1209
ABS components and operation, 1208–1219
  brake pedal feedback, 1217
  brake pedal travel switches, 1217
  components, 1212–1214
  control module, 1210, 1214
  control pressure stages, 1214–1215
  described, 1018–1019
  limitations, 1210
  operation, 1210–1211
  overview, 1208
  safety, 1231
  schematic, 1212
  solenoids, 1214
  system configurations, 1211–1212
  system overview, 1208–1210
  tire pressure monitoring system, 1217
  tire traction and, 1208–1209
  warning lamps, 1214
  wheel speed sensor service, 1218–1219
ABS controller, 627
ABS diagnosis and service, 1220–1238
  Bosch 2 ABS, 1224–1225
  brake warning lamp operation, 1221
  Delphi (Delco) ABS-VI, 1225–1227
  diagnosis procedure, 1221
  diagnostic procedure, 1230
  DTCs, 1223
  generic ABS related “C” codes, 1230–1231
  Kelsey-Hayes antilock, 1223–1224
  OBD-II diagnosis, 1229–1231
  quick and easy WSS diagnosis, 1221
  retrieving diagnosis trouble codes, 1223
  test drive and, 1222
  Teves Mark IV, 1225
  visual inspection, 1221–1222
  wheel speed sensor adjustment, 1228–1229
  wheel speed sensor diagnosis, 1227–1228
Absolute humidity, 714
Absolute pressure, 833
Absorbed glass mat (AGM) battery, 542
  charging, 550
  conductance tester, 548
ABS sensor ring cracked, 1224
Abutments, 1134
Acceleration simulation mode (ASM), 922
Accelerator pedal position (APP) sensor, 166, 893
  cable-operated system, 893–894
  calibration steps, 896
  location, 893
  PCM use of, 659
  two sensors, 894
  voltage signals shown, 894
Accessories
  bulb trade numbers, 607
  computer input sensor, 816
  electrical accessory symptom guide, 656, 683
  installation, 488
Accessory belt tensioner, 240
Accessory circuits
  cruise control, 658–659
  electronic throttle cruise control, 659
  precollision system, 662
  radar cruise control, 659–660
Accessory drive belt, 578–579
  belt routing guide, 140
  belt tension measurement, 139–140
    belt tension gauge, 139–140
    inspection, 139–140
    long-handled tool, 139
    noisy camshaft, 329
    types, 139
    typical worn, 140
    visual inspection, 589
Accessory drive belt tension
  belt tension gauge, 194–195
  deflection, 195
  marks on tensioner, 195
  torque wrench reading, 195
A/C compressor clutch, 740
  cycling off and on rapidly, 741
Accountant, 23
AC coupling, 462
Accumulator/drier service, 752–753
Accumulators, 722–723, 868
  ABS pump motor, 1215–1216
  hydraulic motor assembly, 1215
  operation, 1575
  precautions, 1216–1217
  purpose and function, 1574–1575
  transmission, 1574
AC/DC clamp-on digital multimeter, 450
  testing blower motor, 656
ACEA (Association des Constructeurs Européens d’Automobiles) engine oil ratings, 200–201
  on oil container, 201
AC generator as alternator, 578
Acid-core solder, 475
Acid materials, 111–112, 273
  water and, 111
Acids, 111
Ackerman Effect, 1424
AC motors, inverters, 522
Acoustical energy, 699
Acoustics, 112
A/C pressure gauge chart, 740
AC ripple current test procedure, 590–591
AC ripple voltage check
  principles, 590
  testing procedure, 590
Activated charcoal, 928
  cabin filters, 732
Active crossovers, 705
Active fuel management, 335
  components, 335
Active mode, tire-pressure sensors, 1265
Active sensors, 1213
Actuators, 732, 1343
  definition, 814, 816
  electronic suspension system, 1348–1349
  malfunction indicator light (MIL), 298
  motors, 1349
  solenoids, 1348–1349
  stator coils, 1349
Acura
  automatic transmission fluid, 138
  battery replacement, 554
  battery sizes, 543
  electronic load detection circuit, 588
  FRM-lined cylinders, 354
  lane keep assist system (LKAS), 641
  oil drain plug gasket, 206
  oil specifications, 203
  precollision system, 662
  remote keyless programming, 673
AC voltage check, 1228
AC volts (ACV), 447
  digital meter usage, 457
  ripple voltage, 463
  true sinusoidal or nonsinusoidal, 453
Adaptive front lighting (AFS) system, 616
  aiming, 616
  dash-mounted switch, 616
  two motors, 616
Adaptive learning, 1581
Adaptor for testing back pressure, 952
AD converter, 813
Adding and subtracting, 115
Additive package, 201
Additives, engine oil
  to improve base oil, 201
  to protect base oil, 201–202
  to protect the engine, 202
Additives, gasoline, 760
  ethanol, 760
  octane improver, 760
  oxygenated, 760
Adhesion utilization (torque wheel method), 1020
Adhesive-lined heat shrink tubing, 476
Adhesive wheel weights, 1279
Adjustable pedal assembly, 670, 1019
  diagram, 670
Adjustable pedal position switch, 670, 1019
Adjustable pedals, 1019
  check the remote, 670
  definition, 670
  diagnosis and service, 670
Adjustable wrenches, 68
Adjusting links, 1095–1096
Adjusting screw springs, 1105
ADP (alternator decoupling pulley), 578
Adsorption, 928
Advisor, 31
Advocate, 31
Aerated, 328
AF (air-fuel) sensor, 854
AFR (air-fuel ratio) sensor, 857
AFS (adaptive front lighting) system, 616
Afterblow, 731
Aftermarket catalytic converter, 953
  dimensions, 953
  installation, 953
Aftermarket parts, 29–30
  air filters, 226
  catalytic converter, 953
  high-performance rocker arms, 391
  supplies guides and catalogs, 78
Aftermarket scan tools, ABS diagnosis, 1230
Aftermarket service manuals, 71–73, 120–121
Aftermarket sound system upgrades, 705–706
  capacitor installation, 706
  power and ground upgrades, 705
  powerline capacitor, 705–706
Aftermarket supplies guides and catalogs, 124
AFVs, 768–771
Aggressive driving, and OnStar, 697
Agitation, 275
AGM (absorbed glass mat) battery, 542
  charging, 550
  conductance tester, 548
AIR (air-injection reaction) system, 945
  testing, 947
Airbag, 687–691
  auxiliary power supply, 691
  Byteflight BUS system, 534
  control module diagram, 692
  dash warning lights, 691, 695
  deployment circuit diagram, 689
  deployment safety, 695
  diagnosis tools and equipment, 691–692
  disposal, 54
  driver side module replacement, 694
  dual-stage, 691
  EDR (event data recorder), 697
  front airbags, 687–691
  historical background, 2
  inflator connectors view, 691
  integral sensor, 690
  magnetic sensor, 690
  negative battery terminal precaution, 692
  occupant detection systems, 695–696
  OnStar, 639
  operation, 689
  parts involved, 688–689
  purpose and function, 687–688
  ribbon-type crash sensor, 690
  seat airbags, 696–697
  self-test procedure, 691–692
  sensor operation, 690
  service, 693–694
    precautions, 692–693
  side curtain airbags, 697
  smart airbag systems, 691, 693
  system diagram, 689
  timeline for deployment, 689–690
  two-stage, 691
  types of inflators, 689
  wiring, 691
Airbag lamp
  dash warning symbols, 626, 694
  passenger detection, 695
  passenger side “on” lamp, 696
  resetting, 554
Air bags
  inflator module, 1358
  load capacity, 1328
Airbag service
  diagnosis and service procedure, 693–694
  inflator module diagram, 695
  knee airbags, 694
  self-diagnosis, 694
  shorting bars, 694
  temporary disconnection, 693
Air-blow guns, 84
Air bubbles, 1063, 1064
Air charge cooler, 166
  cooling compressed air, 167
  cutaway view, 231
  superchargers, 230
AIR check valve, testing back pressure, 248
Air compressor, 82
  safety, 82
Air conditioning
  A/C pressure gauge chart, 740
  actuators, 732
  checking system performance, 740
  control doors shown, 731
  expansion valve systems, 715–716
  leak detection, 744
  major portions shown, 731
  radio “pop” trick, 728
  rear air-conditioning system, 735
  refrigerants, 718–720
  refrigeration cycle, 715
  temperature and pressure measurements, 740–744
  typical settings, 731
  underlying principle for, 715
Air-conditioning circuits, diodes in, 511
Air-conditioning compressor clutch, reducing spikes, 512
Air-conditioning compressor operation, 829
Air-conditioning condensate, color of leak, 239
Air conditioning diagnosis
  clogged orifice tube test, 742
  “frosting,” 742
Air-conditioning refrigerant, recovering, 263
Air conditioning service
  blower motor service, 746
  cooling system service, 746
  evacuation procedure, 748
  noncondensable gases, 748–749
  recharging a system, 750
  refrigerant recovery procedures, 746–748
  refrigerant, specified amount, 751
  temperature and humidity gauge, 750
Air conditioning system
  factory service manuals, 73, 121
  refrigerant oil disposal, 54
Air cooled, 151
Air dam, 746
Air distribution manifolds and nozzles, 946
Air drills, 84
Air filter, 132
  debris in inlet passage, 133
  inspection, 132
  replacement, 132–133
  typical dirty, 133
Air filter restriction indicator, GM, 221
Air filters, 5
  aftermarket, 226
  clogged, 235
  construction, 220
  debris deposited, 220
  dust trapped, 220
  elements, 220
  housing location, 220
  inspection, 221
  remotely mounted, 220
  replacement, 220
Airflow management, 731–732
  defroster ducts, 739
Airflow requirements, 228
  factors for calculating, 228
Airflow sensors
  false air, 843
  PCM uses, 842
  vane airflow (VAF) sensor, 840
Air-fuel (AF) sensor. *See* Wide-band oxygen sensors (O2S)
Air-fuel mixture, MAP sensor signals, 836
Air-fuel ratio (AFR) sensor. *See* Wide-band oxygen sensors (O2S)
Air-fuel ratios, 757
  diesel engines, 159–160
  visualizing, 757
Air gap, 1213
Air hammers, valve seat installation, 313
Air hose safety, 5, 82
Air impact wrenches
  drive pinion nut precautions, 1531
  procedure with, 1526
Air inlet pressure, measuring, 411
Air intake ducts, dog food in, 926
Air intake filtration
  air filter elements, 220
  air filter restriction indicator, 220
  filter replacement, 220
  need for, 219–220
  remotely mounted air filters and ducts, 220

Air intake system, 5
Airless blaster, 275
Air nozzles, OSHA-approved, 82
Air-operated grease guns, 84
Air operated tools, 82–84
Air-powered grinder, cleaning cylinder head, 272
Air pressure, 45
Air pressure check, 1604
  reassembly of transmission/transaxle, 1604–1605
Air pressure sensor, 1346, 1347
AIR pump, 945
  belt-driven, 946
  diagnosis, 947
  electric motor-driven, 946–947
  typical belt-driven, 946
Air punch method, 1062–1063
Air ratchets, 83
Air reference chamber, 855
Air shocks
  installation, 1341
  load capacity, 1328
Air shocks/struts, 1304–1305
Air springs, 1306
  compressor assembly, 1351
Air suspension, 1345
Air suspension sensor, 1344
AIR system testing, 947
Air vane sensors, fuel shutoff in case of accident, 862
Aisin AW, 1560
AKI (antiknock index), 758
Alarm systems. *See* Antitheft systems
Alcohol-based gasoline additives, 760
  engine operation impact, 762
  higher than 10%, 760
  phase separation, 760
  testing for alcohol content, 762, 765
Alemite fittings, 143
Alemite tool, 1505
Alert mode, tire-pressure sensors, 1265
Algorithm, life of engine oil, 135
Align boring, 286, 356
Align honing, 356
Alkaline, 111
All-except-type questions, 36
Alligator clip ends, 444
Alloy steel, 294
All-season tires, 1250–1251
All wheel drive, 1537
  center differential, 1537
  definition, 125
  four wheel drive compared, 1535
Alternative fuels
  comparison chart, 775
  safety procedures, 776
Alternative-fuel vehicles (AFVs), 768–771
Alternator (generator), 6, 578
  access to, 594
  AC ripple voltage check, 590
  assembly, 597
  battery drain, 555
  carbon pile test procedure, 592–593
  changing AC to DC, 578
  clock positions, 594
  components and operation, 579–581
  computer-controlled, 585–586
  construction, 578
  cooling, 585
  cutaway view, 580
  definition, 578
  diagnosing charging problem, 591
  diodes, 511
  disassembly, 594–596
  exploded view, 581
  horsepower and engine operation, 243
  housing, 578
  how it works, 581–583
  installation procedure, 597
  output factors, 583
  output test, 592–593
  overhaul procedure, 598–603
  principles, 578
  reassembly, 596–597
  remanufactured/rebuilt, 595, 597
  removal, 593–594
  sniff test, 594
  stator winding overheating, 555
  troubleshooting low or no output, 590
  two-minute repair, 597
  water spray trick, 195
  whine, 708
Alternator (generator) bench tester, 597
Alternator components and operation
  diodes, 580–581
  rotor construction, 579–580
  rotor current, 580
  rotor magnetic fields, 580
  stator construction, 580
Alternator decoupling pulley (ADP), 578
Alternator disassembly, 594–596
  diode trio testing, 595–596
  marking the case, 594
  procedure, 594–596
  rotor testing, 595
  stator testing, 595
Alternator output
  higher output units, precautions with, 593
  minimum required, 593
Alternator output terminal
  fusible links and mega fuses, 473
  suppression capacitors for, 497
Alternator output test, 592–593
  carbon pile test procedure, 592–593
Alternator overrunning pulleys (OAP), 578–579
  purpose and function, 578–579
Alternator regular battery starter test (ARBST), 548
Alternator removal, 593–594
Alternator stator windings, 467
Alternator voltage regulation
  battery condition and charging voltage, 584
  electronic, 584
  operation, 584
  principles, 583–584
Alternator whine, 708
Altitude
  barometric pressure, inverse relation, 837
  horsepower and, 157
  MAP sensor vacuum readings, 836
  MAP sensor voltage chart, 837
  MAP sensor voltage effects, 836
  mountainous driving, 837
  radiator pressure cap, 187
  speed-density-type fuel injection, 837
Aluminized valves, 294–295
  refacing, 301
Aluminum, 375
  care while cleaning, 272
  crack-welding, 278
  expanding cylinder head, 286–287
  expansion factor, 286
  precautions with cleaning agents, 274
  wrought alloys, 113
Aluminum Association (AA), 113
Aluminum bearings, 375
Aluminum cylinder blocks, 352–353
  casting mold, 352
  surface finish, 358
Aluminum cylinder heads
  drainback hole size, 285
  “integral” cam bearings, 380
  interference fit specifications, 307
  purpose and function, 286
  restoring a warped, 287
  surface finish roughness recommendations, 288
  valve seat inserts, 289, 306
  valve spring seat, 310
  valve stem-to-guide clearance, 290
  warped, 286–287
Aluminum drums, 1158
Aluminum metal matrix composite rotors, 1165–1166
Aluminum tire valve stems, 1264
Aluminum wheels, 1256
  cleaning bead area, 1273
Aluminum wire repair, 477
Amber ABS warning lamp, 1221
  mystery of, 1227
Ambient air temperature sensor, 732
  location shown, 732
Ambient side electrode, 846
American metric tire designations, 1243
American Petroleum Institute (API)
  “doughnut” label, 199
  engine oil rating, 199–200
  gear lubes, 144
  synthetic engine oil (groups), 202–203
American Society for Testing and Materials (ASTM), 756
  diesel fuel grades, 778
  penetration test for grease, 143
American wire gauge (AWG), 467
Ammeter
  blower motor testing, 656
  inductive ammeters, 450
  installation in series, 448
  measuring amperes, 424
  measuring with digital meters, 448
  reading digital meter displays, 453
  use of prefixes, 452
AM modulation, 699
  characteristics, 700
Ampere
  abbreviations, 424
  definition, 424
  fuse ratings, 470
  reading digital meter displays, 452
Ampére, Andrè Marie, 424
Ampere hour, 543
Ampere-turns, 502
Amplification, transistors, 517
Amplifier
  interference and radio noise, 708–710
  specifications, 706
Amplitude, 369
Amplitude modulation (AM), 700
Anaerobic sealers, 386
  for machined surfaces, 386
  prevailing torque nuts, 60
Analog (needle-type) meters, precautions with, 446
Analog dash instruments, 629
Analog MAF sensor
  digital MAF sensor compared, 841
  grams per second/voltage chart, 843
Analog scopes, 461
  glitches missed, 465
Analog-to-digital (AD) converter circuit, 813
  in binary system, 816
Anchor eyes, 1091
Anchor plates, 1122
Angle gauge, 392
Anhydrous ethanol, 767
Annulus gear, 1540
Anode, 510, 514, 515
ANSI (American National Standards Institute), safety glasses, 41
Antacid, 111
Antenna
  input, 700
  lightning damage, 710
  receiver input/output circuits, 700
  satellite radio, 707–708
  types of, 700–701
Antenna diagnosis
  antenna height, 701
  power antenna testing and service, 701–702
  testing, 701
Antennaftermarket XM radio antenna, 394–395
Antenna repair, hole in the fender cover trick, 702
Anti-dive, 1299
Antidrainback valve, 204
Antifreeze
  best freeze protection, 178
  color of leak, 239
Antifreeze (ethylene glycol), disposal, 136
Antifreeze, pet-friendly, 177
Antifreeze-water mixture, 820
Antifriction bearings, 1071–1072
Antiknock index (AKI), 758
Antimony, 539
Antirattle clips, 1117
Anti-roll (roll bar), 1301–1302
Antiseize compound, 387
  on bolt threads, 387
  brakes, 1137
Anti-squat, 1299
Antistatic spray, to prevent shocks from door handles, 492
Anti-sway (sway) bar, 1301–1302
Antitheft systems
  diagnosis, 679
  immobilizer or vehicle theft deterrent key learn procedures, 678–679
  parts and operation, 678–679
  shock sensor, 678–679
  testing and service, 679
API (American Petroleum Institute)
  “doughnut” label, 199
  engine oil rating, 199–200
  synthetic engine oil (groups), 202–203
API gear lubes, 144
API gravity, 778
API gravity comparison chart, 779
API gravity levels, 754
API groups (engine oil), 202–203
APP (accelerator pedal position) sensor, 166
Application cables, 1148
Application force, 1029–1030
Applied position, 1033–1034, 1200
Apply devices, 1571
Apply system, 1017
Apprentice programs, 17
Aqueous-based solutions, 274
Aramid fiber, 1121
Arbor check method, 357
  precision arbor, 357
ARBST (alternator regular battery starter test), 548
Argon gas, 689
Arithmetic average roughness height (RA), 287, 1167
  graph, 288
Arm, construction, 383
Armature, 560, 1349
  assembly removal, 574
  copper wire connections, 561
  definition, 502
  relay, 485
  starter motor, 561
  starter motor (diagram), 559
  starter motor service, 570
  starter, palm-size, 565
Armature circuit, suppression capacitor for, 497
Armature shaft
  measuring, 571
  starter installation, 572
Arming sensor, 689
Armor, 381
Armored brake lines, 1056
Aromatic hydrocarbons, 760
ARP (American Racing Products®) lubricants, 402
Arrows, in wiring schematics, 480
Articulation test, 1384, 1385
AS (air suspension)
  AS system, 1350
  sensor, 1345, 1351
Asbestos, 49–50
  in clutch lining, 1455
Asbestosis, 49
ASE
  logo, 35
  service areas tested, 34
  test registration, 35
ASE Certified Master Automobile Technician, 35
ASE tests
  experience-based questions, 35
  frequently asked questions about, 35–37
  key and distracter, 35
  recertification, 42–43
  service areas covered, 34
    automatic transmissions/transaxles, 38
    brakes, 39
    electrical systems, 39
    engine performance, 39
    engine repair, 38
    heating and air conditioning, 39
    manual drive train and axles, 38
    suspension and steering, 38
  tips for taking, 37–38
  types of questions, 35–36
  work experience required, 35
    substitutions, 35
Ash loading, 170
Ashtray, bulb trade numbers, 607
Asian vehicles
  OBD-II data link connector, 536
  oil specifications, 204
ASM (acceleration simulation mode), 922
ASM 25/25 test, 922
ASM 50/15 test, 922
ASM test, 922
Aspect ratio, 1243
Aspirator tube, 732
Aspire (hotline), 124
Assembly lube, 392
Assembly sealants
  anaerobic sealers, 386
  antiseize compounds, 387
  nonhardening sealers, 386
  RTV silicone, 385–386
  summary chart, 387
Assist hybrid, 990
Association des Constructeurs Européens d’Automobiles (ACEA) engine oil ratings, 200–201
  on oil container, 201
ASTM (American Society for Testing and Materials), 756
Asymmetrical, 320
ATC systems, 732
  block diagram, 733
ATF. *See* Automatic transmission fluid
Atmospheric pressure, 1196
  altitude related, 1197
ATO fuse, 471
Atoms, 421
  hydrogen atom, 421
AT-PZEV (advanced technology partially-zero-emission vehicle), 127
AT-PZEV (advanced technology partial zero-emission vehicle), 919
At-rest position, 1033
Attorney (lawyer), 23
Audi
  direct fuel injection, 887
  five-valve cylinder head, 283
  oil specifications, 204
  radar cruise control, 661
  rotating shafts, 388, 389
  W-8 engine, 388, 389
Audio output/input, GPS system, 638
Audio system. *See also* Radio
  aftermarket upgrades, 705–706
  AM characteristics, 700
  amplifier specifications, 706
  audio noise summary, 710
  audio noise symptom chart, 710
  bass blocker, 704
  crossovers, 704–705
  FM characteristics, 700
  fundamentals, 699
  lightning damage, 710
  modulation, 699
  multipath, 700
  noise, 700
  noise symptom chart, 710
  radio, 526
    interference, 708–710
  radio wave transmission, 700
  separate battery trick, 709
  speakers, 702–704
  terminology, 699
  types of energy, 699

Auto down/up features on power windows, 665
Autohotlineusa, 124
Auto link, 471
Autolocking hubs, 1534
Automatic air-conditioning system, 731
airflow management, 731–732
Automatic brake adjusters, 1097–1100
Automatic dimming mirror
diagnosis and service, 619
diagram, 619
parts and operation, 617–618
Automatic headlights, 613
lighting system diodes, 514
Automatic level control (ALC), 1350
compressor, 1355
inflator or compressor relay, 1354–1355
Automatic level control sensor, 1344
Automatic parking brake release, 1147
Automatic temperature control (ATC), 732
block diagram, 733
Automatic transaxle, speedometer problem, 636
Automatic transaxles, 1561
Automatic transmission, 5
ASE task list, 38
chart of gears, 118
factory service manuals, 72–73, 121
installation, 416
radiator transmission fluid cooler, 187
Automatic transmission band adjustment, 1596
Automatic transmission clutch pack clearance, 1605
Automatic transmission cooler flushing, 1607
Automatic transmission dipstick, tight installation, 1586
Automatic transmission dipstick fluid levels, 1586
Automatic transmission disassembly
clutch packs, 1603
clutch piston inspection, 1604
clutch piston removal and inspection, 1603
friction disc inspection, 1603
hubs, drums, shells, and planetaries, 1604
mount to holding fixture, 1600
pump assembly, 1601
return spring inspection, 1604
steel disc inspection, 1603
torque converter checks, 1600
unit disassembly, 1601–1603
valve body, 1601
Automatic transmission end play measurement, 1606
Automatic transmission filter service, 1595
Automatic transmission fluid (ATF)
checking, 138–139, 1586
color of leak, 239
high temperature and TCC, 1593
hot, precautions with, 1595
purpose and function, 1567
selected sample chart, 1568
service, 138–139
types, 1567
typical applications, 1567
typical dipstick, 138
vacuum gauge readings, 246
white exhaust smoke, 238
Automatic transmission fluid cooler, 1568–1569
flushing, 1607
Automatic transmission fluid heater, 1569
Automatic transmission fluid service, 138–139
leak diagnosis, 1591
paper towel test, 138
steps involved, 138
types, 138–139
Automatic transmission installation, 1508
Automatic transmission linkage adjustment, 1597
Automatic transmission oil pan removal, 1594
Automatic transmission power flow, 1582
Automatic transmission pump, 1569
Automatic transmission reassembly
air pressure checks, 1604–1605
bushings, 1605
clutch assembly, 1604
end play checks, 1606
one-way clutches, 1605
pump assembly, 1606
special tools, 1605
valve body checks, 1606–1607
Automatic transmission repair
ATF cooler flushing, 1607
disassembly, 1600–1604
dynamometer testing, 1608
installation, 1508
reassembling, 1604–1607
reinstalling, 1608
removing unit, 1599–1600
road test, 1608–1609
scan tool data, 1589
torque converter flushing, 1607
verifying need for repair, 1598–1599
Automatic transmissions
background, 1551
checking wiring, 1596
Chrysler PowerFlite shown, 1552
commanding shifts, 1587–1588
companies that build, 1560
customized van story, 1594
dual clutch, 1565–1566
letters and numbers on, 1560
listed by make, 1552
not upshifting, 1594
planetary gear set, 1558–1559
quick and easy diagnosis, 1587
scan tool data, 1589
shift modes, 1557–1558
tag number, 1599
test drive, 1587
torque converters, 1551–1556
Automatic transmission shift points, 829
Automatic transmission torque converter diagnosis, 1592
Automobiles, historical background, 1–2
Automotive industry, other careers, 14
Automotive machine shops, 285
Automotive organization arrangement, large dealerships, 14–15
Automotive service
eight areas, 6–7
need for, 8
Automotive Service Association, 40
Automotive technician (tech)
applying for jobs, 18–20
benefits, 22
communications, 24–26
computer skills, 16
cooperative education programs, 17
desire and interest, 16
duties, 27–29
employment and advancement, 11–12
flat-rate pay methods, 20–21
incentive (commission) pay, 21
job classifications, 10–13
job shadowing, 16–17
locating faults, 11
master technician, 31
most common reason for getting fired, 32
need for, 8
net earnings (take-home pay), 21
payroll deductions, 21
professionalism, 24
clean clothes, 24, 30, 32
ethics, 24
skill level and severe service, 29
skills and abilities, 11, 17
specific tasks, 11–12
straight-time pay methods, 20
technical knowledge and skills, 16
training, 10, 11
working conditions, 11
work sites, 9–10
Automotive wiring. *See* Wiring
Automotive Youth Education System (AYES), 11
Autoranging digital multimeters
interpreting the reading, 452
OL indication, 451
range setting, 448
reading displays, 451
scale display, 448
use of prefixes, 451–452
Auxiliary automatic transmission cooler, 1609
Auxiliary electric water pump, 715
Aviation tin snips, 75
AWG (American wire gauge), 467
conversion to metric, 480
length and resistance, 467
sizing and price, 468
Axial compressors, 728
Axial loads, 1071
Axial plate, 728
Axis, 1472
Axle assembly number, 1524
Axle end play, 1545
Axle housing cover
correct installation, 1532
shown, 1532
Axle ratio, 1519
determining differential, 1524
high-performance tip, 1519
Axles
solid I-beam, 1291
steerable rear, 1378
Axle shaft
care with seal, 1531
shown, 1524
Axle windup, 1336
AYES (Automotive Youth Education System), 11

B

B20 biodiesel blend, 780
Babbitt, 375
Babbitt, Isaac, 375
Back clearance, 343
compression ring seals, 343
Backing plates, 1089–1090, 1104
Backlash
checking, 1529
correcting, 1529–1530
determining, 1525
noises to expect, 1530
quick and easy test, 1525
tooth contact pattern test, 1526
Backlash test, 1509
Backlight, 662
Back pressure, 248
testing with pressure gauge, 248
testing with vacuum gauge, 248
Back pressure adapter, how to make, 248
Back pressure tool, construction, 952
Back spacing, 1255
Back taper, 1480
Backup camera
diagnosis and service, 640
fisheye-type, 640
parts and operation, 640
visual inspection, 640
Backup lights
bulb trade numbers, 607
troubleshooting, 488
Backup sensors
components, 641
diagnosis, 641
display location, 641
operation, 641
ultrasonic sensors in bumper, 641
Baffle, 860
Baking soda as cleaning agent, 111, 273
advantages, 273
Balance shafts, 267
90-degree V-6 engines, 371–372
applications, 371–372
GM 4-cylinder engine, 372
purpose and function, 371
Balance valve, 1570
Balancing bosses (pads), 346
diagram, 346
Balancing crankshafts, 369–370
Balancing hole, 365
Ball and ramp actuation, 1151
Ball bearings, 1071
Ball bearings/rear axles, 1523
Ball flare fitting, 1055
Ball joints
BJI, 1421
design, 1300
diagnosis and inspection, 1318
indicator, 1318
load-carrying, 1300
low-friction versus steel-on-steel, 1320
non-indicator, 1318–1320
non-load-carrying, 1300
non-replaceable, 1321
pinch bolt, 1321
removal, 1320
riveted, 1321
rivet removal, 1321
Ball nut assembly, 1366
Ball-peen hammer, 73
Ballpoint pen test, 1169
Ball socket assembly, 1373
service, 1384–1385
Ball-type positive rotator, 299
Bank, 367
Bar, 188
metric pressure to PSI, 188
Bar magnet, 498
BARO (barometric pressure) sensor, 837
DTCs, 838–839
pulse width, 873
Barometric manifold absolute pressure (BMAP) sensor, 837
pulse width, 878
Barometric pressure, altitude, inverse relation, 837
Barometric pressure (BARO) sensor, 837
Barrel, 99
Barrel face ring, 344
line contact, 344
Barrier hoses, 723
Barrier-type refrigerant hoses, 719
BAS (belt alternator starter), 987–989
BAS (brake assist system), 1201
brake force shown, 1202
during panic condition, 1202
Base, 516
Base brakes, 1016, 1209–1210
Bases, 111
Bass blocker, 704
Batteries
AGM, 542
capacity, determining, 543
causes and type of failure, 542
charge indicators, 541–542
charging voltage, 542
as closed circuits, 432
condition and charging voltage, 584
construction, 538–540
cranking circuit, 556–557
date codes, 552
deep cycling, 543
diagnosing sound system interference, 709
disposal, 53
electrochemistry principle, 426
flooded cell, 542
gelled electrolyte (gel), 542
handling and storage, 53
heavy-duty trucks, 548
importance of, 538
jump starting safety, 44–45
lead-acid battery, 540
lead-acid battery waste, 53
light-duty vehicles, 548
load test, 547
location, 555
normal life, 542
operation, 540
overcharging, effects of, 542, 550
positive terminal, 480
purpose and function, 538
ratings, 542–543
reading codes on, 552
recombinant, 542
reserve capacity, 543
return path, 429
reverse charged (reversed polarity), 547
schematics for, 429
schematic symbols, 481–482
settings in RAM, 814
sizes, 543
SLI, 539
specific gravity, 540–541
storage, 552
SVR, 542
temperature compensation, 584–585
vehicle with two batteries, 548
visual inspection, 545
Battery acid, how to neutralize, 546
Battery cables, 469
corrosion on, 545
disconnecting, safety precautions, 593
maintenance, 545–546
safety procedures, 545
visual inspection, 545
voltage drop measurement, 567
warm/hot, meaning of, 567
wire gauge for, 469
Battery charge indicators, 541, 541–542
Battery charging, 549–550
at 1% of CCA rating, 550
charge time, 549, 550
charging rate, 550
guidelines for charging times, 549
location of 12 volt and high-voltage batteries, 551
procedure, 549–550
Battery construction
case, 538
cells, 539
cutaway view, 539, 540
electrolyte, 540
grids, 538–539
negative plates, 539
partitions, 539–540
positive plates, 539
separators, 539
Battery Council International (BCI), 53
battery sizes, 543
Battery electrical drain test, 552–555
battery drain and reserve capacity, 553–554
finding source of drain, 554
memory saver, 554
procedure, 553–555
reset all memory functions, 553
specifications, 553
terminology, 552–553
what to do if it still exists, 555
Battery electric vehicles (BEV), 983
Battery hold-downs, 542
hold-down bracket, 546
maintenance aspects, 545–546
Battery jump box, 550, 552
Battery maintenance
need for, 545
terminal cleaning, 545
Battery-operated grease guns, 84
Battery operation
during charging, 540
during discharging, 540
easy way to remember, 541
fully discharged state, 540
principle involved, 540
Battery positive terminals, fusible links and mega fuses, 473
Battery ratings
ampere hour, 543
cold-cranking amperes (CCA), 542–543
cranking amperes (CA), 543
marine cranking amperes (MCA), 543
reserve capacity, 543
Battery service
battery voltage test, 546–547
hazards, 545
safety, 545
symptoms of weak/defective unit, 545

Battery sizes, 543
BCI sizes, 543
typical group size applications, 543
Battery state of charge, 588
Battery testing
battery access point, 555
conductance tester, 548–549
electrical drain test, 552–555
electronic conductance, 548–549
hydrometer, 547
ignition off draw (IOD) test, 552–553
load test, 547
parasitic load test, 552–553
Battery testing. *See also* Battery electrical drain test
symptom guide, 555
three-minute charge test, 548
troubleshooting, 555
typical tester, 592
Battery voltage
digital meter usage, 456
measuring via lighter plug, 591
scope display, 465
scope usage, 465
Battery voltage correction factor, definition, 884
Battery voltage tests, 546–547
state of charge, 546–547
Baudot, J. M. Emile, 815
Baud rate, 815
BCI (Battery Council International), 53
BCM (body control module), 653
BDC (bottom dead center), 149
Bead, 1241
Bead flanges, 1254
Beam axle
exploded view, 1337
rear suspension, 1338
Beam-type torque wrenches, 70
accessory drive belt tension, 195
belt tensioner reading, 140
Bearing caps
disassembling overhead camshaft head, 285
position marking, 267
Bearing clearance, 377–379
Bearing crown, 374
Bearing crush, 378–379
spread and, 378–379
Bearing diagnosis, 1074–1075
Bearing failure analysis, 1082–1084
Bearing failure, premature, 393
Bearing fatigue, 376
Bearing greases, 1072–1074
Bearingized finish, 1105
Bearing journal overlap, cast crankshafts, 367
Bearing journal scoring, 372
Bearing noise, 1074
Bearing overload, 1084
Bearing replacement, oil hole position, 379
Bearings. *See* Engine bearings; Wheel bearings and service
Bearing service and replacement, 596
Bearing shell, 375
Bearing splitter, 85
Bearing spread, 378–379
crush and, 378–379
Bearing tang, 378
Beary, Karl Friedrick, 1
Becquerel, Edmond, 426
Bedded-in brake pads, 1136–1137
Bedding-in replacement brake pads, 1136–1137
Bedplate design blocks, 353
location, 353
Beehive holdowns, 1094
Belleville spring, 1458
Bell housing, 1476
Bell housing alignment, 416
Bellmouth drums, 1160
Belt alternator system (BAS), 987–989
Belt and pulley CVT, 1563
Belt-driven air pumps, 946
operation shown, 946
Belt-driven auxiliary vacuum pump, 1197
Belt retractors, 687
Belt routing guide, 140
Belts, tire, 1242
Belt tension, 1403
before checking water pump, 190
cooling system inspection, 194–195
Belt tensioner, 589
marks on, 589
Belt tension gauge, 139–140, 194–195, 589
chart, 195
shown, 140
Belt tension measurement, 139–140
spring-loaded tensioner, 140
Bench bleeding master cylinders, 1061
Bench grinders, 84–85
Bench-mounted tray for crankshafts, 374
Bench testing, 571
Bench vise, 85
Bend, 286
Bending brake lines, 1056
Bendix drive mechanism, 563
BEV (battery electric vehicles), 983
Bevel gear, 1473
Bevel gear differential, 1541
Bevis, John, 493
Bias ply, 1241
Bias-ply tires, 1241
Bias voltage, 848
Bicarbonate of soda as cleaning agent, 273
Bidirectional scan tool, 653
Billet, 367
Billet crankshafts, 367
Bimetal flashers, 611
Binary code, 813
Binary digits, 813
Binary system, 816
BIN number, 127–128
Bin numbers
air pollution score, 919, 920
Tier 2 emission limits, 919
Biodiesel, 779–780
blends, 780
definition, 779–780
features of, 780
vegetable oil compared, 780
Biomass, 772
cellulosic biomass, 767
Bipolar transistor, 516
Bi-state dampers, 1352–1353
Bi-xenon headlights, 614
BJI (ball joint inclination), 1421
Black conduit with green stripes, 477
Black exhaust smoke, 171
IAT sensor defective, 825
possible causes, 238
Black light
locating AFT leak, 1592
refrigerant testing, 744
Black meter lead
position, 447
reading digital meters, 452
Blade screwdrivers, 72
Blade-type circuit breakers, 472
Blade-type fuses, 470–471
amperage and colors, 470
three sizes, 471
Bleed and squirt test, 1129
Bleeder valves, 739, 1061
loosening methods, 1062–1063
refilling the cooling system, 196
Bleed hole, 190, 346
Bleeding
gravity, 1065
hydraulic clutch, 1466
manual brakes, 1063–1064
master cylinder, 1061–1062
power, 1066–1067
pressure, 1066–1067
vacuum, 1064–1065
Bleeding air, out of power steering, 1404–1405
Blend door position, 734
Blinder clips, 81
Blinking LED theft deterrent, 520
rigging a fake alarm indicator, 520
Block, 147
Block cleaning, 361–362
debris, 362–363
Block deck, 353–354
location, 354
Block detailing, 363
Blocker rings, 1477
worn, 1486
Block inspection, 267
pressure testing, 276
vintage Ford V-8, 276
Blocks of tread, 1275
Blowby
definition, 942
ring gap, 343
Blowby gases, crankcase vent hose, 238
Blower motor, 714
20 ampere fuse test, 655
afterblow, 731
assembly with squirrel cage blower, 734
circuit diagram, 655
on command, 519
computer controls, 816
control, 734
“credit card” resistor, 734
diagnosis, 655–656
clogged evaporator, 743
heating system, 714
high-voltage surges, 512
parts and operation, 654
purpose and function, 654
resistor location, 654
resistor pack, 655
service, 746
squirrel cage, 654
testing, 656
testing with DC ammeter, 656
troubleshooting guide, 656
variable speed control, 654
voltage drops in circuits, 436
Blower motor control, 734
Blower motor service, 746
Blown (open) fuses, 429
Blow-off valve (BOV), 234
flow diagnosis, 234
Blue (oil) smoke, valve stem seals defective, 308
Blue assembly lube, 1606
Blue conduit, 478
Blue exhaust smoke, 172
oil leaks, 238
possible causes, 238
Bluetooth, 78, 124, 707
origin of name, 707
use of two telephones, 707
BMAP (barometric manifold absolute pressure) sensor, 837
BMW
direct fuel injection, 887
head bolt threads, 390
oil specifications, 203
radar cruise control, 661
remote keyless programming, 673
variable camshaft timing, 330
BNC connector, 465
BOB (breakout box), 1227
Body
avoiding damage to, 3
early wood framework, 2
historical background, 2
terms shown, 3
Body control module (BCM), 524, 653
blower motors, 655
Body ground wires, 469
Body-on-frame (BOF) vehicles, 3
Body plies, 1241
Body ply, 1241
Boiling point, 713
refrigerants compared, 718
Boiling point testers, 1052–1053
Bolt circle, 1256
Bolt extractors, 77
Bolts, 58, 59
clamping force of new, 402
damaged heads, 76–77
keeping track of, 80
SAE designation chart, 59
wax trick, 77
Bolts or nuts, KISS test method, 242
Bolt stretch, 403
Bonded linings, 1092, 1120
Bonding, 1092
Boost, 228
compression ratios, 229
result of restriction, 234
Booster vacuum supply, 1197
Boost system, 1017
Bore oversize, determining, 359
Bores, 152, 352
cylinder boring, 358–359
Boring bar, 359
Boring hones, 360
Borrowing tools, 79
Bosch, modes of operation, 889
Bosch 2 ABS, 1224–1225
Bosch L-Jetronic, vane airflow sensor, 840
Bosch-Siemans-Temic (BST) BUS communication, 534
Bottom dead center (BDC), 149
Bottoming tap, 363
Bottoming taps, 60
Boundary lubrication, 211
Bound electrons, 422
BOV (blow-off valve), 234
Boxed components, schematic symbol, 483
Box-end wrenches, 68
Boxer engine design, 149
Boyle, Robert, 112
Boyle’s law, 112
BPP (brake pedal position), sensor, 1402
BPP sensor, 1403
Braided fabric seals, 396
Braided ground straps, 468
for EMI suppression, 507
skin effect, 468–469
Braided ground wire, radio interference, 709
Brake-actuated traction control, 1537
Brake assembly fluid, 1133
Brake assist system (BAS), 1201
brake force shown, 1202
during panic condition, 1202
Brake balance control system, 1017
Brake bleeding methods and procedures, 1061–1069
bleeder valve loosening methods, 1062–1063
bleeding sequence, 1063
brake fluid replacement/flushing, 1069
gravity bleeding, 1065
manual bleeding, 1063–1064
overview, 1061–1062
pressure bleeding, 1066–1067
vacuum bleeding, 1064–1065
Brake blocks, 1121
Brake booster, vacuum, typical, 1196
Brake cables
linkage, 1148
swollen, 1148
Brake caliper rebuilding, 1132
Brake design requirements, 1017
Brake drum balancing, 1280
Brake drum chamfer, 1162
Brake drum damage, checking for warpage, 1161
Brake drums
damage, 1158–1159
described, 1094
distortion, 1159–1161
machining, 1158, 1176–1181
machining steps, 1162–1163
measuring, 1162
reassembling, 1108
removing, 1161
Brake drums. *See also* Machining brake drums and rotors
storing, 1160
types, 1158
Brake drum slide hammer trick, 1080
Brake dust, 50, 1118
Brake fade, 1025, 1089, 1110
Brake fluid, 133, 1050–1054
blue, 1051
brake pedals and, 1029
color of leak, 239
contamination precautions, 134
inspection and testing, 1052–1054
low, 1043
physical properties, 1050
purpose and function, 1050
replacement/flushing, 1069
service procedures and precautions, 1054
silicone, 133–134
specifications, 1050–1052
testing, 134, 1052
boiling point, 134
test strips, 134
visual inspection, 134
types of brake master cylinders, 133
Brake fluid level sensor, 629
Brake fluid level sensor switches, 1042–1043
warning lights, 1227
Brake fluid tester, handheld, 134
Brake fluid test strips, 134
Brake hardware kit, 1107
Brake heat test, 1020
Brake hold down spring tool, 1103
Brake horsepower (bhp), 108
Brake hoses
double-checking your work, 1136
flexible, 1058–1060
Brake hub cleaning, 1174
Brake hydraulic hose, 1325
Brake hydraulic systems, 1027
hydraulic principles, 1027, 1030–1031
master cylinder diagnosis and troubleshooting, 1037–1038
master cylinders, 1031–1039
master cylinder service, 1038–1039
Pascal’s law, 1028–1031
Brake lathe, 1163
“diameter graduated,” 1164
Brake light circuit, electrical problems, 430
Brake lights, 608–609
bulb failure warning light, 626
LEDs, 514, 609
operation, 608–609
schematic, 609
Brake light switches, 1048–1049
Brake line flaring, 1055
Brake lines, 1054–1057
armored, 1056
coiled, 1056
cutting tools for, 1056
double flaring shown, 1057
flexible brake hoses, 1058–1060
Brake linings, 1081, 1092–1093, 1120–1122
inspection, 1104
Brake master cylinder
avoid overfilling, 133
with transparent reservoir, 133
types, 133
Brake pads, 1118–1122
bedding-in, 1136–1137
edge code chart, 1122
Brake pad warning lamp, 627
Brake pedal depressor trick, 1036
Brake pedal effort, 1139, 1207
Brake pedal feedback, 1217
Brake pedal free play, 1037
Brake pedal height, 1037
Brake pedal position (BPP), sensor, 1402
Brake pedal pressure, 1109–1110
Brake pedal reserve distance, 1037, 1038
Brake pedal return, 1207

Brake pedals
apply system and, 1017
assembly, 1019
low, 1037, 1109, 1201
parking, 1146–1147
pulsating, 1110, 1139
sinking, 1038, 1053
spongy, 1037, 1109
Brake pedal travel, 1110, 1139
Brake pedal travel switches (sensors), 1217
Brake pipes, 1054. *See also* Brake lines
Brake pressure, unequal, 1043
Brake pull, 1089
Brake return spring tool, 1103
Brake rotors, 1122. *See also* Disc brake rotors; Machining brake drums and rotors
Brakes, 108
ASE task list, 39
kinetic energy and, 109
laws of physics and, 109
system overview, 2
Brake safety switch
adjustment procedures, 659
cruise control, 659
Brake shoe clearance gauge, 1109
Brake shoe holdowns, 1093–1094
Brake shoe return springs, 1094
Brake shoes, 1091. *See also* Shoes
disposal, 49
Brake shoe setting gauge, 1109
Brake-specific fuel consumption, 884
Brake spring inspection, 1105
Brake spring pliers, 1108
Brake spring tool shown, 1103
Brake switch schematic, 609
Brake system categories, 1017–1018
Brake system parts, 1016–1017
Brake system principles, 1021–1026
brake fade, 1025
deceleration rates, 1026
energy principles, 1022–1023
friction and heat, 1025–1026
friction principles, 1024–1026
inertia, 1023
Brake tubing, 1054. *See also* Brake lines
Brake type dynamometers, 410
Brake warning lights, 1017–1018
Brake warning switches, 1041–1042
Braking distance, 1209
Braking system components and performance standards, 1015–1020
ABS, 1018–1019
brake design requirements, 1017
brake repair and the law, 1020
brake system categories, 1017–1018
brake system parts, 1016–1017
federal brake standards, 1019–1020
Braking system principles, 1021–1026
brake fade, 1025
deceleration rates, 1026
energy principles, 1022–1023
friction and heat, 1025–1026
friction principles, 1024–1026
inertia, 1023
mechanical principles, 1023–1024
Braking traction shown, 1209
Branches, 438. *See also* Legs
Brand names, tool, 74
Brazil, 767, 774
Breakdown voltage, 512
Breaker bars, 69
Break-in engine oil, 418
Breaking in engine
break-in oil, 418
engine start, 418–419
normal operating temperature, 418
precautions, 419
test drive, 418
warming up cold engine, 419
Breakout box (BOB), 1227
European vehicles, 533
testing BUS, 533
Breakout box, TP sensor testing, 830
Breather ports, 1032
Breath test, 663
Brinelling, 1084
British thermal unit (BTU), 757
British Thermal Units (BTUs), 110
Broach, 287
Broadband oxygen sensor. *See* Wide-band oxygen sensors (O2S)
Broadband oxygen sensor, 853
Bronze guide liners, 291–292
boring tool, 291
trimming thin-walled insert, 291
Bronze guides, 291
Brush-end housing, 560
Brushes for starter motor, 561
Brush holder, replacement, 595
BST (Bosch-Siemans-Temic) BUS communication, 534
BTUs, 110
Bubble balancer, 1280
Bubble flare fitting, 1055
Bucket valve opening design, hydraulic lifters in, 342
Buick
alternator replacement, 594
clogged evaporator problem, 743
remote keyless programming, 673
Buick V-6
number of bolts in oil pan, 379
vibration problem, 368
Bulbs
bulb numbers, 605–608
schematic symbol, 483
suffixes, 277, 605
Bulkhead, 1290
Bulkhead flex, 1466
Bump caps, 42
Bump problems with cruise control, 659
Bump steer, 1382
kits, 1448
Bump stops, 1308
Burn in, 511
Burnish procedure, 1020, 1136–1137
Burn kV, 809
Burn test, 112–113
Burping the boot, 1512
BUS, 526
BUS bar, 525
BUS communication
definition, 526
differential type, 524
multiplexing, 524–525
parallel type, 524
serial data type, 524
typical system schematics, 527
Bushing, 1455
Bushings
automatic transmission, 1604
strut rod, 1327
Bushing service, 1326–1327
Butane-powered soldering irons, 80
wire repair, 475
Butt-type piston ring gap, 343
Buzzer method (short circuits), 490
BWM STEP training, 17
"BXX" biodiesel blends, 780
Bypass, 184
Bypass ignition control, 792–793
Bypassing, 1038
Bypass ports, 1032
Bypass regulator for fuel line pressure, 882
Bypass valves, 204, 230
bypass actuator shown, 230
Byteflight BUS communication, 534

C

CA (cranking amperes), 543
CAA (Clean Air Act), 49
CAB (controller anti-lock brakes), 1214
Cabin filter, 732
typical, 733
Cabin filters, 132
location, 132
replacement, 132
Cable adjuster, 1097
Cable guide, 1149
Cable-operated clutch linkage, 1466
typical, 1483
Cadillac
air conditioning problems, 750
battery sizes, 543
electric mirror control, 671
electronic stability control, 2
rebuilt engine, 390
remote keyless programming, 673, 674
story about, 750
voice command icon, 707
Cadmium sulfide, 514
Caged-needle bearing, 1461
Cages, 1071
Calcium, 539
Calculated numbers, 410
Calculators, electronic, 439
Calendar year (CY), 126
Calibration codes, 128
Calibration resistor, 857
California Air Resources Board (CARB), 127, 958
OBD-II objectives, 958
California emission standards, 919
Caliper-actuated disc parking brakes, 1150–1153
Caliper bore, 1132–1133
Caliper pistons
disc brake pad installation, 1154
removal, 1131
Calipers
assembly, 1132–1133
disc brake, 1118
fixed brake, 1122
floating, 1122
loaded, 1134
low-drag, 1125
mount service, 1133–1134
pin-slider, 1124
pressure testing, 1139
service, 1130–1137
sliding, 1122, 1126
Caliphers, disc brake service, 1130–1137
Calories (c), 713
Cam bearing
installation, 393–394
short block assembly, 393–394
Cam bearing bores, 356
Cam bearing installing tool, 393
Cam bearing wear, 216
Camber, 1414–1416
adjusting front, 1440–1442
adjusting rear, 1438–1439
aftermarket kits, 1447, 1448
diagnosing, 1435
kits, 1447, 1448
measuring, 1433
Camber roll, 1417, 1418
tire wear, 1418
Cam chucking, 319
Cam followers, 323
hydraulic lifters in, 323
Cam ground pistons, 339
piston cam shape, 339
Cam-in-block (OHV) design, 150
break-in lubrication, 418
cam phaser, 334
camshaft position actuator, 334
camshaft removal, 328–329
cylinder head, 267–268
engine disassembly, 264–265
lifter and pushrod installation, 405–406
location, 315
timing chain and gear installation, 405
Cam lobe height
dial indicator, 329
measuring, 329
Campaigns, 78, 123
vehicle manufacturer, 78, 123
Cam phasing device types, 332
Cam retard value, 806
Camshaft bearings, 315
replacement, 379–380
Camshaft belt drives, 318–319
timing belts, 318–319
Camshaft chain drives, 317–318
Camshaft design
camshaft bearing journals, 316
construction, 315–316
fuel pump eccentrics, 316
hardness, 316
lubrication, 316
Camshaft diagnosis, rotating pushrod test, 329
Camshaft drives
camshaft belt drives, 318–319
camshaft chain drives, 317–318
purpose and function, 317
Camshaft duration, 323
lifter (tappet), 323–324
Camshaft installation
precautions, 397
prelubrication, 397
vertical position, 395
Camshaft lobe lift, 319–320
Camshaft measurement, locations on journal, 100
Camshaft movement
camshaft lobe lift, 319–320
reasons they move, 319
why flat-bottom lifters move, 319
Camshaft position (CMP) sensor
CKP sensor relationship, 806
distributor indexing, 805–806
worn distributor drive gear, 806
Camshaft position actuator, 331
cam-in-block (OHV) design, 334
Camshaft removal, cam-in-block engines, 328–329
Camshafts, 150
camshaft gear and crankshaft gear relationship, 317
checking for wear, 101
design, 315–316
distributor and oil pump, 315
drives, 317–318
high-performance, 315
intake and exhaust valve relationship, 324
lifter bore bushings, 363
lifters or tappets, 326
location, 315–336
lubrication, 327–328
measurement, 99–100
measuring, 329
movement, 319–320
operation, 315
overhead camshaft valve trains, 323
overlap, 324
parts and nomenclature, 316
purpose and function, 315
pushrods, 322–323
removal, 328–329
replacing, 329–330
rocker arms, 320–322
rotation, 331
selecting, 329–330
specifications, 323–326
telescopic gauge for measuring, 100
valve and camshaft number and location, 149–150
valve train lubrication, 327–328
valve train problem diagnosis, 328
variable lift and cylinder deactivation systems, 334–335
variable valve timing, 330–334
worn, 316
Camshaft specifications
calculating valve overlap, 324–325
camshaft duration, 323
cam timing, 325–326
cam timing specs chart, 326
high-performance, 326
lobe centers, 324–325
lobe separation effects on valve operation, 325
valve overlap, 324
Cam timing, typical diagram, 325
Cam timing specifications, 325
chart, 326
typical timing diagram, 326
Cam tunnel, 286
Cam-within-a-cam, Dodge Viper, 332
CAN (controller area network), 527
background, 530
BUS connected to accessories and systems, 531
Class A, B, and C, 531–532
diagnostic systems, 530–532
differential module communication, 532
features, 530–531
CAN A, 531
Canada, Inter-Provincial Certificate, 40
CAN B, 531–532
CAN C, 532
CAN H circuit, 536
CAN L circuit, 536
CANDi (CAN diagnostic interface) module, 529
Candlepower, 605
Candlestick, 1461
Canister purge (CANP) valve/solenoid, 930
Canister purge system pressure test, 932–933
Canister vent valve, 930
Capacitance
definition, 493
factors of, 495
measurement of, 495
Capacitive coupling, 506
Capacitive strip airbag sensor, 696
Capacitors, 507
charging, 494
in circuits, 496–497
coaxial, 709
construction, 494
operation, 494
safe discharge of, 494
schematic symbol, 483
symbols, 495
uses for, 495–496
Capillary action, 64
Capillary tube, 723–724
Cap screws, 58
Capture problem, 700
CARB (California Air Resources Board), 127, 958
Carbon balls in EGR valves, 940
Carbon cleaning, 891
Carbon deposits
intake valve, 297
valve fault diagnosis, 296
Carbon dioxide (CO2)
exhaust analysis, 923
as measure of efficiency, 925
measuring, 925
Carbon dioxide (COsub2), as refrigerant, 719
Carbon dioxide (COsub2) fire extinguishers, 46
Carbon fiber reinforced carbon (CFRC), 1121
Carbon fouling, 803
shown, 803
Carbon issues, 891
Carbon knock, 282
decarbonization, 282
KISS test method, 242
Carbon monoxide (CO)
CO as meaning "clogged oxygen," 924
CO too high, 924
dizzy feeling or headache, 925
dog food in air intake ducts, 926
exhaust analysis, 923
high, cause and correction, 926
same as O2 reading, 924
Carbon monoxide (CO) emissions, 5
Carbon pile, 547
Carbon pile test procedure, 592–593
Carcass ply, 1241

Cardan-type U-joints, 1498
double-Cardan, 1498
FWD, 1542
Jeep Wrangler, 1542
Carrier wave, 385
Case hardening, 366
Cast-aluminum engine blocks, 352–353
Cast aluminum pistons, 338
Cast connecting rods, 346
before and after machining, 347
Cast covers, 407
Cast crankshafts, 367
bearing journal overlap, 367
Caster, 1416–1418
measuring, 1433
Casters, 92
Caster sweep, 1433
Casting numbers, 128
engine block location, 354
engine blocks, 353
Cast iron, 113
engine blocks, 351
Cast-iron camshaft, hardness, 316
Cast-iron cylinder block
casting, 351–352
surface finish, 358
Cast-iron cylinder head
integral seats, 296
replacement valve seat, 306
surface finish roughness recommendations, 288
surface grinder, 287
Cast-iron drums, 1158
Cast-iron guides, 291
Cast iron welding, 277
Cast pistons, 338
Catalyst, 949
Catalytic converter, 5
acceptable exhaust emissions, 924
clogged, 247
construction, 949
converter-damaging conditions, 951
defective, 951, 952, 954
diagnosis, 952–954
light-off temperature, 949
location, 949
monolithic substrate shown, 949
OBD-II catalytic converter performance, 950–951
operation, 949, 955–956
oxygen sensor signals, 850
purpose and function, 949
replacement, 953, 954
guidelines, 954
usage, 950
Catalytic converter diagnosis, 952
defective, 951, 952, 954
DTCs, 953, 954
efficiency tests, 953–954
tap test, 952
testing back pressure
with pressure gauge, 952
with vacuum gauge, 952–953
testing for temperature rise, 953
Catalytic cracking, 754
Cathode, 510, 514, 515
Cathode ray tube (CRT), 461
CAT I meter, 454
CAT II meter, 454
CAT III meter, 454
CAT III rated digital multimeter, 992
CAT IV meter, 454
Caustic materials, 111, 273–274
Cavalier convertible story, 837
Cavitate, 213
prevention by sheet metal covers, 213
CBV (compressor bypass valve), 234
CCA (cold-cranking amperes), 542–543
CCA rating
battery charging at 1%, 550
battery load test, 547
CCD multiplex networks
“collision,” meaning of term, 530
plus and minus signals, 530
CCM (comprehensive component monitor), 959
CCOT (cycling clutch orifice tube), 716
cycling off and on rapidly, 741
typical accumulator, 723
typical system, 717
CCVRTMR, 1355
Cell phone interference, 507
Cells, battery, 539
Cellulose ethanol, 767
Cellulosic biomass, 767
Celsius, Anders, 98
Celsius temperature scale, 98, 110
CEMF (counter electromotive force), 504
series starter motor, 559
Center bolt, 1295
Center bolts, 1342
Center differential, 1541
cutaway view, 1537
locking methods, 1536
Center high-mounted stoplight (CHMSL), 515, 659
bulb trade numbers, 606–607
cruise control, 659
definition, 609
Centering pin, 1295
Centerline steering, 1444
Center link, 1372
wear and nonwear, 1380
Center section of wheel, 1254
Center support bearing, 1495
Center take-off racks, 1374
Centigrade, 110
Central port fuel injection, 883–884
diagram, 883
factory replacement unit, 884
Central processing unit (CPU), computer, 814
Centrifugal pump, 189
Centrifugal supercharger, 230
Centrifugal-type washer pump, 652
Ceramic-coated piston rings, 345
Ceramic friction material, 1121
Cerium, 949
in aftermarket catalytic converter, 953
Certification tests, 34–40
recertification, 40
Cetane number, 777
for E-diesel, 780–781
Cetane number of diesel fuel, 777
CFC (chlorofluorocarbon), 719
chemical breakdown, 719
CFC-12 (R-12), 718
refrigerant leak detector, 744
retrofitting to HFC-134a system, 751
service machine shown, 747
sight glass shown, 740
CFL (cold cathode fluorescent lighting), 634
CFR (Code of Federal Regulations), 48
CFRC (carbon fiber reinforced carbon), 1121
CGI (compacted graphite iron), 353
Chain-drive transfer cases, 1543
Chamfering cylinder bores, 362
tapered sanding cone, 363
Changes of state, 713
Channel, 464
Channel Locks, 74
Channels, 1211
Chapman strut, 1339
Charcoal canister, 928
location, 928
Charcoal filters, 1198
Charge density, 228
Charging battery, 540
Charging circuit
mega fuses, 473
scan testing, 588
voltage drop test voltmeter hookup, 592
Charging rise time, 796
Charging system
alternator construction, 578
alternator operation, 578
alternator overrunning pulleys (OAP), 578–579
computer controlled, 586
diagnosis and service, 588
full-fielding test, 588
older vehicles, 588
typical tester, 592
voltage check, 590
voltage drop testing, 591–592
warning lamp, 626
Charging system warning lamp, 626
Charging voltage
alternator, 584
temperature compensation, 584–585
Charging voltage test, 588
Charles, Jacque, 112
Charles’s law, 112
Chart, 118
interpreting, 118
reading, 118
Chassis, 2–3
components, 2–3
early 1950s vehicle shown, 2
Chassis dynamometer, 410
Chassis lubrication, 143
Chatter, 1139
drum brakes, 1110
power brakes, 1207
Chattering, differential lubricants, 1532
Cheater bars, 71
safety with, 80
Check balls, 1577
Check engine indicator lamp, shown, 958
“Check engine” light, 5, 626
Check engine light, visual inspection, 909
“Check engine” light, wrong oil viscosity, 200
Check gas cap indication lamp, 932
Check valve, 862
Check valves
definition, 946
failure, 946
location, 946
Chek-Chart, 120
Chemical cleaners
eye protection, 273
pH, 273
solvent-based cleaning, 273
water-based chemical cleaning, 274
Chemical/microbe cleaning, 44
safe use, 44
Chemical poisoning, 51
Chemical tester, head gasket diagnosis, 248
Chevrolet
battery drain test, 554
battery sizes, 543
O-ring valve stem seal, 308–309
remote keyless programming, 673, 674
Chevrolet Blazer
CV joints, 1543
EVRV replacement, 940
Chevrolet Cobalt, no-start story, 535
Chevrolet Colorado, casting mold for engine blocks, 352
Chevrolet Corvette
catalytic converter location, 949
dry sump oil system, 218
OAP on alternator, 579
SAI pump, 947
Chevrolet Equinox, schematic with GMLAN BUS, 537
Chevrolet HHR, hard-to-start, 798
Chevrolet LT1 V-8, reversed-flow cooling systems, 284
Chevrolet pickup
PCM location, 815
two-minute alternator repair, 597
Chevrolet pickup story, 848
Chevrolet Prism, cruise control below 25 mph, 72, 120
Chevrolet S-10 pickup, differential, 1521
Chevrolet Silverado, electrohydraulic power steering, 1402
Chevrolet small block V-8
block with dipstick hole, 355
checking angle, 392
LHD, 354
oil gallery plugs, 355
tightening retaining nut, 406
valve spring, 391
Chevrolet V-6, dual nozzle TBI unit, 876
Chevrolet V-6 pickup
cam retard value, 806
rough idle story, 1591
Chevrolet V-8
alternator, 578
bearing removal, 267
cutaway of block, 354
cutaway view to thermostat, 185
dual turbocharger system, 235
hot lifter, 329
internally/externally balanced engine, 370
no start condition, 798
oil gallery plugs, 354
oil passages, 217
rust in cylinders, 268
timing chain replacement, 320
valve guide replacement, 292
Chilton, 120
Chirping noise, clutch, 1462
Chisels, 76
Chlorinated hydrocarbon, 51
CHMSL (center high-mounted stoplight), 515
bulb trade numbers, 606–607
cruise control, 659
definition, 609
Christmas tree clips, 62
Chrome rings, 365
Chrome-vanadium steel, 68
Chromium piston rings, 344–345
chrome facing, 345
Chrysler
5-volt reference of oxygen sensor, 851
ABS summary guide, 1222
airbag control module diagram, 692
ATF+4 fluid, 138
brake fluid, 134
ceramic disk MAP sensor, 834–835
combined BARO and IAT sensor (older models), 837
communication protocols, 530
compound-wound starter motors, 560
crate engines, 262
cylinder head setup, 310
diagnostic connector, 1223
distributor indexing, 806
ECT sensor without pull-up resistor, 822
ECT sensor with pull-up resistor switched by PCM, 822
electric fuel pumps, 867
electronic conductance tester, 548–549
ETC warning lamp, 896
Flex Fuel vehicles, 770
how to read VIN, 771
H-valve, 726
ignition coil circuit design, 806
immobilizer or vehicle theft deterrent key learn procedures, 680
injector resistance table, 904
MAP sensor chart, 835
multiple displacement system, 335
OBD-II data link connector, 536
ODS test weight, 696
oil specifications, 203
PAG oil, 720
PCM location, 815
pressure-type Karman Vortex sensor, 842
PTC circuit protectors, 472–473
refilling the cooling system, 196
remote keyless programming, 675
SCI and CCD module communication, 530
stepped ECT circuits, 819
task manager, 958
thermostat location, 183
transaxle sensor temperature to resistance, 826
valve stem-to-guide clearance, 291
variable camshaft timing, 330
wire repair, 477
Chrysler CAP training, 17
Chrysler Hemi V-8
combination spark plug system, 790
combustion chamber, 281
oiling system, 216
PM connecting rods, 346–347
Chryster Hemi, lubrication, 384
CHT (cylinder head temperature) sensor, 826
CID (component identification), 964
Cigarette (cigar) lighter, 470
CIP (constant differential injector pressure), 881
Circlips, 342
Circuit breaker method, 489
for short circuits, 489
Circuit breakers, 472–473
blade-type, 472
cycling-type, 472
electrical symbols for, 472
Circuit diagrams
color code legend, 485
electrical and electronic symbols, 481
Circuit fault types, 429–431
Circuit numbers, schematic symbol, 480
Circuits, 428–429
calculating value of, 431–432
excessive resistance, 567
fault types, 429–431
information in schematics, 479–480
intermittent electrical problems, 491
locating a short circuit, 489–491
parallel circuits, 438
series, 434
series-parallel, 441–442
troubleshooting procedure, 488–489
voltage drops used in, 436
waterwheel analogy, 431
Clacking noises, 241
Clamping diodes, 512
application, 512
Clamping force, 402
Clamping load, 403
Clamp mount for dial indicator, 103
Class 2 communications, 528
diagnosis circuit check, 534
no-start story, 535
Clatter, possible causes, 241
Claw poles, 580
Clean Air Act (1990), 958
Clean Air Act (CAA), 49
Section 609, 719
Clean Air Act Amendments (CAAA), 127, 919
exhaust analysis testing, 919
Clean floor, 31
Cleaning
engine covering between work sessions, 391
new cylinder heads beforehand, 310
Cleaning brake parts, 1107
Cleaning engine
chemical cleaners, 273–274
introduction, 272
mechanical cleaning, 272–273
spray and steam washing, 274
tank and vapor cleaning, 275
thermal cleaning, 274–275
ultrasound and vibratory cleaning, 275
Cleaning machine, fuel-injection service, 911
Cleaning methods, 43–44
Clear flood mode, 829
Clearing codes, 972
Clicker-type torque wrenches, 70
Clicking noises, 240, 241
Click-type torque wrenches, 143

Climate control circuit solenoids, despiking resistors, 513
Climate control units
high-voltage surges, 512
navigation enhanced, 639
C-lock (C-clip type), 1080
Clock generator, 815
Clock-in, 20
Clock positions, 594
Clock speed, 815
Clockspring, 691
flat conductor wire, 695
Clock time, 20
C-lock-type axles, 1080–1081
Clogged evaporator problem, 743
Clogged orifice tube test, 742
Closed circuit, 432
Closed loop, 855
wide-band oxygen sensor, 855
Closed-loop operation, 849
wide-band oxygen sensor, 855
Close-end wrenches, 68
Cloud point of diesel fuel, 777
CLS (constrained layer shims), 1137
Clunking noise
possible causes, 241
spline bind cure, 1506
Cluster gears, 1476
Cluster shaft, 1476
Clutch assembly, reassembly, 1604
Clutch diagnosis, hard-to-shift problems, 1485–1486
Clutch disc, 1454
described, 1455
high-performance, 1456
stock, 1457
Clutch drum, 1573
Clutches, 1476
bleeding a hydraulic, 1466–1467
cable-operated, 1455, 1457
clutch pedal replacement, 1465–1466
component parts and operation, 1454–1462
driving clutches, 1573–1574
engaged and released positions shown, 1456
faults, 1462–1463
holding (braking) clutches, 1573
hydraulic, 1455, 1457
levers and rods, 1455
Mazda pickup story, 1461
multiple-plate clutches, 1572–1574
oil leak repairs before replacement, 1460
pre-loaded, 1520–1521
problem diagnosis, 1462–1463
purpose and function, 1454
replacement, 1464–1465
symptom guide, 1467
typical assembly shown, 1455
typical master cylinder and reservoir, 1457
worn components shown, 1463–1465
Clutch free play adjustment, 416
Clutch friction disc, 415
Clutch gear, 1476
Clutch grabs, possible causes, 1467
Clutch master cylinder, 134
Clutch pack, 1572
checking, 1605
checking clearance with dial indicator, 1605
disassembly, 1603
inner and outer seals, 1605
typical assembly, 1573
Clutch pedal, bulkhead flex, 1466
Clutch pedal adjustment, 1465–1466
Clutch pedal linkage, 1455
Clutch piston
inspection, 1604
removal and inspection, 1603
Clutch plate, cutaway view, 1458
Clutch release bearing, 1461
Clutch release yoke, 416
Clutch replacement, flywheels, 1460
Clutch replacement procedure, 1464–1465
step by step, 1468–1470
Clutch safety switch, 557
cruise control, 659
Clutch slave cylinder, 1455
corrosion shown, 1466
Clutch symptom guide, 1467
CNG (compressed natural gas), 772–774
Coach, 30
Coal to liquid (CTL) fuel, 775–776
Coast-down stall, ETC performance issues, 898
Coast side, 1518
FWD, 1526
Coaxial capacitors, 709
Code of Federal Regulations (CFR), 48
Coefficient of friction, 1024
CO emissions, 5
CO_2 fire extinguishers, 46
Coil
conductor, 501
definition, 485
for EMI suppression, 507
high-voltage spikes, 513
pickup, 446
Coil bind, 320
Coiled brake lines, 1056
Coil-on-plug (COP) ignition
adjusting ignition timing, 805
advantages, 788, 790
ion-sensing ignition, 790–791
overhead camshaft engine, 790
scope-testing, 810
terminology, 788
types of systems, 790–791
typical system, 790
Coil-on-plug (COP) ignition coils, 505
ICM in assembly, 784
Coil-on-plug system, 782
Coil-over-plug-type ignition systems, 790
Coil-over shock absorbers, 1306
coil spring shown, 1309
Coil primary wiring, tachometer trick, 785
Coil spring, broken, 145
Coil spring clutch, 1458, 1459
Coil springs, 1291–1295
coatings, 1295
constant rate, 1293
front, 1327–1328
lowering the vehicle, 1294
mounting, 1294–1295
Coil springs (rear replacement), 1341
Coil springs
spring frequency, 1293
static load, 1293
variable-rate, 1293
wheel rate, 1294–1295
Coke, 232
Cold cathode fluorescent lighting (CFL) displays, 634
Cold chisels, 76
Cold climate power steering fluid, 1404
Cold-cranking amperes (CCA), 542–543
information on battery, 548
Cold effectiveness, 1020
Cold engine, how to warm up, 419
Cold placard inflation pressure, 1262
Cold solder joint, 476
Cold-start warm-up, 890–891
Cold tank cleaning, 275
Collapsed radiator hose story, 189
Collapsible column, 1360–1361
Collapsible spacer, 1528
Collector, 516
Color shift in headlights, 614–615
Color tracers, 480
Combination circuits, 441–442
Combination turn signal and hazard warning flasher, 611
Combination valves, 1048–1049
“pistol grip,” 1049
typical two-function, 1048
Combination wrenches, 68
Combustion, 147
diesel engine, 159, 161
three phases, 161
typical temperatures, 182
Combustion chamber, 147
carbon deposits in, 282
hemi design, 282
pentroof design, 282
piston sealing, 337
pressure differential diagram, 220
showing squish area, 281
surface-to-volume ratio, 281
wedge design, 282
Combustion chamber volume, 156
Commission pay, 21
earning more money, 28
Common (COM) terminal on digital meters, 452
Common ground, 487
Common power source, 487
Communication, listening, 24–25
Communications
eye contact, 25
nonverbal communication, 25
profanity use, 25
reading, 26
talking, 25
telephone, 25–26
pen and paper for, 25
writing, 26
Communications network, 524
Commutator, 560–561
Commutator-end housing, 560
Commutator segments, 561
inspection, 575
Compact disc player, 528
Compacted graphite iron (CGI), 353
Companion cylinder
definition, 787
determining, 788
Companion flange, 1521
Compensating ports, 1032
Compensation, 1035
Competitively priced brakes, 1121
Complete circuits, 428–429
Component identification (CID), 964
Component location, service manuals, 121
Component location guide, 75
Component locator manuals, 75
Component replacement, as repair option, 262
Composite adaptor, 1172
Composite camshaft, 315–316
hollow tube, 316
Composite headlights, 613
aiming, 616
typical headlamp assembly, 613
Composite leaf springs, 1296
Composite rotors, 1164–1165, 1170
Compound circuits, 441–442
Compound motors, 560
wiring diagram, 220
Compound planetary gear set, 1559–1560
Comprehensive component monitor (CCM), 959
number of times for fault detection, 964
operation, 959
Compressed air
air compressor, 82
safe air pressure recommendations, 45
Compressed gas inflators, 689
Compressed natural gas (CNG), 772–774
amount equal to in gasoline, 773
CNG label on vehicles, 772
composition, 773
ethyl mercaptan (“skunk”) for leak detection, 772
fuel systems, 773–774
refueling a vehicle, 774
refueling station pressures, 774
vehicle design, 772–773
Compression, shock absorbers, 1307
Compression gauge
compression testing, 173
readings, 243
Compression gauge set, 243
Compression ignition, 158
Compression ratio (CR), 155
boost, 229
changing, 157
formula for calculating, 156
resurfacing cylinder head, 287
Compression rings, 343
combustion chamber sealed, 343
identification marks, 350
installation, 350
Compression-sensing waste-spark ignition systems, 788
firing diagram, 789
Compression spring, 563
Compression test, 242–244
avoiding burned exhaust valve, 244
grounding ignition coil wire, 800
step by step, 250–251
Compression testing
compression gauge, 173
diesel engines, 173
Compressor, 715
air conditioning
additional filter for, 752
clutch circuits, 728
controls, 729–730
diode replacement, 728
electromagnetic clutch, 729–730
engagement lacking, 750
high-pressure switch, 729
low-pressure switch, 729
pistons and rings, 728
power steering pressure switch, 730
service, 751–752
variable displacement, 728
air dryer, 1355
ALC system, 1355
diagram, 716
exhaust solenoid, 1355
functions, 725–726
positive-displacement piston, 726–727
removal, 752
Compressor bypass valve (CBV), 234
Compressor clutch service, 751–752
Compressor drive belt, 751
Compressor removal (steps), 752
Compressor service, 751–752
additional filter, 752
special tool for magnetic clutch, 752
Compressor tool, 1603
Computer balancer, 1280
Computer Command Ride (CCR), 1347
GM, 1351–1353
Computer components or circuits
logic highs and lows, 519
precaution with analog (needle-type) meters, 446
precaution with ohmmeters, 448
precaution with test lights, 446
Computer-controlled alternator, 585–586
GM electrical power management system, 585–586
types of systems, 585
Computer controlled charging system, 586
Computer-controlled diesel engine fuel injectors, 162–163
Computer-controlled lights, 605
Computer-controlled purge, 929
Computer-controlled starting, 557–558
jump starting, 520
operation, 518–519
Computer controlled windshield wipers, 648
Computer controls, diodes in, 511
Computer data line circuit schematic, 536
Computer dynamic balancer, 1280
Computer functions
basic, 813
input, 813
output, 814
processing, 813
storage, 813–814
Computer fundamentals
purpose and function, 812–813
voltage signals, 813
Computer input sensors, 816
Computer memory, capacitor for, 496
Computer outputs, 816–818
Computer skills, 16
importance of, 17
Computer systems
basic functions, 813
computer input sensors, 816
computer outputs, 816–818
digital computers, 814–815
electromagnetic interference (EMI), 506
output controls, 816–818
output functions, 814
processing, 813
scope control, 464
Computer systems. *See also* Electronic components
storage, 813
types of memory, 813
Concave side, 1518
FWD, 1526
Concentric, 289
Condensate lines, 721
Condensation point, 713
Condenser, 493, 715
condensation process, 720
diagnosis, high-side pressure, 741
diagram, 716
fin comb, 752
hand test, 739
overcharge and undercharge lines, 741
in point-type ignition system, 495
service, 752
testing, airflow readings, 742
two systems shown, 721
Condenser cycling clutch orifice tube (CCOT), 716
cycling off and on rapidly, 741
typical accumulator, 723
typical system, 717
Condenser microphones, capacitor for, 496
Condenses, 720
Conductance, definition, 548
Conductance tester, 548–549
Conduction, 110
Conductive coupling, 506
Conductivity
conductor ratings, 427
gold versus copper, 426
reasons to choose copper, 422–423
wiring (metals compared), 467
Conductors, 422
alternator, 582
how electrons move through, 423–424
insulators compared, 110
resistance and, 426–427
water as, 423
Conduits, electrical color-coded, 477–478
Cone clutch, 1478
Conformability of bearings, 376–377
Conicity and ply steer, tire, 1247, 1249
conicity diagram, 1249
Connecting rod bearing journal, 337
checking clearance, 398
micrometer use, 399
piston-to-crankshaft counterweight clearance, 398
scored, 373
testing, 372
Connecting rod design, 345–346
Connecting rods, 149
cast connecting rods, 347
design, 345–346
forged, 346
identification marks, 398
marking before removal, 266
powdered metal (PM), 346–347
press tool, 346
purpose and function, 345
shapes, 345
spit holes, 346
stress on, 345

Connecting rod service
checking for twist, 348–349
honing operation, 348
inspection, 347–348
reconditioning procedure, 348
removing pistons from rods, 347
rod alignment fixture, 348
Connecting springs, 1105
Connections
corroded, 474
electronic component failure, 519
intermittent electrical problems, 491
location numbers, 482
loose or broken, 486
schematic symbol, 482
Connector #210 (C210), 480
Connector position assurance (CPA), 474
Connectors
(partially) disconnected, 486
crimp-and-seal, 476
definition, 474
even- and odd-numbered, 482
plastic, 482
schematic symbol, 481
wire terminal ends, 474
Constant-mesh gears, 1482
Constrained layer shims (CLS), 1137
Construction overview, 147
Contaminants, 51
Contamination test, 1053–1054
Continuity, 428
Continuity lights, 445
Continuity test lights, 445
Continuously variable (CV) transmission, 1561–1565
Continuous monitors, 959
Continuous running monitors, 960
Continuous-wave-type sensor, 1265
Contract labor, 22
Control arm bushings, 1330
puller tool, 1330
Control arms, 1299–1300
Control cables, 1148
Control circuit, 485
diagnosing a relay, 485–486
parts and operation, 557
testing, 568
Control circuit testing, 568
Control current, 161
Controlled combustion, 161
Controller, 812
Controllers, communication with other computers, 814
Control module
ABS, 1214
antilock brake, 1210
EHPS, 1402
electric power steering, 1400–1401
locations, 815
power train, 1402
rear wheel steering, 1376–1378
Control modules, electronic brake (EBCM), 1346
Control valves, 1210–1211
Control wires, 666
Convection, 110, 1158
Conventional theory of current flow, 424
Conversion, engine size, 154
Converter clutch control, 1556–1557
Converter light-off temperature, 949–950
Converters, 521
examples of, 521
Convex side, 1518
FWD, 1526
shown, 1518
Convex soft plugs, 428–429
Coolant, 5
50/50 with water, 178
antifreeze and water mix, 136
boiling point, 175–176
bypass diagrams, 184, 185
composition, 176
disposal, 52–53, 136, 197
storage, 137
drain before engine removal, 263
embittered, 177
ethylene glycol based, 176
flow diagram, 183
flow in the engine, 190–191
flushing, 195
freezing/boiling temperatures, 175–176, 178
“G” coolant, 177
heater trouble diagnosis, 738
hot/cold/hot/cold heater diagnosis, 740
leaking intake manifold gasket, 254
level (inspection), 194
low level, 740
percentage of antifreeze, 176
propylene glycol (PG), 177
purpose of, 175
recovery systems, 188
recycling, 181
replacement, 181
service precautions, 136
testing, 179–180
thermostat temperature rating, 184
types of, 176–178
hybrid organic acid technology (HOAT), 177
inorganic acid technology (IAT), 176
organic acid technology (OAT), 176–177
phosphate hybrid organic acid technology (PHOAT), 177
universal coolant, 177
universal, 177
visual inspection, 136
water and, 178
water jacket diagram, 183
Coolant bubbles, head gasket diagnosis, 248
Coolant dye leak testing, 193
specific dye to use, 193
Coolant exchange machine, 195
view of, 196
Coolant flow in the engine, 190–191
head gasket design and, 191
types of systems, 190–191
Coolant flow passages, 284
cutaway head, 285
head gasket holes, 285
Coolant heaters, 778
Coolant hydrometers, 179
Coolant level and condition, visual inspection, 238–239
Coolant pump. *See* Water pump
Coolant recovery systems, 188
diagram, 188
purpose and function, 188
surge tank, 188
Coolant replacement issues
intervals, 181
passivation, 181
Coolant temperature warning light
common causes of overheating, 194
“engine” dash light, 249
precautions, 194
preventing engine damage, 249
purpose and function, 194
Coolant testing, 136
electrolysis, 180
galvanic activity, 180
hydrometer, 179
pH, 180
refractometer, 179
test strip testing, 180
Coolant test strips, 136
Coolant voltage, testing coolant, 180
Cooler-out line location, 1607
Cooling fan
assembly diagram, 191
ECT sensor testing, 820
electronically controlled, 191
heat sink, 518
safety, 191
service, 746
speed control, 818
thermostatic, 191–192
Cooling fins, 186
Cooling jacket, 354
Cooling methods, 151
Cooling slits, heat sink, 518
Cooling system
bleeder valves, 739
described, 148
engine installation, 417
high-temperature engine problems, 183
inspection, 194–195
low-temperature engine problems, 182–183
operation, 183
overview, 5
purpose and function, 182
quick and easy diagnosis, 197
service, 195–197
testing, 192–193
thermostat to control, 148
Cooling system inspection
accessory drive belt tension, 194–195
antifreeze/coolant disposal, 136
coolant level, 194
coolant testing, 136
cut-and-peel trick, 138
emission-related hoses, 137
hose clamps, 137
radiator and heater hoses, 137
steps, 136
Cooling system operation, 183
purpose and function, 183
Cooling system service, 746
coolant exchange machine, 195
flushing coolant, 195
hose inspection, 195–196
thermostat replacement, 746
Cooling system testing, 192–193
coolant dye leak testing, 193
pressure testing, 193
visual inspection, 192–193
Cooperative education, 17
COP (coil-on-plug) ignition coils, 505
COP (coil-on-plug) ignition system
coil-near-plug system, 790
three primary wires, 790
two primary wires, 790
variety of systems, 790–791
Copper
as conductor, 422–423
as ground wire, 469
price preference, 426
resistance, 426
wiring, 467
wiring (metals compared), 467
Copper jaw covers, 85
Copper-lead alloy, 375
Copper spacer shim, 289
Copper wire, NTC thermistor compared, 515
Core, 29, 262, 597
Core charge, 29, 1091
Core parts, 262
Core plugs, 352
Cork gaskets, 383
avoiding sealer with, 386
Cornering light, bulb trade numbers, 607
Corrected horsepower, calculated numbers, 411
Corrected torque, 411
Correction factor, 411
Corroded connections, 429, 431, 474
Corrosion resistance, 377
Corrosive materials, 48
Corvette, shown without body, 4
Cotter pins, 63
Coulomb, 424
Counselor, 30
Counterbore, 306
Counterbore cutting tool, integral valve seat replacement, 306
Counterclockwise (CCW), 152
Counter electromotive force (CEMF), 504
series starter motor, 559
Counter gears, 1476
Counterrotating balance shafts, 371
Countershaft, 1476
“Christmas tree” assembly, 1477
rotation, 1477
Counterweights, 365
vibration damage, 369
Country of origin, 126
Counts on digital multimeters (DMMs), 454
Coupling phase, 1555
Courtesy lights, 617
definition, 617
doorjamb switch, 619
Cover gasket materials
cork gaskets, 383
fiber gaskets, 383
formed in place gaskets (FIPG), 71
silicone rubber, 384
plastic/rubber gaskets, 384
requirements, 383
rubber-coated metal (RCM) gaskets, 384
synthetic rubber gaskets, 383
Cover gaskets materials, 383–384
Cover letters, 19
sample, 19
Cow catcher (strut) design, 1325
CP (customer pay), 28
CPU (central processing unit), 814
CR (compression ratio), 155
calculating, 156
changing, 157
Crack detection
dye-penetrant testing, 276
fluorescent-penetrant testing, 276
introduction, 272
magnetic crack detection, 276
pressure testing, 276
visual inspection, 276
Zyglo, 276
Cracking, 754, 1158–1159
Crack plugging, 278
reaming and tapping, 278
screwing and cutting, 278
Crack repair
crack concerns, 276–277
crack plugging, 278
crack plugging cylinder head, 279
crack-welding aluminum, 278
crack-welding cast iron, 277
stop drilling, 277
Cradle, 264, 1289
Cradle placement, 1423
Cranes, portable crane and chain hoist, 85–86
Crankcase vacuum test, 944
Crankcase ventilation
orifice-controlled PCV systems, 943
PCV valves, 943
purpose and function, 942–943
separator systems, 943
Crankcase ventilation filter, 943
Crank cheeks, 365
Cranking amperes (CA), 543
Cranking circuit
control circuit parts and operation, 557
high voltage drop, 566
parts involved, 556–557
solenoid-type, voltmeter hookups, 567
typical tester, 592
Cranking vacuum test, 246
Crankpin, 337, 365
Crankshaft, 149
construction, 366–367
end-to-end movement, 365
engine types, 367–369
four-stroke cycle, 149
internal and externally balanced, 369–370
journal hardness, 366
main bearing and rod journals, 365
main bearing journals, 365
major parts listed, 365
measurement, 99
polishing, 374
purpose and function, 365
rod bearing journals, 365–366
SAE 4340 alloy, 113
service, 372–374
showing main journals, 365
storage, 374
storing, 374
surface finish, 366
thrust bearing, 365
thrust surface, 366
timing, 404
trial assembly, 391
welding, 374
Crankshaft bearing installation
details, 379–380
oil passages not blocked, 379
Crankshaft bearing journals, measuring, 394
Crankshaft bearings
bearing installation details, 379–380
types, 379
Crankshaft centerline, 365
Crankshaft construction
billet, 367
cast, 367
forged, 366
Crankshaft deflections, 369
Crankshaft-driven oil pump, 212
Crankshaft end play, 396
Crankshaft gear, camshaft gear relationship, 317
Crankshaft grinders, 373
grinding and polishing, 373–374
Crankshaft grinding, 373
rounded fillet area, 373
undersize, 373
Crankshaft installation, 396
Crankshaft measurement
journal, 100
out-of-round, 99
taper, 99
Crankshaft oiling holes, 367
chamfered oil holes, 368
cutaway view, 358
Crankshaft polishing, 374
Crankshaft position (CKP) sensors, 499
Crankshaft position sensor
checking wiring of ignition control module, 806
CMP sensor relationship, 806
Hall-effect sensor, 786
magnetic sensor testing, 796, 798
tachometer trick, 785
Crankshaft rotating torque, 397
by engine size, 397
Crankshaft service
grinding, 373
measuring out-of-round, 373
measuring taper, 373
stress relieving, 374
visual inspection, 372
welding a crankshaft, 374
Crankshaft-to-camshaft centerline dimension, 289
Crankshaft welding, 374
journals, 374
Crank snout, 365
Crank throw, 337
Crash sensor, 690
Crate engines, 262
Chrysler, 262
Creep, 1555
Creepers, 92
Crest of the thread, 58
Crimp-and-seal connectors, 476, 477
Crimp connector, 477
Crimping terminals, 476
Critical thinking, 31
Cross-drilled crankshaft, 368
Cross-drilling, 1165
Crossflow head, 281
Crossflow head design, 281
typical, 282

Cross-flow radiators, 187
Cross-groove plunge joint, 1501
Crosshatch finish, 361
  oil control, 361
  typical honed cylinder, 361
Crossover, 704–705
  diagram, 705
Crossover network, 705
Cross-steer linkage, 1372
Cross symbol (+), 500
Crowfoot socket, 70
Crown, 1518
CRP (constant rail pressure), 881
CRT (cathode ray tube) dash display, 634
Crude oil
  low-gravity and high-gravity, 754
  "sweet" and "sour," 754
Crude oil, types of, 754
Cruise (speed) control, 658–659
  brake safety switch, 659
  bump problems, 659
  CHMSL, 659
  circuit diagram, 660
  computer or cruise control module, 658
  diagnosis, 659
  operation, 658–659
  owner manual, 72, 120
  parts involved, 658
  precautions with rainy or slick roads, 658
  safety release switches, 658
  servo unit with connections, 658
  speed set control, 658
  symptom guide, 683
  Toyota system, 120
  troubleshooting, 636, 659
Cruise (speed) control servo, 658
Crush, 378
Cubic inch displacement
  chart, 155
  formula, 154
Cummins diesel engine
  calibration number for injector, 174
  Dodge pickup, 159
  pressure gauge on lift pump, 173
  rod/piston assembly, 160
  troubleshooting chart, 172
  turbocharger, 166
Cupped tire wear, 1324
Cup-type element for oxygen sensor, 846
Cup-type soft plugs, 393
  installation, 393
  use of, 393
Curb weight, 1290
Cured tires, 1242
Curie, Pierre and Jacques, 426
Current flow (amperes)
  conventional theory, 424
  electrons, 424
  electron theory, 424
  examples for calculating flow, 437
  excessive and electronic component failure, 520
  hole theory, 510
  parallel circuits, 439
  reading digital meter displays, 453
  series-parallel circuit examples, 442–443
Current ramping ignition coils, 795–796
  faults shown, 797
  good coil pattern, 797
  ignition cool ramp times, 797
  test procedure, 796
Cushioning spring, 1457
Customer pay (CP), 28
Customers
  non-English speaking, 26, 28
  talking to, 27–28
Customized van story, 1594
Cut-and-peel trick, 138
Cutters, 75
Cutting metal (procedure), 90
Cutting the nails trick, 1103
CV (constant velocity) joints, 1498–1502
  boot materials, 1501–1502
  burping the boot, 1512
  double-Cardan joint, 1498
  drive axle shafts, 1500–1501
  fixed, 1499
  grease, 1502
  inner, 1499–1500, 1501
  outer, 1499
  plunge, 1500
  Rzeppa, 1498
  service, 1509–1513
  steer torque, 1439
  tripod fixed, 613
CV joint boot, 1501–1502
  split-style replacement, 1502
CV joints
  Chevrolet Blazer, 1543
  differential assembly, 1543
  FWD, 1543
CVT transmission, 1561
  belt and pulley, 1563
  fuel economy, 1564
  parts and operation, 1563
  purpose and function, 1562
  servicing, 1564–1565
  shifter paddles, 1564
  terminology, 1561–1562
  what it is like to drive, 1564
Cycle, 149
Cycle time, 815
Cycling-type circuit breakers, 472
Cylinder
  arrangement, 149, 151
  cleaning, 392
  distortion, 416
  operation, 149
Cylinder blocks
  core plug, 352
  extension, 352
  precautions with deforming, 383
Cylinder bore
  chamfering, 362
  measuring, cylinder taper, 358
  wear patterns, 358
Cylinder bore, measuring, 100
  removal from engine, 266
Cylinder boring machine, 359
Cylinder deactivation systems, 335
Cylinder head, tightening sequence, 402
Cylinder head bolts (cap screws)
  forces applied to head gaskets, 381
  removal procedure, 265
Cylinder head gasket, white steam, 238
Cylinder head installation
  clamping force, 402
  fastener steps, 402
  head bolt torque sequence, 401–402
  installing camshaft for OHC engines, 400–401
  thread lubricant, 402
Cylinder head installation procedure, 310
Cylinder head passages
  coolant flow passages, 284
  head gasket holes, 285
  lubricating oil passages, 285
Cylinder head preparation, engine assembly, 390–391
Cylinder head resurfacing
  refinishing methods, 287
  surface finish, 287–288
Cylinder heads
  cleaning "ready to install," 310
  cleaning with air-powered grinder, 272
  combustion chamber designs, 282
  construction, 280
  crack plugging, 279
  described, 147
  design features, 280–281
  disassembly, 265
    OHV engine, 267–268
  examining for wear, 265
  fire deck, 286
  four-valve cylinder heads, 282–283
  four valves, 147
  heat tabs, 409
  inspection equipment, 286
  installation procedure, 310
  need for cleaning new, 310
  passages, 284–285
  potato chip problem, 287
  pressure testing, 277
  resurfacing, 287–288
  safety, 268
Cylinder heads. *See also* Aluminum cylinder heads
  valve placement, 281
  warpage, 265, 286, 296
Cylinder head service
  aluminum cylinder head straightening, 286–287
  cylinder heads, 280–283
  disassembling overhead camshaft head, 285
  intake and exhaust ports, 283–284
  intake manifold alignment, 288–289
  introduction, 280
  passages, 284–285
  repair using plugs, 279
  resurfacing, 287–288
  sequence, 285
  servicing, 285–286
  valve guides, 289–291
    replacement, 291–292
  valve train disassembly, 285–286
Cylinder head temperature (CHT) sensor, 826
Cylinder honing, 359–360
  minimum amount recommended, 361
  procedure, 362
  reading Ra roughness, 362
  surface finish tool, 362
Cylinder leakage test, 244–245
  handheld tester, 244
  step by step, 244–245
Cylinder power balance test, 245
Cylinder ridge
  removal, 266
  removal with ridge reamer, 266
Cylinders
  honing for clearance, 361
  preventing distortion, 1486
  transmission problem diagnosis, 1589
Cylinder surface finish, 361–362
Cylinder taper, measuring, 358

D

D2B (domestic digital BUS) communication system, 534
D3EA (Dual Dynamometer Differential Effectiveness Analysis), 1121
Daimler-Chrysler, H-valve, 725
Daimler/Chrysler Corporation, wire repairs, 477
Damage analysis
  hidden structural, 1449
  tips, 1434
Damage resistance, bearing, 377
Dampening, 371
Damping modes, 1353
Darlington pair, 517
Darlington, Sydney, 517
Dash dimmer light control, rheostat, 427
Dash instruments
  electronic dash instrument diagnosis and troubleshooting, 642
  static electricity precautions, 642
  test equipment, 642
  test procedure, 642
Dash light dimmer circuit, variable resistor, 441
Dash lights
  headlight switch, 605
  voltage drops in circuits, 436
  WOW display, 634
Dash voltage display, 586
Dash warning lights
  airbag, 691
  bulb test, 634
  check engine light, 626
  electrical system-related, 626
  engine coolant temperature, 625
  engine fault warnings listed, 625–626
  engine oil pressure, 625
  maintenance reminder lamps, 642
  maintenance required warning, 625–626
  malfunction indicator lamp (MIL), 626
  purpose and function, 625
  safety-related, 626–627
  symbols, 625–628
  water in diesel fuel warning, 625
Data link connector (DLC), 533
DAT sensor, 732
Daytime running lights
  bulb trade numbers, 605
  circuit diagram, 618
Daytime running lights (DRLs), 617
  intensity of, 617
  LEDs, 514
  purpose and function, 617
DC-AC inverters, 522
DC bias voltage, ABS, 1228
DC coupling, 462
DC-DC converter
  circuit testing, 521
  definition, 521
DC volts (DCV), 447
  digital meter usage, 458
DDMs. *See* Digital multimeters (DMMs)
Dead-blow hammers, 73
Dealerships
  vehicle warranties, 8–9
  as work site, 9
Deburring, 389
Decarboning, engine assembly, 910
Decarbonization, 282
Deceleration detection, MAP sensor voltage, 836
Deceleration rates, 1026
Deceleration sensors, 690
Decibel (dB), 704
  acceptable sound levels, 42
  sound levels, 704
Decibel scale, 704
Decimal point, 115
Decking the block, 357
  grinding, 358
Deck surface finish, 358
Deck surface of block
  checking flatness, 358
  machining, 357
Deductions, 21
Deep cycling, 543
Deep well sockets, 71
DEF (diesel exhaust fluid), 170
  storage, 171
Default gear, 1581
Deflection rate, 1292–1293
Deflector valve stem seals, 308
Defoggers, rear window, 662–663
Defogging inside windshield, typical settings, 732
Defroster ducts airflow, 739
Defrosting inside windshield, typical settings, 732
Defrost switch, 718
Deglazing hone, 360
  ball-type, 360
Degrees, 1431
Degree wheel, 404
DE housing, 578
Delco, 2
Delco (Delphi) Battery, 547
Delivery system, 860
Delphi (Delco) ABS-VI, 1225–1227
Delta, 1267
Delta pressure feedback EGR (DPFE) sensor, 939
  diagram, 939
Delta pressure method, 1267
Delta winding, 583
Demand delivery system (DDS), 881–882
Denatonium benzoate, 177
Density, 228
  high and low, 228
Department of Transportation (DOT), 610
  brake standards, 1019
Deployed inflator module, 693
Depressed park position, wipers, 650
Depressed wipers, 648, 649
Depth micrometer, 104
  measuring oil pump rotor, 104
  pinion shaft shim thickness, 1528
Derived units, 98
Desiccant, 721–722
Despiking diodes, 512–513
Despiking resistors, 513
Dessicant, 1355
Detonation, 758, 760, 791–792
  EGR sensors, 936
  gasket failure, 384
  octane rating related, 760
DEX-COOL, 176
DI (direct injection) diesel engine, 160
  combustion chamber, 160
DI (distributor ignition), 782
Diagnostic executive, 958
  enabling criteria, 960–961
Diagnostic trouble codes (DTCs)
  ABS, 1223–1227
  BARO sensor, 838–839
  cam timing, 332
  catalytic converter, 953, 954
  charging system, 586
  clearing, automatic, 962
  coolant temperature below thermostat regulating temperature, 253
  crankshaft position/camshaft position, 333
  EGR-related OBD-II, 941
  emission-related, 960–961
  EVAP system-related, 934
  IAT sensor, 825
  individual cylinder misfires, 959
  knock sensor, 791
  lean exhaust, 254
  MAF-related, 844
  major categories, 961–962
  MAP sensor, 838–839
    Cavalier convertible, 837
  misfire, 328
  multiple cylinder misfire, 959
  non-emission-related, 962
  numbering explanation, 962
  oxygen sensor, 859
  priority (0 through 4), 962
  SAI-related, 947
  temperature sensors, 827
  thermostat stuck partially open, 253
  for TP sensor, 831
  transmission problem diagnosis, 1588–1589
  transmission/transaxle list, 1588
  Type A codes, 962
  Type B codes, 962
  Type C and D codes, 962
  types of, 962
Diagonal pliers, 73–74
Diagonal split master cylinders, 1036
Diagram, 118, 479
  interpreting, 118
  or wiring schematic, 479
Dial bore gauge, 103
  measuring, cylinder taper, 358
Dial indicator, 103
  cam lobe height, 329
  crankshaft end play, 396
  starter drive, checking, 570–571
  valve seat concentricity, 304
  valve stem-to-guide clearance, 290

Dial-type torque wrenches, 70
Diamond dressing tool, 304
Diaphragm spring style pressure plate, 1458, 1459
Die grinders, 84
Dielectric
  constants of selected materials, 494
  definition, 494
Dies, 60
  handle, 61
  usage, 60–61
Dies and taps, 60–61
Diesel emission testing, 174
  opacity test, 174
Diesel engine glow plug circuits, 438
Diesel engines
  accelerator pedal position (APP) sensor, 166
  advantages/disadvantages, 159
  air-fuel ratios, 159–160
  compression testing, 173
  construction, 159
  diesel exhaust particulate filter, 169–170
  diesel exhaust smoke diagnosis, 172
  diesel fuel heaters, 166
  diesel fuel ignition, 160
  diesel injector nozzles, 164
  diesel oxidation catalyst, 168
  diesel particulate matter (PM), 168
  engine-driven vacuum pump, 166
  engine oil ratings, 200
  exhaust gas recirculation (EGR), 167–168
  fuel tank and lift pump, 161
  fundamentals, 158–159
  gasoline engine compared, 159
  glow plug resistance balance test, 173
  glow plugs, 164–165
  HEUI system, 162–163
  how combustion occurs, 159
  indirect and direct injection, 160
  injection pump, 161–162
  injector pop testing, 173
  particulate matter (PM), 168
  performance diagnosis, 172
  three main fuels, 780
  three phases of combustion, 161
  turbochargers, 166–167
Diesel engine turbochargers, 166–167
  air charge cooler, 166
  turbocharged diesels, 166
  variable turbocharger, 167
Diesel exhaust, aftertreatment of, 169
Diesel exhaust fluid (DEF), 170
  storage, 171
Diesel exhaust particulate filter (DPFs), 169–170
  ash loading, 171
  diesel particulate filter regeneration, 169–170
  DPF differential pressure sensor, 169
  DPF regeneration process, 170
  DPF regeneration types, 170
  exhaust gas temperature sensors, 169
  operation, 169
  purpose and function, 169
Diesel exhaust smoke diagnosis, 171–172
  performance diagnosis, 172
Diesel fuel, 777
  color of, 778
  colors, 166
  gasoline accidentally added to, 778
  gasoline compared, 166
  grades of, 778
  heaters, 778, 779
  requirements, 777
  specific gravity testing for, 778
  sulfur content, 777–778
  ultra-low-sulfur, 778–779
Diesel fuel heaters, 166, 778, 779
Diesel injector needle valve, 164
Diesel injector nozzles, 164
  operation, 164
  parts involved, 164
Diesel oxidation catalyst (DOC), 168
  chemical reaction with, 169
Diesel particulate matter (PM), 168
Diesel performance diagnosis, sensor value chart, 172
Diesel, Rudolf, 1, 158
Diesel vehicles, water in diesel fuel warning, 625
Diesohol (E-diesel), 780–781
Differential, 6
Differential assembly
  diagram, 1517
  reassembly, 1531
Differential axle bearings, 1523
Differential axle ratios, front and rear, 1537
Differential backlash, 1525, 1529
Differential bearing caps, 1528
Differential case, 1517
  checking backlash, 1529
  shown, 1518
Differential drive pinion depth, 1523, 1526
Differential fluid
  check, 144
  leaking assembly, 144
  lubricants, 144
  reason for low levels, 144
Differential form of BUS communication, 524
Differential gear ratios, 1519
Differential identification, 1524
Differential lubricant story, 1517
Differential pinion gear preload, 1528
Differential pressure sensor (DPS), 169
Differentials (diff.), 1519–1520
  components, 1521–1523
  damage shown, 1525
  disassembly, 1526
  drive wheels shown, 1517
  Eaton locker differential, 1521
  identification, 1524
  inspection, 1525
  limited slip differential, 1520–1521
  lubrication, 1532, 1544
  parts, 1517–1518
  purpose and function, 1517
  torque flow through standard open differential, 1519–1520
  Torsen differentials, 1521
Differential side bearing preload, 1530
Differential vents, 1081, 1544
Diffusion chamber, 855
Digital computers, 814–815
  baud rate, 815
  binary digits converted, 816
  central processing unit (CPU), 814
  clock rates and timing, 815
  computer programs, 814
  computer speeds, 815
  control module locations, 815
  definition, 814
  engine mapping, 814
  memory, 814
  parts of a computer, 814
Digital control, computer controls, 816
Digital EGR valve, 938
Digital electronic display operation, types, 625
Digital MAF sensor, analog MAF sensor compared, 841
Digital MAP sensor, 835
  scope waveform shown, 835
Digital multimeter (DMM) displays
  accuracy, 455
  autorange setting, 459
  charging system testing, 588
  counts, 454
  digit rattle, 454
  digits, 454
  diode testing, voltage drop, 513
  how to read (steps), 452
  meter resolution, 454
  MIN/MAX feature, 458–459
  range button, 459
  steps to follow, 452
  RMS versus average, 453
Digital multimeters (DMMs)
  AC/DC clamp-on digital multimeter, 450
  AC ripple voltage check, 590
  battery electrical drain test, 553
  checking BUS for voltages, 534
  common symbols and abbreviations, 447
  diode check, 521
  diode trio testing, 596
  ECT sensor testing, 820, 823
  fuel injector pulse readings, 904
  fuse your meter leads!, 449
  high-impedance test meters, 446
  hybrid electric vehicles, 454
  MAF sensor testing, 844
  MAP sensor testing, 838
  measuring amperes, 448–449
  measuring resistance, 447–448
  measuring voltage, 447
  mini-clamp battery tester, 553
  Min/Max function, for TP sensors, 831
  over limit display, 451
  oxygen sensor testing, 850
  MIN/MAX function, 851
  reading displays on, 452
  recommendations for purchase, 454
  single-filament bulb test, 608
  terminology, 446
  testing battery voltage, 425
  TP sensor testing procedure, 830
  typical waveform, 830
  usage instructions, 456–459
  wide-band oxygen sensor testing, 857
  zero as test lead resistance, 448
Digital oscilloscope, 461
Digital readout rotor micrometer, 1169
Digital storage oscilloscope (DSO), 461
  BUS circuit faults, 535
  connecting to oxygen sensor signal wire, 852–853
  display, 462
  fuel injector connection, 907–908
  fuel injector testing, 907–908
  fuel pressure test, 900
  oxygen sensor (good) waveform, 854
  TP sensor testing, 830
Digital system voltage, 816
Digital voltmeter
  Hall-effect sensor testing, 799
  for oxygen sensor testing, 850–851
  for testing TP sensor, 830
Digital volt-ohm-milliammeter (DVOM), 446–450
Digital wheel speed diagnosis, 1229
Digital wheel speed sensors, 1213–1214
Digit rattle, 454
Digits on digital multimeters (DMMs), 454
Dike pliers, 74
Dimmer switches, 617
Diode, 510
  alternator, 578, 580–581
  blown, 518
  construction, 510
  digital meter usage, 458
  high-voltage spikes, 512–513
  operation, 510–511
  relay spike control, 486
  testing, 521
  voltage drop, 513
Diode check, 450
Diode ratings
  specifications, 513
  voltage drop, 513
Diode trio, 581
  layout of typical, 596
  testing, 595–596
DIP (dual inline pins) chips, 518
Dipstick, 134
  automatic transmission fluid, 138
  typical, 135
Direct drive, 117, 1474
Direct injection (DI) diesel engine, 160
  combustion chamber, 160
Direct-injection fuel delivery system
  fuel pressure regulator, 888–889
  fuel rail, 888
  high-pressure pump, 888
  low-pressure supply pump, 887
  two pumps shown, 888
Direct injection fuel pump, 888
Direction wires, 666
Direct Sensors, TPMS, diagnosis, 1266
Direct TPMS (tire pressure monitoring system), diagnosis, 1266
Dirty MAF sensor story, 842
DIS (distributorless ignition system), 787–788
Disassembly
  correction fluid for marking position, 268
  marking position of parts, 268
  as reverse order of assembly, 265
Discard diameter, 1161
Discarding, 1161–1162
Disc brake calipers
  “banjo bolt,” 1130
  brake inspection opening, 1129
  lubrication diagram, 1135
  mount service, 1133–1134
  service, 1132–1137
Disc brake caliper service, 1130–1137
  bleeder valve location, 1130
Disc brake diagnosis and service, 1128–1143
  caliper service, 1130–1137
  diagnosis procedures, 1128
  service, 1141–1143
  symptom guide, 1138–1140
  visual inspection, 1128–1129
Disc brake edge codes, 1122
Disc brake fade, 1115
Disc brake pads
  bedding-in, 1136–1137
  cracked, 1129, 1132
  increasing pad life, 1137
  installation, 1154
  left versus right, 1133
  minimum thickness shown, 1129
  tapered pad wear, 1129
  uneven wear, 1131
Disc brake rotors
  distortion, 1166–1167
  machining, 1170–1174
Disc brake rotors. *See also* Machining brake drums and rotors; Rotor
  thickness, 1167
  types, 1122, 1164–1166
  worn, 1165
Disc brakes, 1114–1127
  advantages, 1115–1117
  brake pads, 1118–1122
  caliper designs, 1122–1126
  construction, 1118
  disadvantages, 1117–1118
  heat barrier, 1128
  inspection, 1128
  parts and operation, 1016–1017, 1115
  rear, 1126–1127
  rotors, 1122
  typical assembly, 1017
Disc brake squeal, 1137
Discharge air temperature (DAT) sensor, 732
Discharge stroke, 727
Discharging battery, 540
Discs, 1164
Disc-type piston valve, 1307
Dish, 339
Disks, 1164
Displacement, 154
  cubic inch displacement formula, 154
Displacement on demand (DOD), 335
Display (parade) position of ignition oscilloscopes, 808
  reading, 808
Disposal
  after tire repair, 1282
  air bags, 54
  air-conditioning refrigerant oil, 54
  batteries, 53
  brake dust and brake shoes, 49
  brake fluid, 50, 1054
  coolant, 52–53
  oil filters, 204
  shop cloths, 43
  used oil and filters, 50–51
  used tires, 54
Distillation, 754
Distillation curve, 756
Distillation index, 756
Distilled water, 545
Distortion, 286
Distortion, cylinder head, 286
Distracters, 35
Distributed system interface (DSI) BUS protocol, 533
Distributor
  indexing, 805–806
  reinstallation, 805
Distributor-driven oil pump, 212
Distributor ignition (DI), 782
  dwell variation, 810
  firing order, 786–787
  magnetic sensor testing, 796
  operation, 786
  purpose and function, 785–786
  rotor gap voltage, 810
Distributor injection pump, 162
  typical pump, 162
Distributor installation, 409
Distributorless ignition system (DIS), 787–788
Distributor pickup coils, AC coupling, 462
Division, 462
“Divorced” type ignition coils, 505
DLC (data link connector), 533
DMMs (digital multimeters). *See* Digital multimeter (DDM) displays; Digital multimeters (DMMs)
DOC (diesel oxidation catalyst), 168
  chemical reaction within, 169
DOD (displacement on demand), 335
Dodge
  battery sizes, 543
  historical background, 2
  immobilizer or vehicle theft deterrent key learn procedures, 680
  remote keyless programming, 675
Dodge Dakota, side bearing preload, 1530
Dodge Durango, wrong oil viscosity, 200
Dodge minivan, electronics and water immersion, 636
Dodge/Plymouth Neon
  five-speed transaxle, 1483
  manual transaxle, 1483
Dodge Viper, cam-within-a-cam, 332
Dog food, in air intake ducts, 926
Dog tracking, 1425
DOHC (double overhead camshaft) design, 4, 151
  direct valve operation, 152
  four camshafts, 152
  timing chains, 318
Dome light
  brightness and starter problems, 569
  bulb trade numbers, 607
  checking, 617
  common ground/power source, 487
  courtesy lights, 617
  headlight switch, 605
Domestic digital BUS (D2B) system, 534
Doorjamb switch, 619
Door locks, electric power, 671
  door panel removal procedure, 684–685
  symptom guide, 683
Doors
  illuminated entry, 617
  panel clips, 62

panel removal procedure, 684–685
switches, 679
Doping, 509
DOT (Department of Transportation), 610
brake standards, 1019
DOT 3 brake fluid, 1050–1051
hydraulic clutches, 134
precautions, 133
from sealed container, 134
testing, 134
DOT 4 brake fluid, 133, 1051
DOT 5 brake fluid, 133–134, 1052
DOT 5.1 brake fluid, 134, 1051
DOT flashers, 610–611
Dot symbol (.), 500
DOT tire code, 1251
date code, 1251
Double-Cardan universal joint, 1498
Double-cut files, 75
Double flare fitting, 1055
Double knock, 341
Double-offset ball-type plunge joint, 1501
Double overhead camshaft (DOHC) design, 4, 151
Double-pole, double-throw (DPDT) switches, 484
power windows, 664
Double-pole, single-throw (DPST) switches, 484
Double roller chain drive, 318
high-performance, 318
"Doughnut" label, API, 200
Down-flow radiators, 187
DPDT (double-pole, double-throw) switches, 484
DPFE (delta pressure feedback EGR) sensor, 939
diagram, 939
DPF regeneration
active, 170
passive, 170
DPFs (diesel exhaust particulate filters), 169–170
ash loading, 171
diesel particulate filter regeneration, 169–170
DPF differential pressure sensor, 169
exhaust gas temperature sensors, 169
operation, 169
purpose and function, 169
DPS (differential pressure sensor), 169
DPST (double-pole, single-throw) switches, 484
Dragging brakes, 1140
Drag racing, spool, 1531
Dressing the engine, 417
Dressing the grinding stone, 304
Drift, 1413
Drive (D), automatic transmission, 1558
Driveability, factory service manuals, 73, 121
Driveability index (DI), 756
Drive axle dampener, 1501
Drive axle shaft
CV joints, 1500–1501
CV joint service, 1509–1513
dampener weight, 1501, 1509
hub nut, 1509
replacement, 1514–1515
replacement shaft, 1509
unequal, 1431
Drive belts
hand cleaner trick, 589
KISS test method, 242
slipping, 589
tension for various widths, 590
tension measurement, 589–590
visual inspection, 589
Drive belts or tensioners, noise from loose, 240
Drive belt tensioner
marks on, 195
water spray trick, 195
Drive-by-wire, 893
Drive coil, 564
Drive cycle, 961
Drive-end (nose) housing, 572
Drive-end housing, 578
Drive gear, 117, 1473–1475
Driveline clunk
backlash test, 1509
spline bind cure, 1506
Driven gear, 117, 1473–1475
Drive-on ramps, 94
Drive pinion depth, 1526–1528
tooth contact pattern test, 1526
Drive pinion gear, 1517
ring gear relationship shown, 1518
Drive pinion gear depth, 1523
Drive pinion gear preload, 1526
Drive pinion nut, tools for, 1526
Driver
in diagnostic process, 238
main seal installation, 395
valve guide replacement, 291
Driver selector switch, 1347
Driver side airbag module replacement, 694
Drive shaft, 5
Driveshaft, 1495
balance, 1496
design, 1495
engine speed, 1503
marking for removal, 1504
pulley attachment, 1406
RWD, 1503, 1506
Drive side, 1518
FWD, 1526
shown, 1518
Drive sizes, 70
Driving clutches, 1573–1574
DRLs (daytime running lights), 617
Drop test, 1105
Drug testing, 17
Drum brake diagnosis and service, 1101–1113
adjusting, 1108–1109
brake parts cleaning, 1107
brake spring inspection, 1105
diagnosis, 1101
disassembly, 1103
hardware kit, 1107
lining inspection, 1104
lubrication checklist, 1109
reassembly tip, 1149
removal, 1101–1103
service, 1111–1113
symptom-based troubleshooting guide, 1109–1110
Drum brakes, 1087–1100
adjustment check, 1089
advantages, 1087–1089
automatic brake adjusters, 1097–1100
disadvantages, 1089
drum brake shoes, 1091–1093
dual-servo brake design, 1095–1097
faults, 1101
need to cool, 1100
non-servo brake design, 1094–1095
overview, 2
parts, 1016, 1089–1090
symptom diagnosis, 1109
typical assembly, 1017
Drum brake shoes, 1091–1093
inspection, 1107
Drum distortion, 1159
Drum parking brakes, 1149–1150
Drums. *See* Brake drums
Dry bulb temperature, 411
Dry chemical fire extinguishers, 46
Dry cylinder sleeves, 353
cast-iron, 353
cast-iron repairs, 359
Dry hole bolts, 401
Dry park test, 1317
looseness in components, 1379
procedure, 1386–1387
Dry sump, 217
Dry sump oil system, 217–218
advantages/disadvantages, 217–218
Chevrolet Corvette, 218
Dry system (N20), 236
DSI (distributed system interface) BUS protocol, 533
DSO (digital storage oscilloscope), 461
TP sensor testing, 830
DTCs. *See* Diagnostic trouble codes (DTCs)
Dual cell planar-type wide-band oxygen sensor, 855–856
diagnosis, 856–857
testing equipment shown, 858
Dual-climate control system, micron vacuum gauge, 749
Dual clutch automatic transmission, 1565–1566
diagram, 1565
dry clutches shown, 1566
Dual-diameter bore master cylinders, 1036
Dual-diaphragm vacuum boosters, 1201
cutaway view, 1201
exploded view, 1204
Dual Dynamometer Differential Effectiveness Analysis (D3EA), 1121
Dual-filament bulb
close-up, 608
corrosion, 608
described, 605
electrical problems, 430
Dual inline pins (DIP), 518
Dual-mass flywheels, 1459
cutaway view, 1460
Dualmatic® manual locking hub, 1545
Dual overhead camshaft (DOHC) engine
intake and exhaust valves, 318
timing chains, 318
Dual-position actuators, 732
Dual-servo brake design, 1095–1097
Dual split master cylinders, 1034–1035
Dual-stage airbags, 691
Dual turbocharger system, 234, 235
Chevrolet V-8, 235
Dual-zone air climate controls, 734
control panel shown, 735
diagram, 735
Dual-zone sunload sensor, 732
Ductile cast iron, 113
Ductile iron, 344
Duesenberg, 2
Dump valve, 234
Duo-Servo, 1095–1097
DuPont Corporation, 718
Durant, William, 1
Durometer, 1330
Dust, brake, 50, 1118
Duty cycle, 464, 817
alternator, 585
alternator output voltage, 251
on-time, 464
Dwell, 792
current-limiting hump, 810
definition, 808
Dwell period, ignition coil testing, 795
Dwell section of ignition scope test, 807
Dwell variation, 810
Dye-penetrant testing, 276
Dye testing, fluid leak diagnosis, 1591–1592
Dynamic balance, 1278
Dynamic compression test, 244
procedure, 244
Dynamic pressure test, 871
Dynamic seals, 1074
Dynamic voltage, 546
Dynamometer (dyno or dyn), 107–108
Dynamometer (dyno or dyn) testing
automatic transmission repair, 1608
brake types, 410
calculated numbers, 410
final notes, 411–412
inertia types, 410
measured values, 410–411
purposes, 410
standards, 411
terminology, 410–411
types, 410
using same one, 412

E

E & C (entertainment and comfort) communication, 528
E2PROM (electrically erasable programmable read-only memory), 813
E10 (ethanol blend gasoline), 760
E85, 768
in cold climate tests, 768
fuel economy of, 768
fuel system requirements, 769
EAC (electronic air control) valve, 885
EAP (electric adjustable pedals), 670, 1019
Easy exit seat programming, 667
Easy out (extractor), 77
Eaton locker differential, 1521
exploded view, 1522
EBCM (electronic brake control module), 1214, 1234, 1346
EBM (electronic brake module), 1214
EBP (electronic brake proportioning), 1046
Eccentric cam lobe, 316
Eccentric cams, 1438
Eccentric distortion, 1160–1161
Eccentricity, 375
E.C.E. sidewalls, 1247, 1248
E coil, 505, 783
steel lamination, 783
ECT circuits, 819
schematic, 820
ECT sensor
construction, 819
location, 819
pulse width, 878
purpose and function, 819
stepped ECT circuits, 819
troubleshooting with DTCs, 827
two sensors, 823
voltage curve reading versus, 820
ECT sensor testing, 820–823
ECU (electronic control unit), 1343
Edge codes, 1092–1093, 1122
E-diesel (diesohol), 780–781
EDR (event data recorder), 697
data extraction, 697
EEPROM (electronically erasable programmable read-only memory), 637
Effective compression ratio, 229
boost pressure compared, 229
Efficiency check, 157
Efficiency tests, catalytic converter, 953–954
EFI injector
described, 878
solenoid-operated injector, 878
EFT (engine fuel temperature) sensor, 826
EGR (exhaust gas recirculation), 5, 167–168
hose, 137
passages, 223–224
EGR (exhaust gas recirculation) passages, 223–224
EGR (exhaust gas recirculation) system
benefits, 936
Blazer story, 940
blower-type exhaust hose use, 940
carbon balls, 940
carbon removal procedure, 940
computer-controlled, 937–938
digital EGR valves, 938
EGR valve position (EVP) sensors, 938
EVP sensors, 938
exhaust and intake manifolds, 937
exhaust gas coolers, 224
introduction, 936
linear EGR, 938
MAP sensor signal, 836
NOx formation and control, 936
OBD-II DTCs, 941
operation, 936
passages, 223–224
positive and negative backpressure EGR valves, 936
snake trick, 940
symptoms of defective, 940
testing procedures, 940–941
EGR (exhaust gas recirculation) temperature sensor, 826
EGR system monitor, 939
EGR valve position sensor, 938
location, 938
replacement checks, 938
EGR valves
back pressure testing, 248
carbon balls in, 940
digital, 938
pintle diagram, 939
vacuum-operated, 937
EHPS module, 1402
EI (electronic ignition), 782
acceleration check, 810
dwell variation, 810
Eight-cylinder engines, maximum amperage draw, 569
Elastic limit, 1160
Elastomer, 369, 1054
shown, 370
ELC (electronic load control), 586
Electric adjustable pedals (EAP), 670, 1019
Electrical accessory symptom guide, 656, 683
Electrical arcing, 1084
Electrical circuits, multiple use of same resistance, 439
Electrical color-coded conduit, 477–478
Electrical components, schematic symbol, 120
Electrical cord safety, 44
Electrical discharge machine (ESM), 77
Electrical hand tools, 79–80
Electrical heater wire, 165, 166
Electrical load (resistance), for circuits, 429
Electrically connected windings ("married" type), 505
Electrically erasable programmable read-only memory (E2PROM), 813
Electrically heated seats, 668–669
replaceable element, 669
Electrically insulated windings ("divorced" type), 505
Electrically operated tools, 79–80
Electrical potential, 424
Electrical power, formula to calculate, 425
Electrical power management (EPM), GM system, 585–586
Electrical problems
excessive current, 415
light bulbs, 608
Toyota truck, 636
Electrical system, 6
ASE task list, 39
engine installation, 417–418
factory service manuals, 73, 121
Electrical tape, solder and, 477
Electrical test, 964
Electrical troubleshooting guide, 491–492
step-by-step troubleshooting procedure, 492
Electrical unit measurement, digital meters, 452
Electrical unit prefixes
definition, 451
use of, 451–452
Electrical wiring, schematic symbols, 482
Electrical work hand tools, 79–80
Electric cooling fans, 191

Electric fuel pumps
control circuits, 867–868
ear test, 870
gerotor, 866
hydrokinetic flow pump, 866
location, 864
modular fuel sender assembly, 866
no danger of fire, 864
no-start condition, 870
positive displacement pump, 865–866
pulsators, 868
pump pulsation dampening, 868
replacement, 871, 874
removing the bed for access, 873
roller cell (vane) pump, 865, 865–866
symptoms of low fuel volume, 872–873
testing, 873–874
turbine pump, 866
variable speed pumps, 868–869
Electric grid-type rear window defoggers, 662–663
Electric heated units, schematic symbol, 484
Electricity
conductors, 422
definition, 421
electronics compared, 511
electron shells, 422
farsighted quality of, 435
free and bound electrons, 422
insulators, 423
intermittent electrical problems, 491
ions, 422
magnetism and, 500
magnets and electrical charges, 421
path of least resistance, 438
positive and negative charges, 421
producing from magnetism, 504
semiconductors, 423
sources of, 425–426
Electricity-related units
ampere, 424
converting to base units, 432
magic circle for calculations, 433
ohms, 425
Ohm's law related, 432
volt, 424–425
Electric mirror fault story, 487
Electric motor-driven air pump, 946–947
Electric motors
efficiencies, 990
magnetic field interaction, 500–501
schematic symbol, 482–483
Electric parking brakes (EPB), 1156
Electric power, 12 volt light to test, 445
Electric power door locks, 671
circuit diagram, 671
door panel removal procedure, 684–685
symptom guide, 683
Electric power steering (EPS) system, 1399–1401
PSCM, 1400
torque sensor, 1399
Electric pusher, 43
Electric servomotor circuits, air conditioning, 733
Electric soldering guns, 79–80
Electric soldering pencils, 80
Electric starter, 2
Electric vehicles, 983
emissions compared, 127–128
Electric vehicles (EV), 983
Electrochemistry, 426
Electrochromic, 617
Electrohydraulic power steering, 1402
BPP, 1402
EHPS module, 1402
power train control module, 1402
Electrolysis, 180
coolant testing for, 180
water added to coolants, 178
Electrolytes, 540
distilled water for, 545
specific gravity, 540–542
Electromagnet, 502, 1348
ignition, 498
Electromagnetic clutch, 717
cutaway view, 718
Electromagnetic energy, audio system, 699
Electromagnetic induction, 504, 782
Lenz's law, 504
mutual induction, 504
principles, 504
self-induction, 504
voltage intensity, 504
Electromagnetic interference (EMI), 506–507, 788
control module locations, 815
definition, 506
four ways of transmitting, 506–507
how it is created, 506–507
radio-frequency interference (RFI), 700
suppression devices, 507
Electromagnetic radiation, 507
Electromagnetic switch, 502
Electromagnetism, 500–502
coil conductor, 501
creating an electromagnet, 500
definition, 500
electromagnetic strength, 501–502
field interaction, 500–501
left-hand and right-hand rules, 500
motor principle, 501
straight conductor, 500
uses of, 502–503
Electromotive force (EMF), 424–425
Electronic air control (EAC) valve, 885
Electronically controlled automatic transmissions, 1580–1581
Electronically controlled clutch assembly, 1536
Electronically controlled cooling fan, 191
Electronically erasable programmable read-only memory (EEPROM), 637
Electronic analog dash displays, 634
Electronic brake control module (EBCM), 535, 1214, 1234
Electronic brake module (EBM), 1214
Electronic brake proportioning (EBP), 1046
Electronic calculators, 439
Electronic circuits, protection from high-voltage spikes, 512–513
Electronic components, 509
battery electrical drain, 552–553
converters and inverters, 521–522
diodes, 510–511
ratings, 513
electrostatic discharge, 523
failure causes, 519–520
high-voltage spike protection, 512–513
integrated circuits, 518
light-emitting diodes, 513–514
operational amplifiers, 519
photodiodes, 514
photoresistors, 514–515
phototransistors, 518
rectifier bridges, 515–516
semiconductors, 509–510
silicon-controlled rectifiers, 515
summarized, 816
testing diodes and transistors, 521–522
thermistors, 515
transistors, 516–517
transistor gates, 518–519
zener diodes, 511–512
Electronic conductance testing, 548–549
terminology, 548–549
test procedure, 549
Electronic contacts, cleaning, 519
Electronic control assembly (ECA), 812
Electronic control module (ECM), 812
ATC system block diagram, 733
Electronic control unit (ECU), 812
Electronic crossover, 704
Electronic dash instruments, diagnosis and troubleshooting, 642
Electronic devices, early failure and burn in, 511
Electronic flasher replacement units, 611
Electronic fuel-injection systems, 875–876
diagnosis using visual inspection, 901–902
ignition primary pulse, 902
speed-density fuel-injection system, 876–877
types of, 876
Electronic fuel injector circuits
despiking Zener diodes, 512–513
determining total resistance in parallel circuits, 438
Electronic fuel level gauges, 637
Electronic ignition (EI), 782
acceleration check, 810
"hump" in dwell section, 810
Electronic ignition modules
heat sink, 518
suppression capacitors for, 497
Electronic ignition spark tester, 796
Electronic ignition systems, 782
Electronic information, 118
Electronic load control (ELC), 586
Electronic load detection circuit, 588
Electronic odometer, 636–637
Electronic pressure regulation, 1570
Electronic refrigerant leak detector, 744
Electronic returnless fuel system (ERFS), 881
diagram, 881
Electronics, electricity compared, 511
Electronic serial number (ESN), 640
satellite radio subscriptions, 709
Electronic service information, 77–78, 122–123
home screen, 77, 122
Internet, 78, 123
recalls and campaigns, 78, 123
subscription format, 78, 122
technical service bulletins (TSBs), 78, 122
toolbars, 77, 122
typical main menu, 123
Electronic spark timing (EST), 792
Electronic speedometers
operation, 635–636
testing, 637
Electronic stability control, Cadillac, 2
Electronic stability control (ESC), 1232–1238
defined, 1232
diagnosis, 1238
Federal Motor Vehicle Safety Standard, 1233
names for, 1234
purpose and function, 1232
sensors, 1234–1236
sine with dwell test, 1233–1234
switches, 1233
traction control, 1236–1238
Electronic suspension
actuators, 1348–1349
air suspension, 1350
ALC, 1354
alignment, 1447
computer Command Ride, 1347
computer Command Ride (CCR), 1351–1353
controls and sensors, 1343–1347
magneto-rheological (MR), 1355–1356
replacing with conventional, 1356
SR (Selectable Ride), 1349–1350
Stabilitrak, 1352
variable-rate air springs, 1350–1351
Electronic suspension position sensor, 1344
Electronic system, 5
components overview, 6
Electronic throttle actuator (servomotor), 893
Electronic throttle control (ETC), 659
accelerator pedal position sensor, 893–894
with covers removed, 660
cruise control, 659
diagnosis, 896–898
diagnosis and service, 659
ETC throttle follower test, 898
normal operation, 893
parts and operation, 659
parts involved, 893
performance issues, 898
schematic, 895
service, 898–899
throttle body assembly, 894
throttle position (TP) sensor, 895–896
Electronic throttle control (ETC) diagnosis
diagnostic procedure, 897–898
fault mode, 896
scan tool data, 898
vacuum leaks, 897
Electronic throttle control (ETC) systems, advantages, 893
Electronic tire pressure gauge, 141
Electronic tone generator tester, 490
Electronic torque wrench, 404
Electronic vacuum regulator valve (EVRV), 940
Electronic variable orifice (EVO), 1397
Electrons, 421
Electron shells, 422
Electron theory of current flow, 424
Electroplating, 375
Electrostatic discharge (ESD)
definition, 523
electronic dish displays and, 642
steps to avoid, 523
Elements, 421
battery, 539
Embedability, 377
foreign material, 377
Embittered, 177, 178
Embittered coolant, 177
labeling, 177
Emergency brakes. *See* Parking brakes
E-metric tire, 1253
EMF (electromotive force), 424–425, 431
EMI (electromagnetic interference), 788
Emission control
air-fuel ratios and, 757
catalytic converter diagnosis, 952–954
catalytic converter related DTCs, 953
catalytic converter replacement, 953
catalytic converters, 949–954
EGR systems, 936–938
diagnosing defective, 940
OBD-II monitoring, 938–939
related DTCs, 941
enhanced EVAP system, 930
EVAP diagnosis, 931–932
EVAP DTCs, 934
EVAP monitor, 933–934
EVAP system, 928–930
EVAP tests (state inspection), 932
leak detection pump system, 931
nonenhanced EVAP system, 929–930
OBD-II EGR monitoring strategies, 938–939
onboard refueling vapor recovery (ORVR), 931
PCV system diagnosis, 943–945
related DTCs, 945
secondary air-injection, 945–947
diagnosis, 947
related DTCs, 947
Emission control system, 5
advances in engine design, 5
factory service manuals, 73, 121
U.S. standards, 127–128
VECI, 126
Emission-related hoses, 137
Emissions standards
age of vehicle and passing the test, 923
California, 919
Europe, 919–920
exhaust analysis testing, 920–923
federal bin number, 919
federal Tier 1 and Tier 2, 919
smog emission information, 919
United States, 919
Emission standards
hybrid electric vehicle, 127
Tier 1, 127
Tier 2, 127–128
Emission tester, nitrogen gas pressurization, 932
Emission testing, Toyota example, 926
Emission tests, diesel engine
opacity test, 174
rolling acceleration test, 174
snap acceleration test, 174
stall acceleration test, 174
EMI suppression devices, 507
Emitter, 516
Employee or contract labor, 22
Employment
acceptance and paperwork, 20
advancement skills, 31
first day on the job, 26–29
formal evaluation, 32
having work double-checked, 32
housekeeping duties, 31–32
informal evaluation, 32
job evaluation, 32
late arrival to work, 27, 30, 31
master technician, 31
sample evaluation, 33
starting times and breaks, 31
Employment application, 20
Employment plan
contacting potential employers, 20
cover letter, 19
interview, 20
locating job possibilities, 17
post-interview, 20
resume, 18–19
selecting a career, 17
skills necessary, 17
soft skills, 17
truthfulness in applications, 20
Enable criteria, 960
Enabling conditions or criteria, 962–963
conflict, 963
pending, 963
rationality test, 963
suspend, 963
Enabling criteria
MIL condition: FLASHING, 961
MIL condition: OFF, 960
MIL condition: ON STEADY, 961
trip, 960
warm-up cycle, 960
End play checks, 1606
double check, 1608
Energy, 106, 1022
kinetic, 713
Energy principles, 1022–1023
Engine
cutaway view, 151
energy and power, 147
exploded view, 73, 121
factory service manuals, 72, 121
purpose and function, 147
systems overview, 5
when it stops, 152
Engine analyzers, typical hookup shown, 807
Engine assembly
beginning steps, 388
covering between work sessions, 391
crankshaft installation, 397
cylinder head
installation, 400–403
preparation, 390–391
deburring sharp edges, 389
final, 406–409
engine painting, 409
manifold installation, 406–407
oil pan installation, 408
oil pump installation, 407
prelubricating the engine, 409
setting ignition timing, 409
timing cover installation, 407
vibration damper installation, 407
water pump installation, 408–409
instructions, importance of, 388
oil and fluids, 392
piston/rod installation, 397–400

short block preparation, 388–390
short block assembly, 392–397
torque-to-yield head bolts, 403–404
trial assembly, 391–392
valve train assembly, 404–406
Engine assembly lube, 392
Engine balance
piston position related, 371
primary and secondary, 370–371
Engine bearing clearance
bearing spread and crush, 378
checking, 377–378
importance, 377
Engine bearing loads, 376
Engine bearing removal
Chevrolet V-8, 267
main bearings and crankshaft, 267
Engine bearings
bearing conformability, 376
bearing embedability, 377
bearing fatigue, 376
bearing wall thickness, 374, 375
corrosion resistance, 377
damage resistance, 377
hint about covering, 86
introduction, 374
loads, 376
manufacturing, 376
materials, 375
replacement, 379–380
score resistance, 377
sizes, 376
two- and three-layer, 376
types, 374–375
undersize dimension, 376
Engine bearing shell types, 374–375, 376
Engine bearing sizes, 376
Engine blocks
aluminum, 352–353
bedplate design, 353
block cleaning, 362–363
block deck, 353–354
block detailing, 363
casting numbers, 353
construction, 351–352
cooling passages, 354
lubricating passages, 354
main bearing caps, 355
manufacturing, 352
preparation for assembly, 363
Engine block service
arbor check method, 357
chamfering the cylinder bores, 362
cylinder boring, 358–359
cylinder honing, 359–360
procedure, 362
cylinder surface finish, 361–362
deck surface finish, 358
machining deck surface, 357
main bearing housing bore alignment, 356–357
procedure, 356
sleeving the cylinder, 359
Engine blueprinting, 356
Engine classification and construction
characteristics, 149–150, 151–152
rotation direction, 152
Engine cleaning. *See* Cleaning engine
Engine clearance specifications, 395
Engine condition diagnosis
back pressure testing
with pressure gauge, 248
with vacuum gauge, 248
compression test, 242–244
step by step, 250–251
cylinder leakage test, 244–245
dash warning lights, 249
driver as resource, 238
engine noise, 240–241
engine smoke diagnosis, 237–238
exhaust restriction test, 247–248
head gasket failure diagnosis, 248–249
KISS test method, 242
misfire diagnosis, 249
oil pressure testing, 241–242
oil pressure warning lamp, 242
power balance test, 245
running (dynamic) compression test, 244
smells and their causes, 239
typical complaints, 237
vacuum tests, 245–247
visual inspection, 238–240
wet compression test, 243
Engine condition monitoring, MAP sensor signals, 836–837
Engine construction
block, 147
cylinder heads, 147
rotating assembly, 147
Engine control module (ECM), alternator control, 585
Engine coolant, passages shown, 1569
Engine coolant temperature (ECT) sensor
computer input, 816
construction, 819
location, 819
pulse width, 878
purpose and function, 819
stepped ECT circuits, 819
troubleshooting with DTCs, 827
two sensors, 823
voltage curve reading versus, 820
Engine coolant temperature (ECT) sensor testing, 820–823
digital meter set to DC volts, 823
multimeter, 820, 823
quick and easy test, 825
scan tool, 823
visual inspection, 820
when to test, 823
Engine coolant temperature, as safety limit, 411
Engine cranking slower than normal, 545
Engine crankshaft types
60-degree V-6 cylinder engine, 369
90-degree V-6 cylinder engine, 369
five-cylinder engine, 368
four-cylinder engine, 368
three-cylinder engine, 368
V-8 engine, 367
Engine diagnosis. *See* Engine condition diagnosis
Engine disassembly
cam-in-block (OHV) engine, 264–265
cylinder heads, 265
mounting engine on a stand, 264
overhead camshaft (OHC) engine, 265
Engine-driven vacuum pump, 166
Engine fault warning lights, 625–626
Engine flywheel, 562–563
Engine fuel temperature (EFT) sensor, 826
Engine idle speed
computer controls, 816
higher-than-normal, 586
improving, 586
system actuator, 814
Engine installation
accessory drive belts, 417
cooling system, 417
electrical system, 417–418
installing the engine, 417–418
reconnecting components and connectors, 417
securing the engine, 417
Engine knock, 758
Engine lubrication systems
normal oil pressure, 211–212
oil temperature, 212
purpose and function, 211
Engine mapping, 814
Engine measurement
bore, 152
calculating cubic inch displacement, 154
displacement, 154
engine size conversion, 154
stroke, 154
Engine misfiring, ignition system symptom guide, 811
Engine miss, 322
Engine mounts, 368
condenser line problems related, 721
Engine noise
cost related, 241
diagnosis, 240–241
Engine-off natural vacuum, 933
Engine oil
acceptable consumption levels, 218
additives, 201–202
API groups, 202–203
API rating, 199–200
brand compatibility, 202
break-in, 418
change intervals, 135
checking, 134–135
C means commercial, 200
color of leak, 239
exhaust valve guide, 308
feeds, 232
functions, 198
high mileage oils, 204
hybrid engines, 256
ILSAC rating, 200
introduction, 198
multiviscosity, 402
normal versus severe use chart, 135
oil burning, 202
oil level, 134
for older-model vehicles, 200
properties, 198
routine inspection, 134–135
SAE rating, 199
S means service, 199
superchargers, 230
switching to synthetic oil, 135
synthetic oil, 202–203
turbochargers, 232
types, 402
vehicle-specific, 203–204
Engine oil filler cap, SAE viscosity rating on, 199
Engine oil pressure, warning light, 625
Engine oil temperature sensor, 827
Engine paints, 409
Engine parts and system
cooling system, 148
fuel system and ignition system, 148–149
intake and exhaust manifolds, 147
lubrication system, 148
Engine performance
ASE task list, 39
factory service manuals, 73, 121
Engine removal and disassembly
cylinder head disassembly, 267–268
disassembly, 264–265
engine removal, 263–264
step by step, 269–270
engine repair options, 262–263
front-wheel-drive vehicle, 263–264
rear-wheel-drive vehicle, 264
removal step by step, 269–270
rotating engine assemblies removal, 267
short block disassembly, 266
transaxle in place, 264
usual procedure, 263–264
Engine repair, ASE task list, 38
Engine smoke diagnosis, 237–238
Engine speed
computer input sensor, 816
formula for, 116
PCM inputs, 1580
Engine speed (RPM), traction control, 1236
Engine stands, 86, 264
graded bolt use, 264, 265
precautions with block work, 356
Engine start
how to warm up a cold engine, 419
normal operating temperature, 418
precautions, 418
Engine start system, 891
Engine torque
calculated numbers, 410
characteristics, 1475
Engine vacuum, valve stem seals, 308
English customary measurement system, 97–98
Enhanced emission testing, clogged EGR passages, 940
Enhanced evaporative control systems, 930
Entrepreneur, 14, 23
Environmental Protection Agency (EPA), 48, 49
catalytic converter replacement, 954
emissions standards, 127–128
EPA (Environmental Protection Agency), 48, 49, 919, 958
emissions standards, 127–128
EP additives, 1532
EPB (electric parking brakes), 1156
EP lubricants, 1484
EPM system, 585–586
EPROM (erasable programmable read-only memory), 813
EPS (electric power steering), 1399–1401
Equalizer, 1148
location, 1149
Equal resistance test, 905
Erasable programmable read-only memory (EPROM), 813
EREVS (extended range electric vehicles), 255
ESC. *See* Electronic stability control (ESC)
ESD, 523
electronic dash displays and, 642
steps to avoid, 523
ESM (electrical discharge machine), 77
ESN (electronic serial numbers), satellite radio subscriptions, 709
EST (electronic spark timing), 792
EST (ignition control) (white) wire, 793
Ester oil, 720
ETC (electronic throttle cruise control), 659
ETC throttle follower test, 898
Ethanol (ethyl alcohol), 760, 767
E10, 760
environmental impact, 767
as octane improver, 760
production of, 767–796
splash blending, 761
switchgrass as base of, 768
Ethics, 24
Ethyl alcohol, 767
Ethylene glycol based coolant, 176
Ethyl tertiary butyl ether (ETBE), 760
European Bosch, ECT sensor, 823
European emission standards, 919–920
European vehicles
BUS communications, 531–532
engine oil ratings, 200–201
OBD-II data link connector, 536
Eutectic pistons, 338
EV (electric vehicles), 983
Evacuation procedures, 748
service valve snugness, 753
EVAP monitor, 933–934
running, 934
tests, 934
Evaporative (EVAP) emission control system
common components, 928
dash display, 932
diagnosis, 931–932
diagram, 928
DTCs, 934
EVAP monitor, 933–934
monitor, 932–934
nonenhanced, 929–930
operation, 928–929
pressure buildup causes, 929
pressure conversion chart, 930
purpose and function, 928
schematic, 929
state inspection tests, 932
Evaporative emission control solenoids, computer controls, 816
Evaporative emissions control (EVAP), monitors, 959
Evaporative emission system (EVAP), 5
Evaporative system monitor, 932–934
engine-off natural vacuum, 933
Evaporator, 715
benefits of, 720–721
clogged, 743
diagram, 715
electromagnetic clutch, 717
how it works, 720
leak-testing, 744
location, 720
mold or mildew smell test, 744
optimal temperature of lines, 744
repairs or replacement, 747
service, 752
two systems shown, 722
water drains, 738
Evaporator outlet temperature sensor, 732
Evaporator pressure regulator (EPR) valve, 718
Evaporator service, 752
Evaporator water drains, 738
EVAP system, 5
common components, 928
diagnostic trouble codes, 934
diagram, 928
enhanced, 930
nonenhanced, 929–930
operation, 928–929
pressure buildup causes, 929
purpose and function, 928
schematic, 929
EVAP system diagnosis
DTCs, 934
locating leaks, 932
symptoms, 931–932
Event data recorder (EDR), 697
EVO (electronic variable orifice), 1397
EVP (EGR valve position) sensor, 938
EVRV (electronic vacuum regulator valve), 940
EWMA (exponentially weighted moving average) monitors, 960
Excessive negative camber, 1414
Excessive positive camber, 1414
Exhaust
two outlets, diesel engine, 171
typical temperatures, 182
Exhaust air cooler, 170
Exhaust analysis
acceptable emission levels (chart), 924
air/fuel ratio by weight shown, 924
burning or watery eyes, 925
checking for leaks, 925
combustion efficiency and, 923–924
CO too high, 924
dizziness or headache, 925
finding leaks in system, 925
HC too high, 924
measuring oxygen (O2) and carbon dioxide (CO2), 925
strong exhaust smell, 925
Exhaust analysis testing, 920–923
acceleration simulation mode (ASM), 922
five-gas equipment, 923
FTP (Federal Test Procedure), 921
hole (diagram), 925
I/M 240 test, 922
I/M test programs, 921
loaded mode test, 921
OBD-II testing, 922
one-speed and two-speed idle test, 921
random roadside testing, 922–923
remote sensing, 922
summary chart, 926
visual tampering checks, 921
Exhaust camshaft timing, 926
Exhaust check valves, 946
Exhaust cooler, cutaway view, 168
Exhaust gas analyzer, 947
head gasket diagnosis, 248
Exhaust gas coolers, 224
typical long gasoline, 224
Exhaust gas recirculation (EGR), 5, 167–168
hose, 137
passages, 223–224

Exhaust gas recirculation (EGR) passages, 223–224
Exhaust gas recirculation (EGR) system
benefits, 936
exhaust and intake manifolds, 937
NOx control, 936
NOx formation, 936
operation, 936
oxygen sensor response, 850
positive and negative backpressure EGR valves, 936
temperature sensor, 826
Exhaust gas recirculation (EGR) temperature sensor, 826
Exhaust gas recirculation (EGR) valves
exhaust gas coolers, 224
purpose and function, 223–224
Exhaust gas summary chart, 926
Exhaust gas temperature, 224
Exhaust gas temperature (EGR) sensors, 169
Exhaust hose, 43
during service work, 131
Exhaust leak in front of the O2S, 851
Exhaust manifold
construction, 224
cracked, and performance, 225
cracked Ford V-8, 241
exhaust manifold gaskets, 224–225
exhaust pipe seals, 407
gas direction diagram, 224
gaskets, 407
operation, 147
purpose and function, 224
spreader tools, 225
visibility of cracks, 225
Exhaust manifold gaskets, 224–225
typical laminated, 225
Exhaust manifold spreader tool, 226
Exhaust ports, 284
Exhaust restriction test, 247–248
Exhaust side electrode, 846
Exhaust smell, 239
Exhaust solenoid, 1355
Exhaust systems
disconnect before engine removal, 263
exhaust gas recirculation passages, 223–224
exhaust manifolds, 224–225
mufflers, 225–226
Exhaust valve, 4
cam timing specifications, 325
clearances, 289
operation, 149
valve size relationships, 294
Exit/entry button, 667
Expandable pilots, 303
Expandable valve guide pilots, 303
Expander, 1041
Expansion plugs, 393
Expansion valve service, 753
Expansion valve systems, 715–716
receiver-drier shown, 723
service, 753
superheat, 724–725
typical, 717
Expansion valve testing, fire extinguisher test, 742, 743
Exploded view, in service manuals, 73, 121
Explosive (pyrotechnic) device, 687
Exponentially weighted moving average (EWMA) monitors, 960
Extended mobility tire (EMT), 1252
Extended range electric vehicles (EREVs), 255
Extended tire mobility (EMT), 1252
Extension housing, 1476
Extensions, 70
Exterior lighting, 605
headlight switch control, 605
External combustion engine, 147
External gears, 1472
mesh shown, 1473
External gear type oil pump, 212
External triggers, 464
Extreme pressure (EP) lubricants, 1484
Eyebrows valve clearance, 339
Eye protection
working with chemicals, 273
work with chemicals, 112
Eye wash stations, 46

F

Factory scan tools, generic OBD-II scan tool air-fuel ratios compared, 857
Factory service manuals, 71–73, 120–121
general information, 72, 120
Fade
brake, 1025, 1089, 1110
gas, 1089, 1116
lining, 1089, 1115–1116
mechanical, 1089, 1115
water, 1089, 1116
Fade resistance, 1115
Fahrenheit, Gabriel, 97–98, 111
Fahrenheit temperature scale, 97–98, 111
Fail safe mode, 896
False air, 843
False lean indication, 851
False modulation, 1224
False rich indication, 851
Fan shroud, 192
Faraday, Michael, 495
Farad capacitor, 496
Farads (F), 495
Fasteners, 58
avoiding broken, 64
cylinder head installation, 402
factory specs for, 28
Fast-fill master cylinders, 1036
Fatigue life, 376
Fault recorders, 964
Federal brake standards, 1019–1020
Federal Motor Vehicle Safety Standard 116, 133
Federal Motor Vehicle Safety Standards (FMVSS), 1019–1020
Safety Standard 135, 1145
Federal tax, 21
Federal Test Procedure (FTP), 921
OBD-II standards, 958
Feedback, 620
example, 620
Feeler gauge, checking transmission pump assembly, 1602
Feeler gauges, 102
connecting rod side clearance, 400
crankshaft end play, 396
piston ring side clearance, 349
ring gap measurement, 349
Female connector, 480, 481
Fender covers, 81
FETs (field-effect transistors), 517
FFV (flexible fuel vehicle), 768
Fiber gaskets, 383
Fiberglass springs, 1296–1297
Fiber optics, 617
Fiber-reinforced matrix (FRM), 354
FICA, 21
Field coils, 560
removable, 571
starter motor, 571
Field current, 581–583
Field-effect transistors (FETs), 517
Field housing, 560
Field poles, 560
Field windings, 559
diagram, 559, 561
Fifth gear, 1481–1482
Filament wire, 605
Files, 75
Filler ports, 1032
Filler tubes, 861
ground strap shown, 861
three-piece assembly, 861
Fillets shown, 365
Fill plug
check before draining, 144
location, 144
Filter basket, 869
Filter crusher, 205
Filter replacement, 1595
Final drive assembly, 1482
automatic transaxles, 1561
cutaway view, 1562
FWD differential, 1517
Final drive gear ratio, 1519
manual transmission (chart), 1537
Final drive gear sets, types of, 1519
Final engine assembly, 406–409
Fin comb, 752
shown, 752
Finger design for oxygen sensor, 846
Finger follower, 323
Finish cut, 1172
Finishing stone, 304
Fire blankets, 46
Fire deck, 286
Fire extinguishers, 45–46
Fire extinguisher test, 742
tools shown, 743
Fire ring, 381
Firing line, 807–808
spark line relationship, 810
Firing order, 786–787
on intake manifold, 787, 805
in service manuals, 805
First aid kits, 46
First-class lever, 109
First-class levers, 1023
First gear, 1480
shown, 1481
First position, automatic transmission, 1558
Fischer-Tropsch synthetic fuel, 775
Fitting wrenches, 68
5 volt V-ref, 521
Five-cylinder engine, crankshafts, 368
Five-speed manual transmission
cross-section view, 1476
torque flow, 1480–1481
Five-speed transmission, 1480–1481
T56 cutaway view, 1482
Five-valve cylinder head, Audi, 283
Five-wheel alignment, 1439
Five whys, 105–106
Fixed brake calipers, 1122
Fixed caliper, 1122
Fixed drums, 1102
Fixed joints, 1499
Rzeppa, 1499
Fixed-orifice tubes, 725
Fixed resistors, 427
Flagging the work order, 29
Flare-nut wrenches, 68
Flash codes, ABS module, 1214
Flasher relay, 611
Flasher units, 611
bimetal flashers, 611
distinguishing between, 610–611
DOT flashers, 610–611
electronic replacement units, 611
hybrid flashers, 611
solid-state flashers, 611
two-prong styles, 611
Flash/service programming, 978
Flat-bottom lifters, 319
break-in engine speed, 418
cutaway view, 327
engine oil concerns, 202
lubricants for older engines, 397
older engines compared, 326
slight angle, 319
zinc additives, 202
Flat head, 4
Flathead design, 4
Flat-head engine, overview, 4
Flat-head engines, 147
Flat lifters, 406
Flat-link type, 316
Flat-rate, 21
non-dealership, 28
time, 122
Flat-rate manuals, 75, 122
Flat-tip screwdrivers, 72
Flat-top pistons, 338
Fleet facilities, 9–10
school bus, 10
Fleet vehicles, oil change, 206
Flex Fuels, 768
components and materials of, 768
sensorless system, 771
vehicle identification, 769
Flexible brake hoses, 1058–1060
Flexible coupling, steering column, 1360
Flexible fuel lines, 863
Flexible-fuel vehicles (FFVs), 768
Flexplate, 1553
Flex plate
checking, 1600
noise from cracked, 240
FlexRay BUS serial communication system, 534
Floating calipers, 1122–1126
clearance shown, 1136
single-piston shown, 1124
Floating drums, 1102–1103
Floating ground system, 704
Floating position, 1518
Flooded cell battery, 542
conductance tester for, 548–549
Floor jack, 91–92
Flow control valve, 1390, 1391
operation, 1393–1396
Flow directing valves, 1576
Fluctuating vacuum, 246
readings, 246–247
Fluid check, 1591–1592
for newer vehicles, 1587
Fluid leak diagnosis, 1591–1593
dye testing, 1591–1592
pressure testing, 1593
range charts, 1593
torque converter clutch diagnosis, 1592–1593
transducers, 1593
visual inspection, 1591
Fluorescent dye, 240
Fluorescent lights, 84
Flushing
ATF, 1595
brake fluid, 1069
fuel-injection service, 910
Flutter, 700
Flux, 498
Flux density, 499
Flux lines, 498
Flying web, 369
Flywheel flange, 365
Flywheels, 1459
broken gear shown, 1459
clutch replacement, 1460
construction, 1459
dual-mass, 1459
removal and resurfacing, 1460, 1465
replacement, 1460
FM modulation, 699
capture problem, 700
characteristics, 700
FMVSS, brake test, 1020
FMVSS (Federal Motor Vehicle Safety Standards), 1019–1020
ESC, 1233
Safety Standard 126, 1233
Safety Standard 135, 1145
Fog/driving lamps, bulb trade numbers, 607
Fogging oil, 392
Follower ball joint, 1300
Foot powder spray trick, 240
Force, 106, 1029–1030, 1388
Forced induction systems
boost and compression ratios, 229
principles, 228–229
purpose and function, 228
Force motors, 1570
Force-sensing resistor sensors, 380
Ford
ABS, 1244
ABS summary guide, 1222
alternator voltage, 583
balance shafts, 371–372
battery locations, 551
battery sizes, 543
capacitor-capsule MAP sensor, 834
compound-wound starter motors, 560
coolant, 177
courtesy lights, 617
diagnostic executive, 958
ECT sensor, 822
electronic conductance tester, 548–549
ETC warning lamp, 896
flat-head engines, 147
flat-head V-8 engine, 4
fuel injectors, 883
gas camp fuel recommendation, 763
immobilizer or vehicle theft deterrent key learn procedures, 680
inertia switch, 862, 869
cutaway view, 863
schematic, 868
injector resistance table, 904
lane departure warning (LDW), 641
MAF sensors, 841
MAP/BARO altitude chart, 837
MAP sensor green signal wire, 834
MAP sensor vacuum readings, 836
Model T, 1
moveable pole shoe starter, 564
network communication protocols, 529–530
OBD-I diagnostic link connector, 529
OBD-I Ford vehicles, 529
OBD-II data link connector, 537
oil specifications, 203
PM connecting rods, 346–347
poor engine operation, 850
precollision system, 662
radar cruise control, 661
rear brake caliper and ball and ramp actuation, 1151
remote keyless programming, 675
SPOUT (spark output), 792
spring-lock coupling, 748
supercharger cutaway view, 231
throttle position (TP) sensor chart, 829
transmission fluid temperature, 826
UBP module communications, 530
vane airflow sensor, 840
variable camshaft timing, 330
voltage drop testing, 568
Ford ASSET training, 17
Ford diesel engines
cooling the piston, 347
oil changes, 163
Ford, Henry, 1
Ford Motor Company
Flex Fuel vehicles, 770
how to read VIN, 771
Ford PowerStroke diesel engine, O-ring location, 163
Ford V-8
COP systems, triple-strike secondary spark event, 811
cracked exhaust manifold, 241
firing order, 787
supercharger, 228
Ford V-8 (vintage), crack in block, 276
Ford van, vibration, 1279
Forged connecting rods, 346
high-performance, 347
Forged crankshaft, 366
high-performance, 366
wide separation lines, 366
Forged pistons, 338
temperatures, 338
Formal evaluation, 32
Formed in place gaskets (FIPG), 384
silicone rubber, 384
Forming stone, 304
Forward bias, 511
Forward steer, 1375
4 X 2, 1534
4 X 4, 1534
Foundation brakes, 1016
401(k) accounts, 21

Four-channel ABS systems, 1211
Four-channel scope, 464
Four-cylinder engines, 371
  3 X 5 card test, 944
  counter-rotating balance shafts, 371–372
  crankshaft type, 368
  cubic inch displacement chart, 155
  fully counter-weighted crankshaft, 369
  GM balance shafts, 371–372
  maximum amperage draw, 569
  primary vibration, 372
Four-gas exhaust analysis, 947
Four-stroke cycle operation
  720-degree cycle, 149
  operation, 149
  principles, 149
Four-terminal relay, 485
Fourth gear, 1481
Four-valve cylinder heads, 282–283
  measuring valve opening space, 282
  in pentroof combustion chamber, 302
  typical, 283
  valve overlap, 282
Four wheel drive, 6, 1534–1536
  adjusting rear camber, 1438–1439
  alignment, 1426, 1436–1437
  all wheel drive compared, 1535
  dash control panel, 6
  definition, 125
  differential lubricant story, 1517
  front and rear differential axle ratios, 1537
  purpose and function, 1534
  safe towing, 1535
  steering linkage, 1375–1378
  transfer case, 1534
Four wheel drive axles, 1542–1543
Four-wire oxygen sensor, 848
Fractional, 1431
Fractional threads, 58
Fractions, 116
Frame/body diagonals, 1449
Frame construction, 1289–1290
Frames, 3–4
Free electrons, 422
Free rotators, 299
  retainer force, 300
Freewheeling, 339
Freewheeling engine, 318
Freeze-frame data, 962
  OBD-II vehicles, 958, 962
Freeze plugs, 352
  core holes in block wall, 393
Freezing/boiling temperatures
  boiling point, 178
  coolant, 175–176
  freezing point, 178
  hydrometer testing, 179
Freon, 718
Frequency, 112, 369
  definition, 451, 463
  FM broadcasting, 699
  radio, 699
  when measurements are used, 451
Frequency modulation (FM), 699
Frequency of the oxygen sensor, 851–852
  normal frequency, 842
Frequency response, 704
Freshening, 262
Fretting, 254
  gasket failure, 384–385
Friction, 425
Frictional horsepower, 411
Friction and heat, 1025–1026
Friction ball joint, 1300
Friction contact area, 1025
Friction disc inspection, 1603
Friction material effects, 1024–1025
Friction principles, 1024–1026
FRM (fiber-reinforced matrix), 354
Front airbags, 687–691
  diagnosis tools and equipment, 691–692
  system service, 693–694
Front and rear differential axle ratios, 1537
Front bearing retainer, 1455, 1476
Front camber
  adjustment, 1440–1442
  guidelines, 1440
Front coil springs, 1327–1328
Front entry parking brake cables, 1149
Front mount caliper, 1130
Front parking lights, headlight switch, 605
Front shock absorbers, 1323–1324
Front steer, 1375
Front suspension
  ball joints, 1318–1322
  control arm bushings, 1330
  front coil springs, 1327–1328
  kingpins, 1312, 1322–1323
  MacPherson struts, 1324–1325
  rattle story, 1322
  road test diagnosis, 1316–1317
  servicing, 1315
  shock absorbers and struts, 1323–1324
  short/long-arm, 1313–1314
  solid axles, 1312
  stabilizer bar, 1326–1327
  steering knuckles, 1328–1329
  strut rod bushings, 1327
  strut suspension, 1314–1315
  torsion bars, 1329–1330
  twin I-beams, 1312
  visual inspection, 1317–1318
Front toe, setting toe, 1442–1444
Front wheel drive
  camber, 1415
  checking frame alignment, 1434
  engine installation, 417
Front-wheel drive (FWD), inertia and weight transfer, 1023
Front wheel drive
  replacement shaft, 1509
  setting toe, 1442–1444
Front-wheel-drive power train, 6
Front-wheel-drive vehicle, removal of engine, 264
Frosting, 742
Frost plugs, 352
FRP (fuel-rail pressure) sensor, 838
FTD (Fischer-Tropsch diesel), 775
FTP (Federal Test Procedure), 921
Fuel
  diesel. *See* Diesel fuel
  electronic fuel level gauges, 637
  gasoline. *See* Gasoline
Fuel cell hybrid vehicle (FCHV), C02 refrigerant, 719
Fuel-cell hybrid vehicle (FCHV), secondary batteries, 345
Fuel compensation sensor, 768
Fuel control, PCM uses of oxygen sensor, 849–850
Fuel delivery system
  electric fuel pumps, 864–869
  fuel filters, 869–870
  fuel lines, 862–864
  fuel pump current draw test, 873
  fuel pump replacement, 874
  fuel pump testing, 870–873
  fuel tanks, 860–862
  leakdown, 871
  scan tool diagnostics, 912
  stratified change mode, 889
  two “must do’s,” 877
Fuel economy
  calculator, 116
  CVT compared, 1564
  E85 use and, 768
  EVAP system problems, 932
  grade of gasoline related, 760
  greenhouse gas score, 920
  IAT sensor defective, 825
  low winter mileage, 756
  metric approach, 116
  postinjection pulses, 170
  tire inflation, 1270
  tire size, 1245
  Toyota knock sensor problem, 792
Fuel fill pipe, restricted, shown, 931
Fuel filters, 869
  inline, installation, 869
  inline filters, 869
  installation, 869
  useful life, 869
Fuel flow, calculating, 410–411
Fuel gauge system, diagnosis, 643–644
Fuel-injection components and operation
  electronic, 875–876
  electronic returnless fuel system, 881
  fuel-pressure regulator, 879–880
  mass airflow, 877
  mechanical returnless fuel system, 881
  port-fuel, 878–879
  speed density, 876–877
  throttle-body, 877–878
  vacuum-biased fuel-pressure regulator, 880–881
Fuel-injection modes of operation, 884
  acceleration enrichment, 884
  clear flood, 884
  closed-loop, 884
  deceleration enleanment, 885
  fuel shutoff, 885
  open-loop, 884
  starting, 884
Fuel-injection system
  airflow information, sources, 834
  clamp recommendations, 863
  filters, 869
  fittings and nylon lines, 863–864
  fuel injector cleaning, 916–917
  fuel lines, 863
  hoses, 863
  idle control, 885
  modes of operation, 884–885
  O-ring seals, 863–864
  pressure-drop balance test, 905–906
  scan tool diagnostics, 912
  service, 908–911
  spring-lock connectors, 864
  symptom chart, 911
Fuel-injection system diagnosis and service, 900, 908–911
  cleaning, 910–911, 916–917
  flushing, 910
  fuel-injection symptom chart, 911
  fuel injector cleaning, 916–917
  fuel-injector resistance checking, 904
  fuel-pump relay circuit diagnosis, 913–915
  idle air speed control diagnosis, 908
  injector-voltage drop tests, 907
  port fuel-injection, 900, 902–903
  pressure-drop balance test, 905–906
  resistance of grouped injectors, measuring, 904
  resistance of individual injectors, measuring, 905
  scan tool diagnostics, 912
  scan tool vacuum leak diagnosis, 902
  scope-testing fuel injectors, 907–908
  testing for an injector pulse, 903–904
  visual inspection, 901–902
Fuel injection systems
  air-fuel ratio, 757
  Honda Civic GX, 773
Fuel injection system testing
  scan tool vacuum leak diagnosis, 902
  stethoscope fuel-injection test, 901
  vacuum leak diagnosis, 902
Fuel injector resistance
  checking, 904
    connections and settings, 905
  grouped, 905
  individual, 905
Fuel injectors, 5
  check at “bends and ends,” 911
  checking resistance, clogged injector, 906
  cleaning, 911, 916–917
  computer controlled, diesel engine, 164
  computer controls, 816
  Ford, 883
  GDI, 889
  injector sizing formula, 884
  multiport, 883
  pulse readings, 903
  pulse width, 451, 464, 878
  reconditioned shown, 908
  replacement of all six, 908
  solenoid-operated, 883
  spray pattern, 878, 883
  system actuator, 814
  ultrasonic cleaning, 275
Fuel injector screens, flushing, 910
Fuel injector testing
  balance test, 905–906
  checking resistance, 904
  injector voltage-drop tests, 907
  measuring resistance
    equal resistance test, 905
    grouped, 905
    harness wiring, 905
    individual, 905
  peak-and-hold type, 908
  quick and easy leak test, 902
  resistance test, 904
  saturated switch type, 907
  scope-testing, 907–908
Fuel inlet location, 861
Fuel levels, problems after refueling, 931
Fuel level sensor, 637
Fuel line mounting, 863
  clips shown, 863
Fuel lines, 862
  flexible, 863
  fuel-injection fittings and nylon lines, 863–864
  fuel-injection lines and clamps, 863
  layout, 864
  rigid lines, 862
Fuel outlet check valve, 865
Fuel pickup tube
  filter sock, 862
  view of assembly, 862
Fuel-pressure gauge, 871
  port fuel-injection system diagnosis, 902–903
  testing fuel-pump volume, 910
Fuel-pressure graph, 901
Fuel-pressure regulator, 879–880, 888–889
  10-micron filter, 880
  checking, 901
  clogged filter, 880
  defective, signs of, 926
  flushing, 910
  testing, 910
  vacuum-biased fuel-pressure regulator, 880–881
  vacuum hose removal, 871
  vacuum pressure diagram, 880
Fuel-pressure sensor, fuel-temperature sensor together with, 881
Fuel-pressure stethoscope test, 871
Fuel pressure test
  instruments used, 900
  pressure transducer, 900
Fuel-pressure tester, fuel pump testing, 910
Fuel pulsator
  diagram, 868
  pump pulsation dampening, 868
Fuel pump current draw test, 873
  hookup, 874
  type of fuel injection (chart), 873
Fuel pump eccentrics, 316
Fuel pump modules
  modular fuel sender assembly, 866, 867
  spring loaded, 867
Fuel-pump relay circuit diagnosis, 913–915
Fuel pumps, 637
  checking, 901
  checking pressure and volume, 910
  fuel recirculated, 864
  GDI fuel rail shown with, 889
  relay circuit diagnosis, 913–915
  testing for fuel volume, 872–873
Fuel pump testing, 870–873
  dynamic pressure test, 871
  ear test, 870
  fuel pump volume testing, 872–873
    quick and easy, 872
  fuel returning to tank, 871
  pressure chart, 870
  pressure testing, 870–871
  rest pressure test, 871
Fuel pump volume testing, 872–873, 910
  symptoms of low fuel volume, 874
Fuel rail, 888
  cleaning, 911
  definition, 882
  flushing, 910
  rectangular-shaped, 882
  shown with pump assembly, 889
Fuel-rail pressure (FRP) sensor, 838
Fuel return line, checking, 902
Fuel safety and storage, 53–54
Fuel system, 5
  components, 148–149
Fuel systems, E85 requirements, 769
Fuel system tester, 872
Fuel tank cap
  dash display, 932
  testing, 932
  tightening screw-type, 933
  tightening until click, 934
Fuel tank filler caps
  capless system (Ford), 928
  EVAP systems, 928
Fuel tank fillups, pump clicking off, 928
Fuel tank pressure (FTP) sensor, 933
  location, 933
Fuel tanks, 860–862
  diesel engine, 161
  filler tubes, 861
  fuel levels and EVAP monitor, 934
  fuel pickup tube, 862
  location and mounting, 861
  overfilling or running out, 760, 763, 764
  pressure-vacuum filler caps, 861
  regulator inside, 900
  rollover leakage protection, 862
  tank venting requirements, 862
  typical installation, 861
  VOC emission concerns, 864
Fuel temperature, 411
Fuel temperature sensor, ice bath test, 161
Fuel trim, 849–850
Fuel trim monitor, 959
Fuel type, 151
Fulcrum, 109, 1023
Full-fielding test, 588
Full-floating axles, 1079
Full-floating piston pins, 341–342
Full-floating rods, 349
Full frame, 1289
Full hybrid, 990
Full-pressure oil system, 212
Full round bearing, 379
Full-time four-wheel drive, 1534, 1536
Fully counterweighted crankshaft, 369
  four-cylinder crankshaft, 369
Fully discharged battery, 540
Functionality tests, 959
  example, 963
Fungible, 755
Fused jumper wire
  as diagnostic tool, 593
  features, 444
  uses, 444–445
Fuse link, 471
Fuse panel illustration, 105
Fuse replacement method, for short circuits, 489
Fuses, 469–474
  blade-type, 470–471
  blown, 487
  blown (open) fuses, 429–430
  checking for common ground, 487–488
  colored blade-type, 470–471
  construction, 469–470
  diagram showing multiple switches and bulbs on one fuse, 488
  maxi, 471

Fuses, (*Continued*)
mega, 473
mini, 471
Pacific fuse element, 471
ratings, 470
short-to-voltage, 430
symbol for, 469
testing, 471
troubleshooting procedure, 489
visual inspection, 487
Fusible links, 275, 473
cause of failure, 473
checking, 473–474
location, 473
replacing, 474
test light for defective, 589
FWD (four-wheel drive), alignment, 1426

G

Gallery, 215
Galvanic activity, 180
bi-metal corrosion shown, 180
testing for, 180
Ganged switch, 484
Gang fired, 878
Garter springs, 1074
Gas analyzer, 902
Gas-charged shock absorbers, 1304
Gas fade, 1089, 1116
Gasket failure
causes, 384
due to movement during installation, 384
fretting, 384–385
Gaskets
asbestos in older-style, 381
cover gasket materials, 383–384
deterioration, 253
head gaskets, 381–383
locations, 382
need for, 381
no-retorque-type gaskets, 381
preventing leaks, 382
usage hints, 385
Gasket scraper, 253
Gas laws, 112
Gas line freeze-up, 763
Gas metal arc welder (GMAW) seat removal trick, 306
Gasoline
accidentally added to diesel fuel, 778
additives, 760
alcohol content, testing for, 762, 765
antiknock ratings, 758
blending, 761
chemical composition, 754
cold-weather driveability, 757
defined, 754
filling containers with, 764
general recommendations, 763–764
grades and octane number, 759
for high altitudes, 759, 760
normal and abnormal combustion, 758
octane rating, 758
overfilling or running out, 760, 763, 764
phase separation, 760
refining, 754–755
reformulated (RFG), 761–762
safety and storage, 53–54
seasonal blending, 756
shipping, 755
sniff test, 763
testing for alcohol content, 762, 765
“top-tier,” 763
volatility, 755–756
weight compared to water, 761
winter-blend, 756
Gasoline blending, 761
in-line, 761
sequential, 761
splash blending, 761
Gasoline combustion process, 757–758
Gasoline direct-injection (GDI) systems
advantages, 887
diagram, 887
direct fuel injection, 887
disadvantages, 887
engine start system, 891
fuel injectors, 889
Lexus port- and direct-injection systems, 890–891
NOx catalyst shown, 888
piston top designs, 890
port fuel-injection compared, 889
service, 891
Gasoline direct-injection (GDI) system service
carbon issues, 891
noise issues, 891
Gasoline direct-injection fuel injectors, 889
Gasoline engine. *See also Engine entries*
diesel engine compared, 159
engine oil ratings, 199
Gasoline engine
Gasoline smell, 239
Gasoline testing kits, 755
Gassing, 539
Gas smell, EVAP leaks, 932
Gas to liquid (GTL) technology, 775
Gate, 518
Gateway module, 535
Gauge, magnetic bubble-type camber/caster, 1427
Gauge rod, 99
Gauges
brake shoe setting gauge, 1109
dial bore, 103
feeler, 102
gages versus, 101
gauge versus gage, 101
small-hole, 100
split-ball, 100
telescopic, 100
thickness, 102
Gauging set, pinion shaft shim thickness, 1528
Gauss gauge
definition, 490
magnetic field measurement, 499
Gauss gauge method (for short circuits), 490
Gauss, Johann Carl Friedrich, 499
GAWR (gross axle weight rating), 126
GC-LB (grease classification), 1073
“G” coolant, 177
Gear lash, 1367
Gear lubes, 144
Gear lubrication, 1487
Gear mesh preload, 1367
Gear nut, 666
Gear ratio, determining, 1474
Gear ratios, 117
categories, 1474
direct drive, 1474
gear reduction, 1474
how to read, 117
idler gears, 1474–1475
overdrive, 1474
Gear reduction, 117, 1474
Gear-reduction starters, 561–562
cutaway view, 562
position, 576
Gear selector shown, 1557
Gear-to-gear transfer case, 1539–1540
Gear type oil pump, 212–213
oil flow, 212
Gel battery, 542
Gel-filled bladder airbag sensor, 696
Gelled electrolyte (gel) batteries, 542
General information, factory service manuals, 72, 120
General Motors
4L60-E torque flow, 1582–1585
6T70 transaxle disassembly and assembly, 1612–1615
ABS summary guide, 1222
active fuel management, 335
air filter restriction indicator, 221
airflow sensors (older), 841, 842
antenna types, 701
balance shafts, 371–372
battery locations, 551
battery sizes, 543
bias voltage, 848
blower motor test, 655
bypass ignition control, 792
central port injection, 883
coil-near-plug system, 790
communication protocols, 527–529
compound-wound starter motors, 560
computer Command Ride (CCR), 1351–1353
diagnostic connector, 1223
diagnostic executive, 958
displacement on demand (DOD), 335
distributor ignition systems, 518
distributor indexing, 806
ECT sensor without pull-up resistor, 822
ECT sensor with pull-up resistor, 820
electric fuel pumps, 867
electronic conductance tester, 548–549
electronic suspension sensors, 1343–1345
engine oil temperature sensor, 827
EST (electronic spark timing), 792
ETC warning lamp, 896
Flex Fuel vehicles, 770
FWD transmission chart, 1581
gasoline direct injection (GDI), 887
GMLAN versions, 528–529
high-performance balancer, 371
history, 1
how to read VIN, 771
immobilizer or vehicle theft deterrent key learn procedures, 678
injector resistance table, 904
Keyword 81, 82, and 2000 serial data, 528
land departure warning (LDW), 641
linear EGR valve, 938
MAP sensor vacuum readings, 836
MAP sensor voltage, 834
MAP sensor voltage (good reading), 834
misfire, 328
nonchecking throttle body units, 880
nylon fuel lines, 864
OBD-II data link connector, 536
oil specifications, 203
OnStar, 639
oxygen sensor problem diagnosis, 853
parking brake application, 1152
passkey series, 680–681
passlock series, 682–683
passlock series diagram, 682
PM connecting rods, 346
precollision system, 662
primary winding location, 783
pushrod lengths, 406
radar cruise control, 661
rain sense module (RSM), 653–654
rear disc brake caliper shown, 1153
rear park assist (RPA), 641
rear parking brake adjustment, 1156
replacement knee bolsters, 693
reset oil service reminder light, 642
RWD hydraulic component chart, 1582
RWD transmission chart, 1581
security radio problem, 710
sensing and diagnostic module (SDM), 690
separate replaceable part schematics, 483
SI-style alternator, 584
solenoid ohmmeter check, 570
Spark Ignition Direct Injection (SIDI), 887
spark plug overtightening, 804
spark plugs and antiseize compound, 804
splice packs, 525
starter replacement, 572
stepped ECT circuits, 819
SUV front axle, 1540
TBI fuel-injection systems, 871
Tech 2 scan tool, 534
thermostat location, 183
TPC tire rating, 1253
transaxle sensor temperature to resistance, 826
two-wire speaker connection, 704
typical rear disc brake, 1152
UART, 527–528
variable camshaft timing, 330
VATS security system, 679
waste-spark ignition coil, 507
wire repair, 476, 477
General Motors ASEP training, 17
General Motors Duramax
diesel troubleshooting chart, 172
injector internal parts, 164
priming pump location, 164
General Motors EcoTec 4-cylinder, ion-sensing ignition, 791
General Motors HEI system
bumps in scope testing, 808
“hump” in dwell section, 810
General Motors minivan, electrical problems, 608
General Motors pickup, electric fuel pump replacement, 873
General Motors trucks, speedometer recalibration, 642
General Motors V-6
firing order, 787
IAT sensor location, 824
piston finish, 339
Schrader valve location, 870
timing gear, 267
General Motors V-8, cylinder boring out-of-round, 359
General service technician, 11–12
Generator. *See* Alternator (generator)
Generic OBD II. *See also* Global OBD II
Gentex Corporation, 617
Geometric centerline, 1434
Germanium, 509
forward voltage, 513
Gerotor, 866
exploded view, 866
Gerotor type oil pump, 213
driven by crankshaft, 213
Girdle, 355
main bearing caps tied together, 356
GL-5 SAE 80W-90 gear lubricant, 1532
Glass beads, cleaning precautions, 272
Glasses, safety, 41
Glitches, 461
Global OBD-II, 964
Glove box light, bulb trade numbers, 607
Gloves, 41–42
Glow plugs, resistance balance test, 173
Glow plugs, diesel engine, 164–165
assortment shown, 165
circuit schematic, 165
heated inlet air, 165
operation, 165
purpose and function, 164–165
GMCAN, Class 2 communications, 528
GM Electrical Power Management System, 585–586
GMLAN (GM local area network), 528–529
GMM (graphing multimeter), 466
fuel pressure test, 900
Goofy mode, 1379
Google, for service information, 26
Governor valve, 1578–1579
defective, signs, 1594
GPS (global positioning system), 637
OnStar, 639–640
window tinting and, 638
GPS satellite signals, 637–639
Grabby brakes, 1110, 1207
Grade, bolt, 58
Grades of gasoline, 759
Grain alcohol, 767
Gram
defined, 98
visualizing, 98
Graph, 117
interpreting, 118
Graphing multimeter (GMM), 466
fuel pressure test, 900
Graphing scan tools, 466
Graticules, 461
scope display, 461
Gravity bleeding, 1065
Gravity die casting, 338
Gray cast iron, 113
Gray exhaust smoke, 172
Grease, 1072–1074
CV joint, 1502, 1512
different colors, 1073
excessive, on wheels, 1278
moly, 1502
spline collars, 1505
U-joints, 1504
Grease additives, 1072–1073
Grease fittings, 143, 1372
caution with too much grease, 143
grease gun tool, 1505
procedure, 143
recent vehicles, 1379
vents that look like, 143
Grease gap pliers, 1075
Grease gun, 84
hand-operated, 143
Grease gun-type bearing packers, 1077
Grease retainers, 1078
Grease seals, 1078
“Green crud,” 474
Greenhouse gases (GHG), cellulose ethanol production and, 768
Greenhouse gas score, 920
Green tires, 1242
Grid, 538–539
Grinding noise, 1110
rear end diagnosis, 1525
Grit size, 361
numbers and dimensions, 362
Groaning noise, ABS, 1222
Grooves, 337
Gross axle weight rating (GAWR), 126
Gross earnings, 21
Gross vehicle weight rating (GVWR), 126, 1020
Ground, 12 volt light to test, 445
Ground (black/white) wire, 792
Ground
for circuits, 429
common, 487–488
definition, 431
fused jumper wire for, 445
lamp problems, 619
location schematics, 482
radios and receivers, 700
schematic symbol, 482
short-to-ground, 430–431
Ground brushes, 561
Grounded, 431
Grounding wrist strap, 523
Ground loop, 704
Ground plane, 701
Ground wires, 468–469
electromagnetic interference, 507
for EMI suppression, 507
Growler, 571
Growling noise, rear end diagnosis, 1525
G-sensor, 1346. *See also* Lateral acceleration sensors
GTL diesel, 775
Gudgeon pins, 340
Guide plate, 326
GVW (gross vehicle weight), 1290
GVWR (gross vehicle weight rating), 126

H

H02S, 848
H02S1, 849
Hacksaws, 77
Half-bearing shells, 379
shown, 376
Half shafts, 1500
Hall effect, 784–785
TP sensors, 895

Hall-effect sensor, 446, 585
camshaft reference sensor, 786
crankshaft reference sensor, 786
on-off voltage signal, 785
testing, 806
testing connection, 799
Hall-effect switch, 784–785
Halogen bulbs
bulb failure diagnosis, 613
care while handling, 613
compared to xenon headlights, 614
headlights, 613
precautions with touching, 613
Halogen sealed beam headlights, 613
Hammers, 73
Hand cleaner trick, 589
Hand-operated bearing packers, 1077
Hand-operated parking brakes, 1146
adjustment, 1155
Hand safety, 42
Hand test, 739
Hand tools
basic list, 78
cutters, 75
electrical, 79–80
experience, importance of, 16
hacksaws, 77
hammers and mallets, 73
magnetic tray for, 43
maintenance, 80–81
pliers, 73–75
punches and chisels, 75–76
ratchets, sockets, and extensions, 69–71
removers, 76–77
safety, 80
screwdrivers, 72–73
seal drivers and pullers, 80
Hand tools. *See also specific tools*
sets and accessories, 78
wrenches, 68–69
Handwheel position sensor, 1234, 1345–1346
Hangers, 226
Hard-blast cleaning in sealed cabinet, 273
Hardness of camshaft, 316
Hard seat stone, 304
Hard spots, 1159
Hardware kit, drum brake, 1107
Harmonic balancer, 369, 370
importance of correct size, 370
removal, 267
vibration damage, 369
Harmonic balancer puller, 267
Haunted mirror story, 671
Hazardous Materials Identification Guide (HMIG), 56
Hazardous waste hauler, 49
Hazardous waste materials, 48
penalties for breaking laws, 48
Hazard warning flasher, 611
combination turn signal and hazard warning flasher, 611
H-bridge circuit, 894
shown, 895
HC emissions, 5
HC exhaust emissions, piston head design, 339
HCU (hydraulic control unit), 1224
Head bolts
order for tightening, 401–402
torque-angle method, 404
torque sequence, 401–402
torque-to-yield, 403–404
Head bolt threads, BMW, 390
Head bolt tightening specification, 404
Head bolt torque sequence, 401–402
Head gasket design, coolant flow in the engine, 191
Head gasket failure
diagnosing, 248–249
leak tester, 248
what to check, 249
Head gasket holes, 285
Head gaskets
“front” markings, 403
highway overheating, 194
multilayered steel (MLS) gaskets, 381–382
perforated steel core gaskets, 381
requirements needed, 381
types, 381–382
Headless bolt trick, 416, 1487
Headless long bolts, 416
Headlight aiming, 615
diagram, 615
optical headlight procedure, 622–623
Headlight and starter circuit, 441
Headlight circuit
circuit breakers, 472
series-parallel circuit, 441
Headlight dimmer switch, 484
Headlights, 611–616
adaptive front lighting system, 616
aiming, 615
automatic, 613
bulb trade numbers, 606
circuit diagram, 612
composite, 613
dimmer switches, 617
halogen sealed beam, 613
HID (high-intensity discharge), 614–615
LED, 615
LEDs, 514
optical headlight procedure, 622–623
positive switching of high- and low-beams, 619
rheostat, 612
sealed beam, 613
switch control, 605
switches, 611–612
wiring precautions, 613
Headlight switch control, 605
Headlight switches, 611–612
Head-up display (HUD), 630, 632
Hearing protection, 42
when to use, 112
Heat, 110, 713
as cause of short circuit, 491
electronic component failure, 519
junction damage, 518
latent, 713
sources of, 474
temperature and, 713
Heat and tap method, 1063
Heat checking, 1159
Heat dams, 339
Heated and cooled seats, 669
seat filter troubleshooting, 669
Heated inlet air, 165
Heated mirrors, 663
Heated oxygen sensor (HO2S), 950
Heated rear window defoggers, 662–663
breath test, 663
diagnosis, 663
electrical grid, 662–663
parts and operation, 662
precaution, 662–663
repair material, 663
repair or replacement, 663
switch and relay control current, 662
troubleshooting, 663
Heated seats, 668–669
replaceable element, 669
Heated steering wheel, 669–670
Heat energy, 757
Heat energy of E85, 768
Heater
diagnosis, 737–738
factory service manuals, 73, 121
hot/cold/hot/cold diagnosis, 740
precautions with handling, 738
trouble diagnosis, 738
Heater circuits, 848
Heater control valve, 739
Heater core, 137, 714
burping air from, 739
HVAC assembly diagram, 192
location shown, 738
problem diagnosis, 192
purpose and function, 192
typical, 715
Heater hoses, 137, 197
cut-and-peel trick, 138
HVAC, 714
replacement, 746
same length, choice of, 746
visual inspection, 746
Heat gun, 75
Heating element, 668–669
Heating metal, procedure, 89
Heating system
blower motor, 714
control doors shown, 731
major portions shown, 731
parts and operation, 714–715
purpose and function, 714
typical settings, 731
Heating, ventilation, and air conditioning (HVAC), 6
ASE task list, 39
diagnostic procedure, 737
factory service manuals, 73, 121
principles involved, 712
purpose and function, 712–714
Heat of compression, 158
Heat shield, 164
Heat shrink tubing, 476
Heat sink, 518
Heat tabs, 409
purchasing, 410
Heavy-duty (HD) flasher, 489
Heel, 1518
Height-sensing proportioning valves, 1045–1046
Height sensor, 1343
HEI pickup, measuring resistance with DM, 798
Held member, 1559
Helical gear, 1472
spur gear compared, 1473
teeth shown, 1472
Helical inserts, 64–65
Helicoil® inserts, 64–65
Cadillac rebuilt engine, 390
Helmholtz, Herman L. F., 221
Helper leaves, 1296
Hemholtz resonator, 221
location, 221
Hemi design, 282
HEPA (high-efficiency particulate air) vacuum, 50
Hertz (Hz), 463
audio system, 699
Hesitation, symptom information chart, 77, 123
HEUI (hydraulic electronic unit injection)
components, 162
operation, 162–163
O-ring grooves, 163
HEV (hybrid electric vehicles), 255–256, 983
driving and owning, 984–985
emission standards, 127–128
features by make and model, 990
heating and cooling, 736
recharge diagram, 985
two cooling systems, 136
Hexadecimal, global OBD-II, 964
HFC-134a (R-134a), 718–719
barrier hoses, 723
refrigerant leak detector, 744
retrofitting, 751
underhood sticker, 751
HID (high-intensity discharge) headlights, 473, 614–615
Hidden wipers, 648, 649
High altitude, oxygenated fuels, 760
High-authority sensors, 843
High carbon steel, 113
High-efficiency particulate air (HEPA) vacuum, 50
High-flotation tires, 1245
High impedance, 446
High-impedance test lights, 445
High-impedance test meters, 446–450
High-intensity discharge (HID) headlights, 473
bi-xenon headlights, 614
diagnosis and service, 614–615
failure symptoms, 614
parts and operation, 614
parts listed, 614
run-up state, 614
start-up or stroke state, 614
steady state, 614
High mileage oils, 204
differences, 204
High-pass filter, 705
High-performance, aluminum rocker arm, 320
High performance, axle ratio tip, 1519
High-performance
balancer, 371
camshafts, 315
camshaft specifications, 326
double roller chain drive, 318
forged connecting rods, 347
forged crankshaft, 366
high-flow rate cylinder heads, 283
stock parts precaution, 370
stud use, 389–390
High-performance clutch disc, 1456
High-performance exhaust system, 936
High pressure, in air conditioning, 743
High-pressure common rail (HPCR) fuel delivery, 162
overview diagram, 163
High-pressure gauge, air conditioning, 740
High-pressure leaks, diesel engine, 174
High-pressure pumps, 888
camshaft-driven, 889
High resistance, 431
High school training
cooperative programs, 16, 17
general service technician, 11
High-side drivers (HSDs), 817
High-side pressure in air conditioning, 740–741
pyrometer to measure, 741
High speed effectiveness, 1020
High-strength thread locker, 386
High valve temperatures, 296–297
High-velocity seating, 297
High-voltage spike protection, 512–513
High-volume oil pump, 214
Hit and tap method, 1062
HLA (hydraulic lash adjusters), 323
in rocker arm, 323
HMIG (Hazardous Materials Identification Guide), 56
HO2S (heated oxygen sensor), four-wire, 848
HOAT (hybrid organic acid technology), 177
Hoisting vehicles, 92–94, 95–96
vehicle hoists, 92–94
Hold-down pins (nails), 1103
Hold-down springs, 1105
Hold-down spring tool, 1103
Holding (braking) clutches, 1573
diagram, 1574
Holding coil, 564
Holding devices, 1571
Holding fixture, 1600
Hold-in winding, 564
Hold-off operation, 1046–1048
Holdowns, brake shoe, 1093–1094
Hold-position operation, 1200
Hole gauge, 102
Hole in the fender cover trick, 702
Holes in P-type material, 510
Hole theory, 510
Hollander manual, 30
Hollow pushrod dirt, 321
HomeLink garage door opener, 664
buttons, 664
diagnosis and service, 664
Homogeneous knock protection mode, 890
Homogeneous lean mode, 889
Homogeneous mode, 889
Homogeneous stratified mode, 889
Honda
automatic transmission fluid, 138
battery sizes, 543
BUS communications, 532
ECT sensor (resistance chart), 823
ECT sensor (voltage chart), 823
electronic load detection circuit, 588
FRM-lined cylinders, 354
HEV heating and cooling, 736
hybrid vehicle emissions, 127
immobilizer or vehicle theft deterrent key learn procedures, 682
lane keep assist system (LKAS), 641
nonplanetary gear set, 1561
shown, 1562
oil drain plug gasket, 206
oil specifications, 203
precollision system, 662
remote keyless programming, 673
scan display, 533
scan tools, 534
VTEC mockup, 334
Honda Civic GX
CNG storage tank, 773
fuel injectors, 773
Honda CVT
belt construction, 1563
construction, 1562–1563
operation, 1563
power flow in drive and low, 1564
power flow in park and neutral, 1563
transmission control module, 1565
Honda Insight (1999-2004), spark plugs, 256
Hone drive motor, 362
Hood removal, 263
Hooke’s Law, 1291
Horizontally opposed engine design, 151
Horn circuits, 646
diagram, 647
procedure for horns, 647
testing, 647
typical circuit with relay, 486
Horn operation, 1358
schematic, 1358
Horn relay, 646, 647
Horns, 646
continuous sound fault, 647
fused jumper wire for, 445
inoperative, 647
measuring current flow, 449
mount to radiator core support, 647
number used, 646
operation, 646
purpose and function, 646
replacement, 647
service, 647
switch and relay, 647
system diagnosis, 647
troubleshooting, 656
Horsepower, 107–108
airflow as, 283
altitude and, 157
as calculated value, 411
calculation, 411, 412
corrected (calculated number), 411
formula, 108, 154
frictional, 411
fuel flow and, 759
graph showing torque and, 117
power related, 154
Hose, oil versus heater, 197
Hose clamp, 137
shown, 138
Hose clamp or wrench trick, 1156
Hose clamp pliers, 138
Hose inspection, 195–196
inspection diagram, 196
Hose inspection, power steering, 1405
Hose trick, 243
Hosting chains, 417
Hotchkiss drive, 1336
Hot/cold/hot/cold heater diagnosis, 740
Hot film mass airflow sensor, 841
sensing wire, 841

Hotline service provider, 78, 124
Hot performance, 1020
Hot restrike test, 615
Hot spots, 1159
Hot tank cleaning, 275
Hot water method, 185
  diagram, 185
Hot wire mass airflow sensor, 841
Hourly rates/annual income, 22
Household pliers, 73
Housekeeping duties, 31–32
Housing expenses, 22
Housing spreader tool, 1530
HOV lane, 989
HPCR (high-pressure common rail) fuel delivery, 162
HSMO (hydraulic system mineral oil), 1052
HTHS (in ACEA oil), 201
Hub, 369, 1477
  shown, 370
Hub assemblies, 1072
Hubcentric wheels, 1281
Hub drums, 1102
Hubless drums, 1102–1103
Hub nut removal, 1509
Hubs
  autolocking hubs, 1534
  locking hubs, 1534
HUD (head-up display), 630, 632
Humidity, 714
Hummer
  bin number, 127
  casting mold for engine blocks, 352
  range shift selector, 1540
Hunting gear sets, 1519
HVAC (heating, ventilation, and air conditioning), 6, 528
  automatic system components, 731
  blower motor service, 746
  diagnosis procedure, 737
  HEV heating and cooling, 736
  purpose and function, 712–714
  rear air-conditioning systems, 735
H-valve, 725
  Chrysler, 726
Hybrid, 989
Hybrid electric vehicles (HEV), 983
  before service, 131
  classification of, 985
  converter driver pump supplemented, 1554
  converter for accessory power, 521
  digital meter usage, 454
  driving and owning, 984–985
  emission standards, 127–128
  features by make and model, 990
  heating and cooling, 736
  recharge diagram, 985
  torque dampener plate, 1552
  two cooling systems, 136
Hybrid electric vehicles (HEV) engine precautions, 255–256
  engine operation, 255
  ready light, 256
  service, 256
Hybrid flashers, 611
Hybrid organic acid technology (HOAT), 177
Hydraulic, 92
Hydraulic ABS service, 1067–1069
  bleeding made easy, 1069
Hydraulically controlled transmission valves, 1577–1579
Hydraulic circuit failure, 1020
Hydraulic clutch bleeding, 1466–1467
Hydraulic clutch linkage, 1466
Hydraulic clutch replacement, Saturn, 1466
Hydraulic components and control systems
  accumulators, 1574–1575
  apply or holding devices, 1571
  ATF, 1567
  bands, 1571–1572
  electronically controlled transmissions, 1580–1581
  hydraulically controlled transmission valves, 1577–1579
  multiple-plate clutches, 1572–1574
  one-way clutches, 1575–1576
  pump, 1569–1571
  typical torque flow, 1582–1585
  valve body, 1576–1577
Hydraulic cylinders, 85
Hydraulic electronic unit injection (HEUI)
  components, 162
  operation, 162–163
Hydraulic fluid, 1388
Hydraulic lash adjusters (HLA), 323
  bleeding tool, 405
  in rocker arm, 323
Hydraulic lifters, 327
  bleeding, 405
  installation, 405
Hydraulic modulators, 1214
Hydraulic press, separating gears from shaft, 1486
Hydraulic presses, 85
Hydraulic pressure, 1029
Hydraulic principles, 1027
  brake design, 1030–1031
Hydraulic roller lifter, 327
  exploded view, 327
Hydraulic servos, 1572
Hydraulic system, brakes, 1017
Hydraulic system leak test, 1202
Hydraulic system mineral oil (HSMO), 1052
Hydraulic systems, 1027
Hydraulic valve lifter, 327
  installation, 405
Hydraulic valves and switches, 1040–1049
  brake fluid level sensor switches, 1042–1043
  brake light switches, 1048–1049
  combination valves, 1048
  electronic brake proportioning, 1046
  metering valve (hold-off) operation, 1046–1048
  pressure-differential switches, 1041–1042
  proportioning valves, 1043–1046
  residual check valves, 1041
Hydro-Boost accumulator test, 1207
Hydro-Boost function test, 1206–1207
Hydro-Boost hydraulic brake boosters, 1203–1207
  in applied position, 1206
  diagnosis, 1205–1206
  exploded view, 1205
  in holding position, 1206
  location shown, 1204
  operation, 1204–1205
  in unapplied position, 1205
Hydro-Boost symptom-based guide, 1207
Hydrocarbon (HC) emissions, 5
Hydrocarbons (HC)
  exhaust analysis, 923
  HC too high, 924
  high, cause and correction, 926
  non-methane hydrocarbon (NMHC), 923
  strong exhaust smell, 925
Hydrocracking, 754
Hydrodynamic lubrication, 211
Hydrodynamic oil film, 367
Hydrogen atom, 422
Hydrokinetic flow pump, 866
Hydrometer, 547
  battery test reading, 547
  checking temperature with, 179
  coolant testing, 136, 179
  definition, 547
  for diesel fuel testing, 778
Hydrophilic, 1251
Hydrophobic rubber, 1251
Hydroplaning, 1240
  diagram, 1241
Hydroseal, 275
Hygrometer, 714
Hygroscopic brake fluid, 1051
Hypereutectic pistons, 338
Hypoid gear sets, 1473
  differential, 1517
  drive pinion shown, 1518
  shown, 1474
Hypothesis, 105
Hyundai
  immobilizer or vehicle theft deterrent key learn procedures, 682
  radar cruise control, 661

I

I (intensity, represents amperes), 424
IAC (idle air control), 908
  airflow shown, 909
  cleaning passages, 910
  diagnosis, 908
  housing, 909
  motor, 885
  typical, 909
IAC (idle air control) valve, 885
IAC counts, 902
  checking with scan tool, 912
  scan tool, 902
IAT (inorganic additive technology), 176
IAT sensor
  DTCs, 825
  in intake manifold, 823
  location, 824
  performance and driveability, 824
  pulse width, 878
  purpose and function, 823–824
  testing, 825
  troubleshooting with DTCs, 827
I-beams, 1299
IC (ignition control), 792
ICE (internal combustion engines), 983
Ice scrappers for cleaning, 272
Icing switch, 718
ICM (ignition control module), 5, 505–506
  operation, 149
Identifix, 124
IDI (indirect injection diesel) engine, 160
  prechamber and glow plug, 160
Idiot lights, 249
Idle air control (IAC), 908
  airflow shown, 909
  cleaning passages, 910
  computer controls, 816
  diagnosis, 908
  housing, 909
  motor, 885
  typical, 909
Idle air control (IAC) counts, 902
  scan tool, 902
Idle air control (IAC) valve, 885
Idle air control passages, cleaning, 910
Idle control, port fuel-injection systems, auxiliary air bypass, 885
Idle control strategy, 829
Idler gears, 1474–1475
Idle stop, 255
Idle stop mode, 989
Idle vacuum test, 246
IDP (isolating decoupler pulley), 578
IEC (International Electrotechnical Commission), 454
Ignitable materials, 48
Igniter (ignition control module, ICM), 505–506
Ignition
  diesel fuel ignition, 160
  external trigger, 464
  point-type, 6, 495
Ignition coil circuits
  bypass control system, 792–793
  terminology, 792
Ignition coils, 504–506
  bad wire, 800
  coil-on-plug (COP) design, 505
  construction, 505, 783
  E coil, 505
  electrically connected windings (“married” type), 505
  electrically insulated windings (“divorced”), 505
  GM waste-spark ignition coil, 507
  operation, 149, 505–506, 782–783, 795
  precaution with sparks, 782
  soft iron and magnetism, 499
  spool design, 505
Ignition coil testing, 795
  current ramping ignition coils, 795–796
  current ramping test procedure, 796
  magnetic pickup tool test, 796
  using an ohmmeter, 795
Ignition coil windings, 504–505
  primary, 504
  secondary, 505
Ignition control (IC), 792
Ignition control (IC) signal, 792
Ignition control circuits, up-integrated ignition, 793
Ignition control module (ICM), 5, 505–506
  operation, 149
Ignition control module (ICM, or igniter)
  ignition coil operation, 782–783
  tachometer trick, 785
Ignition delay, 161
Ignition key off, engine off (KOEO), 619
Ignition misfire, false lean indication, 851
Ignition modules, pulse width, 463
Ignition off draw (IOD) test, 552–553
Ignition primary (pickup coil or crank sensor) pulse, 902
Ignition scope testing, 807
  converting between units (chart), 809
  dwell section, 808
  firing line, 807–808
  intermediate oscillations, 808, 809
  pattern selection, 808
  spark line, 808
  technician’s toughie story, 809
  terminology, 807
  transistor-on point, 808
  typical scope hookups, 807
  typical secondary pattern, 807
Ignition sensors, operation, 149
Ignition sensor testing, 796
Ignition start buttons, 558
  remote, 558
Ignition switch
  bulb test position, 634
  column-mounted, 557
  cranking circuit, 557
  location, 635
  six positions, 635
  typical positions, 635
Ignition switching and triggering, 783–785
  primary circuit operation, 784–785
  switching, 783–784
  triggering, 784
Ignition systems, 5
  background, 782
  coil-on-plug ignition, 788–791
  coil operation, 782–783
  components, 148–149
  computer controlled starting, 557–558
  DI, 785–787, 786–787
  diagnosis, 794–796
  disabling, precautions, 243
  knock sensors, 791–792
  mechanical points, 782
  power balance test, 245
  purpose and function, 782
  switching and triggering, 783–785
  symptom guide, 811
  testing, 794–796
  waste-spark ignition systems, 787–788
Ignition system testing
  checking for spark, 794–795
  ignition coil testing, 795–796
  magnetic sensor testing, 796–798
Ignition timing
  checking, 805
  initial (base) timing chart, 805
  marks on harmonic balancers, 804
  purpose, 804
  setting, 409
Ignition timing control, 814
ILEV (inherently-low-emission vehicle), 127
ILEV (inherently low emission vehicle), 919
Illuminated entry, 617
ILSAC (International Lubricant Standardization and Approval Committee) engine oil ratings, 200
IM 240 test, 922
  OBD-II vehicles, 958
Impact breakage, 297
Impact screwdrivers, 72
Impact sockets, 83
Impact wrenches, 82–83
  rusty, 83
Impedance, 702–703
Impedance matching, 702–703
Impeller, 189, 1551
Impeller (compressor) wheel, 231
  diagram, 231
Impurities, 509
I/M test programs, 921
Incandescent lights, 84
Incentive pay, 21
Inches of mercury (in. Hg), 245, 1196–1197
Inches-of-water manometer (gauge), 944
  gauge shown, 945
Inch-pound torque wrench, 1529
Inclinometer, 1508
Included angle, 1421
  adjusting, 1440
  diagnosing, 1435
Inconal®, 294
Independent service facilities, 9
  shop foreman, 14
Independent suspension, 1290
Independent switches, 664
Indicator ball joints, 1318
Indicator ring, fuel-injection lines, 864
Indirect injection diesel (IDI) engine, 160
  prechamber and glow plug, 160
Indirect tire pressure monitoring system, 1217
  reset switch, 1263
Induced voltage
  described, 504
  reducing, 485
  ways to increase, 504
Induction, 504
Inductive ammeters, 450
  battery electrical drain test, 553
  best location, 593
  minimum electrical load requirements, 593
Inductive coupling, 507
Inert, 455, 936
Inertia, 109, 1023
  definition, 563
  piston operation, 337
Inertia forces, 337
Inertia friction welding, 295
  stem and head, 295
Inertia ring, 369
Inertia switch, 862
  cutaway view, 863
  schematic, 868
Inertia type dynamometers, 410
  at drive wheels, 410
Infiniti, remote keyless programming, 676
Infinity, 448
  battery sizes, 543
  lane departure prevention (LDP) system, 641
  meaning in digital meter, 448
  variable camshaft timing, 330
Inflator module, air bags, 1358
Inflator or compressor relay, 1354–1355
Informal evaluation, 32
Infrared (IR) or optical cameras, 662
Infrared pyrometer method, 185
Infrared thermometer (pyrometer), 952, 953
In. Hg. (inches of mercury), 245
In. Hg (inches of mercury), 1196–1197
Initialization procedures, 1263
Initial torque, 403
Injection pump, 158

Injection pump, diesel engine
distributor injection pump, 162
high-pressure common rail, 162
need for high-pressure, 161
schematic of Standadyne assembly, 162
Injector body, diesel engine, 164
Injector flow rate, 759
Injector pressure chamber, diesel engine, 164
Injector pulse, testing for, 903–904
Injector pulse width (PW), formula for, 877
Injector pump, diesel fuel-injection system, 159
Injectors, diesel engine
calibration number, 174
precautions about switching, 174
Injector voltage-drop tests, 907
Inlet manifold, 221
Inlet ports, 1032
Inline engines, 4
intake manifold, 407
In-line gasoline blending, 761
Inline six-cylinder engine crankshaft, 369
Inline-type engines, exhaust gas control, 936
Inner cones, 1071
Inner liner, of tire, 1242
Inner rings, 1071
Inner wheel bearings, 1072
Inoperative cooling fan, 253
Inorganic additive technology (IAT), 176
Input, 1343
Input conditioning, 813
Input member, 1541
automatic transmission, 1559
Input shaft, 1476
Insert seat, 296
interference fitted, 296
removal methods, 306
Insert valve seats, rings of metal, 306
Inside lighted mirrors, checking for common power source/ground, 487–488
Inside vehicle sensor, 732
Inspection. *See* Visual inspection
Inspection/Maintenance (I/M) testing, 922
age of vehicle and, 923
evaporative emission system, 932
Installation of engine
break-in precautions, 419
dressing the engine, 417
engine start, 418–419
installation procedure, 417–418
preinstallation checklist, 415
transmission installation, 415–416
Installed height, 307
correcting, 307–308
measuring, 307
Instrument panel (IP), 629
instrument cluster removed, 634
Instrument panel (IP) electrical center
bulb trade numbers, 607
E & C (entertainment and comfort) communication, 528
excessive battery drain, 554
Insulated brushes, 561
Insulated wire, jumper wire, 444
Insulation tester, 993
Insulators, 110, 423
coil spring mounting, 1294–1295
conductors compared, 110
spring, 1329
why they don't conduct, 509
Insurance agent, 23
Intake air speeds, 222
Intake air temperature (IAT), resistance and voltage drop versus, 825
Intake air temperature (IAT) sensor
GM V-6 location, 824
in intake manifold, 823
location, 824
performance and driveability, 824
pulse width, 878
purpose and function, 823–824
testing, 825
Intake air temperature (IAT) sensor testing, 825
Intake and exhaust ports
exhaust ports, 284
intake ports, 283–284
purpose and function, 283
Intake and exhaust valves
parts involved, 294
sodium-filled valves, 295
terminology, 294
two-material valves, 295
valve materials, 294–295
valve size relationships, 294
Intake manifold, 5
airflow, 223
air-fuel mixture shown, 284
alignment, 288–289
gasket fretting, 385
inlet manifold, 221
installation, 407
long or short runners, 222
operation, 147
plastic intake, 222
plastic/rubber gaskets, 384
upper and lower, 222–223
variable, 222
Intake manifold alignment
intake manifold template, 288
material to be removed, 289
procedure, 288
purpose, 288
Intake manifold gasket inspection
causes of failure, 254
coolant drawn into cylinders, 254
diagnosis of leak, 254
Intake manifold gasket replacement, 254–255
aftermarket, appearance of, 255
double-check torque specifications, 254
lower intake manifold, 254
sealers, 386
upper intake manifold, 254
Intake manifold pressure, how altitude affects, 837
Intake manifold runners, sonic tuning, 222
Intake manifolds, clogged EGR passages, 940
Intake manifold vacuum
calculating, 834
fuel pressure related (chart), 880
Intake ports, 284
Intake regulator, DDS, 882
Intake systems
air intake infiltration, 221–222
port fuel-injection intake manifolds, 222–223
throttle-body injection intake manifolds, 221–222
Intake valve, 149
cam timing specifications, 325
carbon deposits, 296
exhaust valve size compared, 295
margin, 301
unshrouding, 284
valve size relationships, 294
Intake valves, carbon deposits, 891
Integral ABS, 1211–1212
unit shown, 1211
unit with pump motor, 1216
Integral accumulator, 1575
Integral drum parking brakes, 1150
Integrally molded process, 1120
Integral power steering, 1392–1396
flow control valve operation, 1393–1396
rack-and-pinion, 1393, 1395, 1396
rotary control valve, 1392–1393
standard gear, 1392
Integral power steering gear, 1392
Integral reservoir, 1389
Integral seats, 296
cast-iron cylinder head, 296
Integral sensor, 690
Integral shock solenoid, 1354
Integral valve guides, 289
Integral valve seats, valve seat replacement, 306–307
Integrated antenna, 701
Integrated circuit (IT), 518
computer memory, 814
construction, 518
heat sink, 518
purpose and function, 518
Intensity, 112
Interaxle differential, 1541
Intercooler, 233
Subaru, 233
Interference angle, 302
Interference engine, 318
design, 319
Interference fit piston pins, 342
typical, 342
Interference fit rods, 348–349
heating rod, 349
Interference fit specifications, 307
Interior lights
brightness and starter problems, 569
courtesy lights, 617
headlight switch, 605
illuminated entry, 617
not working, 487–488
Interlocking tapered plugs, 278
showing crack, 278
Interlocks, 1477
Intermediate levers, 1148
shown, 1148
Intermediate oscillations, 808
reading, 810
Internal combustion engine, 4
air pressure related, 833
energy and power, 147
engine design evolution, 4
Internal combustion engine (ICE) vehicles, 983
efficiencies, 990
Internal/external gear type oil pump, 213
mounting location, 213
Internal gear, 1540
Internal oil pump, 1543
Internal ring gears, 1473
International Automotive Technicians Network, 844
training, 40
Web site, 123
Web site help, 26
International Electrotechnical Commission (IEC), 454
International Lubricant Standardization and Approval Committee (ILSAC) engine oil ratings, 200
International Standards Organization fitting, 1055
Internet, 78, 123
electronic service information, 78, 122
Internet translations, non-English speaking clients, 26
Inter-Provincial (IP) Certificate, 40
Interval wipers, 652
In-vehicle engine service
hybrid engine precautions, 255–256
intake manifold gasket inspection, 254
intake manifold gasket replacement, 254–255
thermostat replacement, 253
timing belt replacement, 255
valve adjustment step by step, 257–260
In-vehicle service, 1594–1597
band adjustment, 1596–1597
filter replacement, 1595
flushing ATF, 1595
linkage adjustment, 1597
pan removal, 1594–1595
Inverters, 522
IOD test, 552–553
Ions, 422
Ion-sensing ignition, 790–791
applied voltage for ion-sensing, 791
IP (instrument panel), 629
IP certification, 40
"IR" drop. *See* Voltage drop
Iridium spark plugs, 802
Iron, 113
IRS (independent rear suspension), 1338–1339
ISO (International Standards Organization), relay identification, 485
ISO fitting, 1055
Isolating decoupler pulley (IDP), 578
Isolation solenoids, 1214
Isooctane, 758
IT (integrated circuit), 518
computer memory, 814
construction, 518
heat sink, 518
purpose and function, 518
Izuzu, Flex Fuel vehicles, 770

J

J2534 reprogramming, 979
Jacks, 91–92
Jack stand, 91, *See also* Safety stands
Jam nuts, 63
Japanese Automobile Standards Organization (JASO), 201
Japanese vehicles
battery locations, 551
battery sizes, 543
engine oil ratings, 201
vane airflow sensor, 840
JASO standards, 201
JATCO (Japan Automatic Transmission Company), 1560
JD (Julian Date), 78, 123
Jeep
distributor indexing, 806
immobilizer or vehicle theft deterrent key learn procedures, 680
remote keyless programming, 675
Jeep Wrangler, Cardan-type U-joints, 1542
Jewelry, removal for safety, 42
Jiggle valve, 253
Job applications, 20
Jobber, 29
Job evaluations
formal, 32
informal, 32
sample, 33
Job interviews, 20
Job shadowing, 16–17
Joint angle, 1497
Jounce bumpers, 1308
Jounce/rebound test, 1380
Journal hardness
case hardening, 366
nitriding, 366
tuftriding, 366
Journals, crankshaft welding, 374
Julian Date (JD), 78, 123
Jumper cables, 469, 550
constructing, 469
usage guide, 44
Jumper wire, definition, 444
Jumper wire connections, ABS, 1223
Jump starting
battery access point, 555
battery safety, 44–45
cable usage guide, 552
digital meter usage, 456
electronic component failure associated, 520
frozen battery, precautions, 540, 549
ground for, 555
jump box, 550, 552
Junction, 510
heat damage, 518

K

KAM (keep-alive memory), 814
KAM (long-term memory), 959
Karman Vortex air flow sensor
basic designs, 842
schematic, 842
Keep-alive memory (KAM), 814
Kelsey-Hayes 4WAL system, 1058
Kelsey-Hayes antilock, 1223–1224
Kelvin (K) temperature, 614
Kettering, Charles F., 2, 6
Keviar, 1121
Key, 35
Key fob, 671
Key fob remote
adjustable pedals in memory, 670
with cover removed, 672
Keyless entry
diagram of location of components, 672
keyless entry diagnosis, 672
programming a new remote, 672
programming steps for popular vehicles, 673–678
rolling code reset procedure, 672
Keyless entry key fob, memory seat position, 667
Key-locking inserts, 66
Key-on—engine off (KOEO) test, automatic dimming mirror, 619
Keys, synchronizer, 1478
what they do, 1479
Keyword 81, 82, and 2000 serial data, 528
Kickback, 1369
Killer Bs, 1382
Kilo (K), 451
Kilohms
conversion to ohms, 452
reading DMM displays, 451
Kinetic energy, 108, 713, 1022–1023
brake design, 109
brake design and, 1023
formula for, 1022
how it works, 108–109
Kinetic friction, 1025
Kingpin, 1299
checking, 1435
diagnosis and service, 1322–1323
front suspension, 1312
KPI, 1421
service, 1322
typical assembly, 1322
Kirchhoff, Gustav Robert, 435
Kirchhoff's current (first) law, 438
Kirchhoff's second voltage law, 436
Kirchhoff's voltage law, 435
applying, 435–436
KISS test method, 242
Kliest, Ewald Christian von, 493
Knee airbags, 694
Knee bolsters, 693
Knives, utility, 75
Knocks, diagnosing, 240–241
Knock sensor (KS), 426
diagnosing, 791
items that can fool, 792
loose accessory drive belt, 792
purpose and function, 791
replacing, 792
typical location, 791
typical waveform, 792
KOEO (ignition key off, engine off), 619
Korean Airlines Flight 007, 637
KPI (kingpin inclination), 1421

L

Labor guide, 75
time guides, 76, 122
Labor guide manuals, 122
Labyrinth seals, 1089
Ladder frame, 1289
LAF (lean air-fuel) sensor, 854
Lambda, rich and lean exhaust readings, 857
Laminated soft iron, 505
Lands, 337
Lane departure prevention (LDP) system, 641
Lane departure warning (LDW), 641
Lane departure warning system (LDWS), 641
Lane monitoring system (LMS), 641
Lap, 1519

Lapelletier gear set, 1560
Lapping compound, 305
Lash (valve clearance), 297, 406
adjusting, 298
HL323
pedestal-type rocker arm, 321
valve opening at zero, 323
valve seat recession, 298
Latency period, 49
Lateness getting to work, 27, 30
Latent heat, 713
Latent heat of vaporization, 713
Lateral acceleration sensors, 1346
location, 1236
Lateral accelerometer sensors, 1235
quick and easy test, 1235
Lateral links, 1298
Lateral runout (LRO), 1166, 1277
Latex surgical gloves, 41
Laughing gas, 235
Lawn and garden equipment, synthetic engine oil for, 203
Laws
brake repair and, 1020
Pascal's law, 1028–1031
of physics, 1023, 1210
Laws of physics, ABS and, 1210
Lay shaft, 1476
LCDs (liquid crystal displays), 633
LDA (lobe displacement angle), 324
LDP (lane departure prevention) system, 641
LDP (leak detection pump), 931
LDW (lane departure warning), 641
LDWS (lane departure warning system), 641
Lead, 1413
Lead-acid battery
chemical reactions, 540, 541
valve regulated, 542
waste, 53
Lead-calcium batteries, maintenance, 545
Leadership roles, 31
Leading shoes, 1094
Leading-trailing brakes, 1095
Lead/pull, 1429
Leaf springs, 1295–1297
composite, 1296
rear suspensions, 1336–1337
suspension-beam axle, 1337
suspension-driven axle, 1336–1337
Leak detection pump (LDP), 931
Leak detection pump system
operation, 931
purpose and function, 931
Leaks
air conditioning, 744
color of, 239
diesel engine, 174
in lubrication system, 213–214
Leak tester
EVAP system, 932
head gasket failure, 248
Lean air-fuel (LAF) sensor. *See* Wide-band oxygen sensors (O2S)
Lean exhaust, 856, 857
lambda higher than 1.00, 857
positive current, 857
Lean indicator, 925
Least-likely-type questions, 36
LED (light-emitting diode), 633, 1343
brake lights, 609
definition, 513
headlights, 615
how it emits light, 514
need for current limiting, 514
operation, 513
trouble lights, 84
LED brake lights, 609
Ledges, 1089
LED headlights, 615
LED test lights, 445–446
Left-hand dipstick (LHD), 354
Left-handed threads, 64
Left-hand rule, 341, 500
Left-side courtesy light, 487–488
Legs, 438
calculating total current, 438
Lenz's law, 504
LEV (LEV I, low-emission vehicle), 127
LEV (low emission vehicle), 919
Level-control sensors, 1357
Lever adjuster, 1097
Leverage, 109, 1023
Lever-latch ratchet automatic adjusters, 1099
Levers, 1023
shown, 1475
torque related, 1475
Lever style pressure plate, 1458
Lever type clutch linkage, 1466
Lexus
battery locations, 551
battery sizes, 543
cruise control, 658
below 25 mph, 72, 120
direct fuel injection, 887
emissions decal, 127
GDI, 890–891
immobilizer or vehicle theft deterrent key learn procedures, 682
intake valve deposits, 891
lane monitoring system (LMS), 641
LED headlights, 615
port- and direct injection, 890–891
precollision system, 662
radar cruise control, 661
remote keyless programming, 678
variable camshaft timing, 330
Lexus HEV, ready light, 256
Leyden jar, 493
LHD (left-hand dipstick), 354
License plate light, 607
Lifter (tappet)
camshaft duration, 323–324
hydraulic lifters, 327
purpose and function, 326
solid lifters, 327
valve lash, 327
Lifter bore bushings, 363
Lifting heavy objects safely, 42–43
Lift pump, 161
Light, as source of electricity, 426
Light bulbs
blown (open), 486
bulb numbers, 605–608
dash bulb test, 625
digital multimeter to read ohms, 448
electrical problems, 608
halogen, 613
one-filament stop/turn bulbs, turn signals, 610
schematic symbol, 483
testing, 608
two-filament stop/turn bulbs, 610
visual inspection, 608
wattage and square of voltage, 432
Light-emitting diode (LED), 513–514, 1343. *See also* LED
aftermarket replacement LED bulbs, 609
brake lights, 609
trouble lights, 84
Lighter plug trick, 591
Lighting. *See also* Dome light; Interior lights
adaptive front lighting system, 616
adding additional, 488
automatic dimming mirrors, 617–619
brake lights, 608–609
bulb numbers, 605–608
computer-controlled, 605
courtesy lights, 617
daytime running lights, 617
diagnosis, 620
dimmer switches, 617
exterior, 605
feedback, 620
fiber optics, 617
ground connection faults, 619
headlights, 611–616
illuminated entry, 617
optical headlight aiming, 622–623
symptom guide, 620
taillight bulb replacement, 621
turn signals, 610–611
Lightly loaded vehicle weight (LLVW), 1020
Lightning damage, 710
Light-off converters (LOCs), 950
Light-off time, 855
Light sensors for automatic headlight, 613
Light shield installation, 787
Limited slip differential, 1520
lubricant additives, 1532
Limited slip differentials (LSD), 144
Limited-slip identification tag, 1524
Limp-in gear, 1581
Limp in mode, 896
LIN (local interconnect network), 534
Lincoln
immobilizer or vehicle theft deterrent key learn procedures, 680
precollision system, 662
remote keyless programming, 675, 676
Town Car speedometer, 635
Linear EGR, 938
General Motors, 938
Linear Hall-effect sensor, 1345
Linear measurements, metric, 98
Linear solenoids, 1581
Linesman's gloves, for work on circuits, 478
Linesman's pliers, 73
Lines of force, 498–499
alternator, 581
Line wrenches, 68
Lining assembly methods, 1092–1093
Lining fade, 1089, 1115–1116
Linings, brake, 1092–1093, 1093, 1104, 1120–1122
Lining tables, 1091
Link adjuster, 1097
Linkage adjustment, 1597
Linkage cables, 1148
Linkage design, 1149
Linkage equalizers, 1148–1149
Linkage levers, 1148
Linkage rods, 1147
Lip seal installation, 394–395
drivers for, 395
main bearing, 395
retainer plates, 395
Liquefied natural gas (LNG), 774
Liquid, 713
Liquid crystal displays(LCDs), 633
Liquid petroleum gas (LPG), 772
Liquids, non-compressibility of, 1027
Listening, barriers to, 24–25
Liters to cubic inches chart, 156
Lithium-based brake grease, 1137
Live axle, 1336
Living expenses, 22
LRR (low-rolling-resistance) tires, 1253
LLVW (lightly loaded vehicle weight), 1020
LNG (liquefied natural gas), 774
Load, 428
engine bearing, 376
Load capacity, tire inflation related, 1270
Load-carrying ball joints, 1300
Load detection, MAP sensor signals, 837
Loaded calipers, 1134
package shown, 1136
Loaded mode test, 921
Load index, 1246
Load test, battery, 547
Lobe, 319
Lobe centers, 324–325
angle and overlap, 324
Lobe displacement angle (LDA), 324
Lobe lift, 319–320
base circle, 319
ramps on, 320
Lobe separation, 324
effects on valve operation, 325
Lobe separation angle (LSA) formula, 324
Lobe spread, 324
Local interconnect network (LIN), 534
Location of connections, 482
Lock housing, 1362–1363
Locking hubs, 1534
cutaway view, 1535
diagnosing and servicing, 1544–1545
Dualmatic® manual locking hub, 1545
Locking nuts, 63
for starters, 571
Locking pin, 334
oil pressure, 335
Locking pliers, 74
Lockout switch, 664
Lock plate, 1363
Lock-ring pliers, 75
Lock rings, 342
replacement, 349
Locks (valve keepers), 294
operation, 300
Lock tang, 474
Lockup torque converter, 1556–1557
LOCs (light-off converters), 950
Loctite®, 60, 242, 389
cast cover installation, 407
Lodestone, 498
Logic circuit, 813, 817
Logic high, 519
Logic low, 519
Logic probe, 446
Long block, 262
Longitudinal mounting, 149, 151
Long-range radar (LRR), 662
Long-term memory (KAM), 959
Loose terminals, 429, 431
LOT (light-off time), 855
Loud knocking noises, diagnosing, 240–241
Loudspeakers, 702–704
Low-authority sensors, 843
Low brake pedals, 1037, 1109, 1201
Low coolant level, 740
Low-drag calipers, 1125
Low emission vehicle (LEV), 919
Low fuel indicator light, 627
Low-pass filter, 705
Low position, automatic transmission, 1558
Low pressure, in air conditioning, 743
Low-pressure cycling switch, 744
Low-pressure gas, air conditioning, 715
Low-pressure gauge, air conditioning, 740
Low range, 1539
Low-side drivers (LSDs), 817
Low-side pressure, 741
Low tire pressure warning lamps, 1217
Low-water-loss batteries, 538
LPG (liquified petroleum gas or propane), 772
LP-gas, 772
LRO (lateral runout), 1166
LRR, 1253
LSA (lobe separation angle) formula, 324
Lube oil, 1569
Lube tech/quick service technician, 10
Lubricants, tire mounting, 1272, 1273
Lubricating oil passages, 285
engine block, 354
Lubrication
both pressure and splash (diagram), 217
boundary, 211
camshaft, 316
Chryster Hemi, 328
differentials, 1532
engine break-in, 418
EP lubricants, 1484
factory service manuals, 72, 121
gear lubrication, 1487
hydrodynamic, 211
oil pump gears, 407
overhead valve (OHV) engine, 328
prelubricating the engine, 409
valve train, 328–329
Lubrication checklist, 1109
Lubrication guides, 71, 120
Lubrication system, 5
diagram, 148
engine lubrication systems, 211–212
introduction, 211
operation, 148
principles, 211
purposes of, 211
Lubrication system principles, 211
hydrodynamic lubrication, 211
purpose and function, 211
Lugging, 419
Lug nuts, wheel, 1257–1258
star pattern, 1273
tightening, 1273–1274
tools for, 1274
Lug studs, 1257
Lumbar, 667
Lung cancer, 49

M

M & S tires, 1250
M85, 772
Machining, as term, 1175
Machining brake drums and rotors, 1157–1194
brake drum and rotor damage, 1158–1159
brake drum distortion, 1159–1161
brake drum types, 1158
disc brake rotor distortion, 1166–1167
disc brake rotors, 1164–1166
disc brake rotor thickness, 1167
drum machining step-by-step, 1176–1181
"machine to" *versus* "discard," 1161–1162
machining brake drums (steps), 1162–1163
machining disc brake rotors, 1170–1174
on-the-vehicle lathe step-by-step, 1190–1194
on-the-vehicle rotor machining, 1175
removing drums, 1161
rotor finish, 1168–1169
rotor machining step-by-step, 1182–1189
when rotors should be machined, 1167–1168
MacPherson struts, 1306, 1314
described, 467–468
magnetic alignment head, 1427
MSI, 1421
replacement, 1324–1325
shown, 1310
MAF (mass airflow) sensors
analog versus digital, 841
burn-off circuit, 841
checking hose, 843
contamination, 844
definition, 840
dirty MAF sensor story, 842
DTCs, 844
false air, 843
five-wire unit shown, 841
high-authority sensors, 843
rationality testing, 829
testing, 842–843
types, 840–842
unplug it test, 844
MAF sensor contamination, 844
Magic circle for calculating electricity-related units, 433
Magnasteer, 1398–1399
Magnetically controlled vane phaser, 332–333
Magnetically-trigged-type sensor, 1266
Magnetic bubble-type camber/caster gauge, 1427
Magnetic crack detection, 276
inspection equipment, 276
lines of force broken, 276
Magnetic crankshaft position sensors, 784
AC coupling, 462
variable field strength, 785
Magnetic crankshaft sensors, AC coupling position, 462

Magnetic fields
alternator, 583
rotors, 580
soldering gun, 635
starter motor, 558–559, 559
strength, measuring, 558
Magnetic flux, 498
Magnetic flux density, 501
Magnetic induction, 499
Magnetic mount for dial indicator, 103
Magnetic pickup tool, 796
Magnetic pulse alternator, 784
operational diagram, 784
Magnetic sensor, 784
testing, 796–798, 806
Magnetic sensors, 446
Magnetic tray, 43
Magnetic-type camshaft position (CMP), permeability characteristic, 499
Magnetic vehicle speed sensors, AC coupling, 462
Magnetic wheel speed sensors, AC coupling, 462
Magnetism
attracting or repelling, 499
definition, 498
electricity and, 500
fundamentals, 498–500
lines of force, 498
magnetic induction, 499
magnetizing a steel needle, 499
permeability, 499
reluctance, 499–500
residual magnetism, 499
as source of electricity, 426
Magnetite, 498
Magneto-rheological (MR) suspension, 1355–1356
Magnets, cracked or broken, 498
Magnuson-Moss Act (1975), 136
Mag wheels, 1256
unsprung weight, 1290
Main bearing
correcting clearance, 394
lip seal installation, 395
measuring clearance, 394
touching with bare hands, 394
typical set, 394
Main bearing bores, 356
checking alignment, 358
telescoping gauge, 357
warpage, 357
Main bearing caps, 355
bowing downward, 356
four-bolt, 355
girdle, 355
support bolts, 356
two-bolt, 355
Main bearing housing bore alignment, 356–357
procedure, 356–357
Main-bearing knock noise, 240
Main bearing loads, 376
Main bearing saddles, 389
Main bearing studs, V-8 engine, 389
Main bearing tightening procedure, 396
Main drive pinion assembly, 1476
Main gear, 1476
Mainline pressure, 1570
Main shaft, 1476
“Christmas tree” assembly, 1477
Maintenance, factory service manuals, 72, 121
Maintenance-free battery
definition, 538
electrolytes, 540
Maintenance reminder lamps, 642
owner’s manual, 120
Maintenance required warning light, 625–626
Maintenance schedule, 120
Major overhauls, 262
Major splice, of tire, 1242
Major thrust side, 341
Major thrust surface, 340
power stroke shown, 341
Malfunction indicator lamp (MIL), 958
Malfunction indicator light (MIL), 5
Malleable iron, 367
Mallets, 73
Manifold absolute pressure (MAP) sensor, 816
altitude impact, 836
barometric pressure changes with altitude, 837
ceramic disk MAP sensor, 836
construction, 834–835
defective vacuum hose, 838
definition, 834
DTCs, 839
fuel delivery, 877
high vacuum, applying, 838
PCM inputs, 1580
PCM uses, 835–837
rationality testing, 829
showing three wires, 835
voltage chart showing altitude, 837
Manifold absolute pressure (MAP) sensor testing
using a DMM or scope, 838
using scan tool, 838
Manifold pressure, measuring, 411
Manual bleeding, 1063–1064
Manual brake bleeding, 1063
Manual locking hubs, 1535
Manual transaxle
construction, 1482
cutaway view, 1483
Dodge/Plymouth Neon, 1483
Manual transmission
ASE task list, 38
check fill plug first, 144
final-drive gear ratios, 1537
hard-to-shift problems, 1485–1486
headless bolt trick, 416
installation, 1486–1487
NV-1500 service, 1488–1490
SAE content area, 7
service tips, 1484
torque flow through, 1476–1477
Manual transmission fluid
procedure for checking, 144
types, 144
Manual transmission gear lubrication, 1487
Manual transmission installation, 415–416
Manual valve, 1577
Manufacturer’s suggested retail price (MSRP), 4
MAP (manifold absolute pressure) sensor
altitude impact, 836
capacitor-capsule MAP sensor, 834–835
ceramic disk MAP sensor, 836
construction, 834–835
defective vacuum hose, 838
definition, 834
DTCs, 839
fuel delivery, 877
high vacuum, applying, 838
PCM uses, 835–837
rationality testing, 829
showing three wires, 835
silicon diaphragm strain gauge map sensor, 834
for training purposes, 834
as vacuum gauge, 836
voltage chart showing altitude, 837
MAP (manifold absolute pressure) sensor testing
types of test instruments, 838
using a DMM or scope, 838
using a scan tool, 838
Marcel spring, 1457
shown, 1458
Margin, 301
Marine cranking amperes (MCA), 543
Marking driveshaft for removal, 1504
“Married” type ignition coils, 505
Martensite, 59
Masking tape trick, 1109
Mass, 109, 841
Mass air flow, 876
Mass airflow (MAF) sensor, PCM inputs, 1580
Mass airflow (MAF) sensors, 451
air cleaner housing, 220
analog versus digital, 841
burn-off circuit, 841
checking hose, 843
computer input, 816
contamination, 844
definition, 840
dirty MAF sensor story, 842
DTCs, 844
false air, 843
five-wire unit shown, 841
frequency measurements, 451
high-authority sensors, 843
rationality testing, 829
types, 840–842
hot film sensor, 841
hot wire sensor, 841
unplug it test, 844
Mass airflow (MAF) sensor testing, 842
digital meter test, 844
output test, 843
tap test, 844
visual inspection, 842–843
Mass airflow fuel-injection system, 877
formula, 877
Mass flow rate of fuel, 410
Mass merchandisers, 9
Master certified technician, 35
Master control switch, 664
Master cylinders, 1031–1034
bench bleeding, 1039, 1061
bleeding, 1061–1062
diagnosis and troubleshooting, 1037–1038
diagonal split, 1036
dual-split, 1034–1035
installation, 1039
one-drip-per-second test, 1066
operation, 1032–1034
overfilling, 1034
quick take-up, 1036
reservoir diaphragms, 1031–1032
service, 1038–1039
Master technician, 31
Match mounting, 1272
Material safety data sheets (MSDS), 49
Mathematical formulas, 116
Maxi fuses, 471
amperage and colors, 471
Maximum duty cycle, fuel injector, 884
Mazda
coolant, 177
direct fuel injection, 887
Flex Fuel vehicles, 770
how to read VIN, 771
remote keyless programming, 675, 676
Mazda pickup story, 1461
MCA (marine cranking amperes), 543
MDS (multiple displacement system), 335
Measured values, 410–411
Measurements
adding and subtracting, 115
decimals, 115
fractions, 116
fuel economy calculator, 116
mathematical formulas, 116
multiplying and dividing, 116
percentage, 115
scientific notation, 115
Mechanical advantage, 110, 1024
Mechanical cleaning
abrasive pads or discs, 272
media blasting, 273
principles, 272
scraping, 272
Mechanical compression ratio, 229
Mechanical efficiency, as calculated number, 411
Mechanical fade, 1089, 1115
Mechanical force, 147
Mechanical power, 147
Mechanical principles, 109–110, 1023–1024
Mechanical returnless fuel system, 881
diagram, 882
Mechanic’s gloves, 42
Media blasting, 273
Media oriented system transport (MOST) BUS communication, 533
Medical insurance deductions, 21
Medium carbon steel, 113
Medium hybrid, 989
Mega (M), 451
Mega fuses, 473
cause of failure, 473
checking, 473–474
Megohms
digital meter usage, 458
reading DMM displays, 451
Memory
after battery electrical drain test, 553
digital computers, 814
NVRAM (nonvolatile access memory), 637
Memory saver, 554
Memory seat, 667
easy exit seat programming, 667
module showing three-wire potentiometer, 668
Memory steer, 1429–1430
Mentor, 30–31
qualifications of, 31
roles, 30–31
Mercedes
direct fuel injection, 887
ECT sensor, 822
Mercedes-Benz
Flex Fuel vehicles, 770
how to read VIN, 771
lifetime coolant, 181
oil life monitor, 135
oil specifications, 204
precollision system, 662
radar cruise control, 661
timing chain failure, 319
Mercury, battery sizes, 543
Mercury (element), 54, 1196–1197
warning placard location, 48
Mercury
Flex Fuel vehicles, 770
immobilizer or vehicle theft deterrent key learn procedures, 680
remote keyless programming, 675, 676
Mesh spring, 563
Mesothelioma, 49
Metal
procedure for cutting, 90
procedure for heating, 89
Metal fatigue, wheel bearings, 1082
Metal inert gas (MIG) welding trick, 306
Metal oxide semiconductor (MOS) materials (MOSFETs), 517
Metals, relative conductivity chart, 467
Meter accuracy, 455
Metering valve (hold-off) operation, 1046–1048
Metering valve override tools, 1066–1067
Meter lead connections, 452
Meter resolution, 454
Methanol, 771–772
M85, 772
Methanol (methyl alcohol), 760
Methanol to gasoline (MTG), 776
Methanol-to-gasoline (MTG) process, 776
Methyl alcohol. *See* Methanol (methyl alcohol)
Methyl alcohol (methanol), 771–772
Methylcyclopentadienyl manganese tricarbonyl (MMT), 760
Methyl hydrate. *See* Methanol (methyl alcohol)
Methyl hydrate (methanol), 771–772
Methyl tertiary butyl ether (MTBE), 760
Metric bolts, 58
Metric designations
American, 1243
size recommendations, 1243
for tires, 1243
Metric/fractional chart, 1173
Metric system
fasteners, 59
fuel economy calculations, 116
measurements summarized, 98
Newton-meters conversion, 106, 107
temperature conversion chart, 111
Metric wire gauge, 467
conversion chart, 468
MI (Motorola interconnect) BUS protocol, 533
Microbes, 44
Microbial cleaning, 274
tank, 274
Micro-hybrid drive system, 988–989
Microinches (u), 389, 1168
Micrometer, 99–100
calibration with gauge rod, 99
depth micrometer, 104
diagram, 99
dial indicator type, 304
hole gauge, 102
measuring connecting rod journal, 100
measuring valve guide, 290
metric readings, 100
sample readings, 99
Micron, 220
Micron vacuum gauge, 749
shown, 750
Microprocessors, digital, 1214
Midas, 10
Midbass speaker, 704
Midrange speaker, 704
MIG welder seat removal trick, 306
MIL (malfunction indicator lamp), 958
OBD-I requirements, 958
MIL (malfunction indicator light), 5
MIL condition: FLASHING, 961
MIL condition: OFF, 960
MIL condition: ON STEADY, 961
Mild (low carbon) steel, 113
Mildew, 74
Mild hybrid, 989
Milli (m), 451
Millimeter, wide-band oxygen sensor testing, 858
Millimeters of mercury (mm Hg), 1196–1197
Milling, 287
Milling type of resurfacer, 287
Millisecond (ms) sweep, 809
Milliseconds, 462
Millivolts, digital meter usage, 458
Mini converter, 950
Mini Cooper, radar cruise control, 661
Mini fuses, 471
amperage rating and colors, 471
Minimum required alternator output, 593
procedure, 593
purpose, 593
test results, 593
Minimum wet boiling point, 134
MIN/MAX oxygen sensor testing, 851
test chart, 852
Minor overhaul, 262
Minor thrust, 341
Minutes, 324, 1431
Mirrors, heated, 663
Miscible, 135, 198
HVAC, 720
Misfire
diagnosis, 249
General Motors, 328
Misfire monitor, 959
Misfires, MIL on steady, 961
Misfire type A, 959
Misfire type B, 959
Missing Ford story, 850
Mistakes, how to handle, 32
Mitchell On-Demand software, 77, 122
Mitsubishi
direct fuel injection, 887
smart idle stop system (SISS), 891
MLS head gaskets, 381–382
with aluminum, 383

MmHg (millimeters of mercury), 1196–1197
MMT (methylcyclopentadienyl manganese tricarbonyl), 760
Mode $06, diagnosing problems with, 964
Model weight, 1290
Model year (MY), 126
Mode select switch, 1350
Mode shift, 1539
Modified struts, 1308
Modified vehicles, 1447–1448
Modified X method, 1275
Modular fuel sender assembly, 866, 867
  spring loaded, 867
  typical assembly, 867
Modulation, 699
Module communications
  advantages, 524
  configuration, 525
  need for network, 524
  network fundamentals, 524–525
Module current limits, 796
Modules, communication with other computers, 814
Module status test, 534
Mold-bonded linings, 1120
Mold or mildew smell test, 744
Molybdenum disulfide, 317
Molybdenum disulfide (MOS2) grease, 1137
Molybdenum piston rings, 345
  facing width, 345
Moly-chrome-carbide piston rings, 345
Molydisulfide greases, 418
Moly graphite coating, 339
Moly grease, 1502
Molykote grease, 1137
Momentary switch, 484
Monitor enabling criteria, 960–961
Monitors, 959
  CCM, 959
  continuous, 959
  continuous running, 960
  exponentially weighted moving average (EWMA), 960
  misfire, 959
  noncontinuous, 959
  once per trip, 960
Monoblock, 352
Mono leaf, 1296
Monroney label, 4
Monthly expenses, calculating, 22
Montreal Protocol, 719
Morse type timing chain, 317
MOSFETs (metal oxide semiconductor (MOS) materials), 517
MOST (media oriented system transport) BUS communication, 533
Most-likely-type questions, 36
Motor
  actuator, 1349
  electric power steering, 1401
  rear wheel steering, 1377
Motoring mode, 987, 989, 990
Motorola interconnect (MI) BUS protocol, 533
Moveable pole shoe, 564
  starter, 564
MRRTD, 1355
MSDS (material safety data sheets), 49
MSI (MacPherson strut inclination), 1421
MSRP (manufacturer's suggested retail price), 4
Mufflers
  clogged or restricted, 248
  construction, 226
  corroded, 145
  hole location, 226
  holes in, 226
  passage diagram, 240
  purpose and function, 240
Multigrade engine oil, 199
Multigroove adjustable pliers, 73
Multilayered steel (MLS) gaskets, 381–382
  with aluminum, 383
Multipath audio system, 700
Multiple-choice questions, 36
Multiple displacement system (MDS), 335
Multiple-plate clutches, 1572–1574
  exploded view, 1573
Multiplexing, 524
  advantages, 524–525
Multiplying and dividing, 116
Multiport fuel injector, 883
Musschenbroek, Pieter van, 493
Mutual induction, 504
  ignition coils, 504–506

N

NAO (nonasbestos organic), 1121
NAPA parts store, 9
Narrow band oxygen sensor, 846
Narrowing the valve seat, 304–305
Narrow parting line, 346
NAS (nonasbestos synthetic), 1121
National Automotive Service Task Force, Web site help, 26
National Institute for Automotive Service Excellence (SAE)
  certification tests, 34–40
  contact information, 35
  eight tests, 6–7
  logo, 35
  registration for tests, 35
  steel numbering designations, 113
  test registration booklet, 7
National Lubricating Grease Institute (NGLI), 1073
National Lubricating Grease Institute (NLGI), grease numbers, 143
Natural frequency, 1117
Natural gas vehicles (NGVs), 772
Naturally aspirated, 151, 228
  airflow requirements, 228
  volumetric efficiency, 228
Navigation enhanced climate control, 639
Navigation system
  background, 637
  backup camera view, 640
  diagnosis and service, 638–639
  GPS, 637
  parts and operation, 638
  screen display, 639
  touch screen, 638
  troubleshooting, 639
  typical display, 638
N.C. (normally closed output), 484
  definition, 484
Needle-dial brake drum micrometer, 1162
Needle-nose pliers, 74
Needle rollers, 1071
Negative backpressure, 936
Negative camber, 1414
Negative caster, 1417
Negative O2S voltage, causes, 851
Negative offset, wheel, 1255
Negative-phase mode, 1375
Negative slope, 464–465
Negative temperature coefficient (NTC), 819
Negative temperature coefficient (NTC) sensor, 825
Negative temperature coefficient (NTC) thermistor, 515, 825
Nernst cell, 855–856. *See also* Oxygen sensor (O2S)
Nernst, Walter, 855
Net earnings, 21
Network, 524
  diagnosis, 534–536
  fundamentals, 524–525
  module communications, 525
  types of, 524–525
Neutral, 1480
  automatic transmission, 1558
Neutral charge, 421
Neutral safety switch, 557
Neutrons, 421
New car prep, 10–11
New engines, 263
Newton-meters conversion, 106, 107
Newton's first law of motion, 108
  inertia, 109
Newton, Sir Isaac, 108
Newton's laws of motion, 108
New vehicle preparation for delivery, 10–11
New vehicle sales person, 14
New Venture 241 transfer case shown, 1538
NGLI (National Lubricating Grease Institute), 1073
NGVs, 772
Nibs, 1091
Nippondenso fuel injectors, 883
Nissan
  battery sizes, 543
  ECT sensor, 822
  Flex Fuel vehicles, 770
  how to read VIN, 771
  lane departure prevention (LDP) system, 641
  optical sensor testing, 799
  remote keyless programming, 677
  removing air from lifter, 405
  variable camshaft timing, 330
Nitriding, 366
Nitrile gloves, 41
Nitrile stem seal material, 309
Nitrogen gas pressurization, 932
  emission tester, 933
Nitrogen inflation, 1270, 1271
  special green cap, 1271
Nitrous bottles
  angles for, 236
  electric warming blankets for, 236
Nitrous oxide (N20), 235
  engine changes needed, 236
  engine power adder, 235
  pressure and temperature, 235
  principles, 235
  system installation and calibration, 236
  temperature/pressure chart, 235
  wet and dry system, 235–236
Nitrous oxide injection system, precautions, 236
NLEV (national low-emission vehicle), 127
NLGI grease numbers, 143
NMHC (non-methane hydrocarbon), 923
N.O. (normally open output), 484
  definition, 484
Node, 524, 525
Nodular iron, 367
Noid, use of term, 903
Noid light, 903–904
  precautions with, 904
Noise, 1209
  audio noise summary, 710
  audio noise symptom chart, 710
  bearings, 1074
  capacitors for filtering, 495
  clutch-related, 1462, 1467
  disc brake squeal, 1137
  drum brakes, 1110
  engine, 240–241
  radio-frequency interference, 700
  rear end diagnosis, 1525
  signal-to-noise ratio, 706
  sniffer construction, 709
Noise and vibration, acceleration only, 1513
Noise issues, GDI systems, 891
Nonasbestos friction material, 1121
Nonasbestos organic (NAO), 1121
Nonasbestos synthetic (NAS), 1121
Nonchecking, 880
Noncondensable gas, 748–749
  recycling, 749
Noncontinuous monitors, 959
Non-dealership flat-rate, 28
Nondirectional finish, 1172
Nondirectional finish tools, 1172
Non-English speaking clients
  Internet translation tools, 26
  speaking with, 28
Nonenhanced evaporative (EVAP) control systems, 929–930
Nonhardening sealers, 386
  trade names, 386
Nonhunting gear sets, 1519
Nonhygroscopic fluid, 1052
Non-indicator ball joints, 1318–1320
Nonintegral ABS, 1211–1212
  location shown, 1212
Non-load-carrying ball joints, 1300
Non-methane hydrocarbon (NMHC), 923
Nonplanetary gear set, 1561
Nonpowered test lights, 445
Nonprincipal end, 152
Non-replaceable ball joints, 1321
Non-servo brake design, 1094–1095
Non-servo brake starwheel automatic adjusters, 1098–1099
Nonsinusoidal, 453
Nonsynchronized throttle-body fuel-injection, 877
Nonverbal communication, 25
Nonvolatile access memory (NVRAM), 637
Nonvolatile RAM, 814
No-retorque-type gaskets, 381
Normally aspirated, 228
  airflow requirements, 228
  volumetric efficiency, 228
Normal operating temperature, 418
Nose end, 1035
No-spark (intermittent spark) condition
  causes, 794
  symptom guide, 811
No-start condition
  Chevrolet pickup V-8, 798
  diagnosis, 806
  electronic fuel-injection systems, 902
  ignition system diagnosis, 794–795
  inoperative electric fuel pump, 870
  radio shorted-to-ground, 535
  tachometer trick, 785
No-start diagnosis, 806
Notched wheel, permeability characteristic, 500
NOx. *See also* Oxides of nitrogen (Nox)
NOx emissions, 5
NOx reduction standards
  exhaust cam phasing, 331
  failure, 332
NPN transistor, 516
NTC (negative temperature coefficient) thermistor, 515, 825
N-type material, 509
  diodes, 511
  transistor symbol arrow, 516
Nuts, 60
  damaged heads, 76–77
  jam (pal), 63
  locking, 63
Nut splitter, 76
NV231 transfer case, 1541, 1542
NV-242 transfer case service, 1546–1549
NV-350 transaxle service, 1491–1493
NV-1500 manual transmission service, 1488–1490
NVRAM (nonvolatile access memory), 637

O

OAD (overrunning alternator dampener), 578–579
  failure, causes of, 579
  purpose, 579
  special installation equipment, 579
  special tool, 580
OAP (overrunning alternator pulley), 578–579
  exploded view, 579
  failure, causes of, 579
  purpose, 579
  special installation equipment, 579
OAT (organic acid technology), 176–177
OAT sensor, 732
OBD (on-board diagnosis), 958
OBD-I
  California requirements, 958
  data link connector (Ford), 529
  Ford vehicles, 529
OBD-II, 953
  global, 964
  objectives, 958
OBD-II (onboard diagnosis second generation), 5, 813
  16 pin DLC, 536
  background, 958
  catalytic converter monitor, 850, 951
  catalytic converter performance, 950–951
  DLC (data link connector), 536
  enhanced evaporative control systems, 930
  location of terminals, 533
  testing, 922
OBD-II drive cycle, 977, 981
OBD-II DTC numbering designation, 961–962
OBD-II EGR monitoring strategies
  delta pressure feedback EGR (DPFE) sensor, 939
  MAP sensor as EGR monitor, 939
  OBD-II active test, 940
  oxygen in exhaust, 939
  purpose and function, 938–939
OBD-II freeze frame data, 958, 962
OBD-II monitor information, 959–960
OBD-II scan tool, dual cell diagnosis, 856–857
Occupant detection system (ODS), 695
  diagnosis, 696
  purpose and function, 695
  test weight, 696
  types of seat sensor, 696
Occupational Health and Safety Act (OSHA), 48, 49–50
Octane improver additives, 760
Octane rating, 758
  antiknock properties, 758
  high-altitude, 759
OCV (oil control valve), 330–331
Odometer
  electronic, 636–637
  mechanical, 636
  memory chip, 814
  purpose and function, 636–637
  service, 637
  speedometer/odometer service, 637
  tire size related, 1245
ODS (occupant detection system), 695–696
OEM parts, 136
Offset crankshaft, 369
  crank throw, 370
Offset left aviation snips, 75
Offset right aviation snips, 75
Offset screwdrivers, 72
Offset, wheel, 1254–1255
OHC (overhead camshaft) design, 4
OHC (overhead camshaft) engine disassembly, 265
Ohm, George Simon, 425, 431
Ohmmeter, 425
  antenna testing, 702
  coil shorted to ground, 796
  definition, 447
  ignition coil testing, 795
  light bulbs, 608
  measuring injector resistance, 905
  measuring resistance, 447–448
  reading digital meter displays, 453
  setup for testing ignition coil, 796, 798
  solenoid check, 570
  stator winding readings, 595
  testing alternator rotor, 595
  testing diodes and transistors, 520
  voltage applied by, 448
  zero ohms, 448
Ohmmeter method (short circuits), 490
Ohms
  definition, 425
  digital meter usage, 457
  reading DMM displays, 451
Ohm's law, 431
  applied to simple circuits, 432
  examples, 437
  formulas, 431–432

"magic circle" of most formulas, 433
relationship with three units of electricity, 432
series circuits, 434–435
OHV (cam-in-block) engine, variable timing, 331–332
OHV (cam-in-block) engine disassembly, 264–265
camshaft location, 328
camshaft removal, 328–329
cylinder heads, 267–268
Oil burning, KISS test method, 242
Oil change
dirty oil impact, 202
fleet vehicles, 206
Ford diesel engines, 163
intervals, 204–205
monitoring systems, 205
oil life monitors, 205
procedure, 205–206
by seasons, 206
step-by-step, 207–209
three facts, 200
used engine oil precautions, 205
warning lamp, 206
Oil change monitoring systems
algorithm, 205
mileage only, 205
Oil condition sensor, 135
Oil consumption excessive
timing chain replacement, 320
valve leakage, 308
valve stem-to-guide clearance, 289
Oil control rings, 343
installation, 349
typical three-piece, 343
Oil control valve (OCV), 330–331
magnetically controlled vane phaser, 332–333
vane phaser system, 332
Oil coolers, 218
oil filter adaptor, 218
Oil drain plug gasket, 205
Oil filter, 5
antidrainback valve, 204
antidrainback valve rubber diaphragm, 204
bypass valve, 204
construction, 204
dirt trapped by, 205
disposal, 205
removal (pick trick), 206
spin-on, cutaway view, 205
Oil filter disposal, 204
filter crusher, 205
Oil filter valves, 204
Oil fouling, 803
Oil galleries, 5, 148, 354
cleaning, 393
Oil gallery plugs, 354
Chevrolet V-8, 355
left off, 409
removal, 268
Oil groove, 379
annular, 379
Oil leaks
before clutch replacement, 1460
black light to spot, 240
blue exhaust smoke, 238
checking with engine off, 944
fluorescent dye, 240
foot powder spray trick, 240
timing belt failure, 318
visual inspection, 239–240
where they appear, 239
Oil level, 135
MIN/MAX marks, 135
Oil level and condition, visual inspection, 238
Oil level indicator, 134
typical, 135
Oil life computer program, 135
Oil life monitor, 135
Oil pan, 5
bolts, 379
checking clearance, 408
gasket rail surface, 408
installation, 408
purpose and function, 217
removal, 266
typical, 217
Oil pan gaskets
leak, 239
RCM gaskets, 384
Oil passage
overhead camshaft engine, 216
purpose and function, 215–216
valve train lubrication, 216–217
Oil passage check valve, 409
Oil pressure
factors affecting, 213–214
locking pin, 335
measuring, 411
normal, 211–212
regulation by oil pump, 213
VTEC system, 335
Oil pressure gauge
on dashboard, 212
fabrication, 241
Oil pressure sending (sender) unit location, 241
Oil pressure testing, 241–242
gauge use, 241
Oil pressure warning lamp, 242
"engine" dash light, 249
Oil pump, 5
capacity and oil pressure, 214
checks, 214–215
debris in, 214
driven by camshaft, 213
drive or distributor shaft problems, 215
factors affecting oil pressure, 213–214
failure of new, 408
as "garbage pit" of engine, 214
high-pressure or high-volume, 214
installation, 407
oil pressure regulation, 213
parts and operation, 212
purpose and function, 212
types of, 212–214
external gear type, 212
gerotor type, 213
internal/external gear type, 213
positive displacement, 212–213
rotor type, 213
typical clearances, 214
visual inspection, 214
Oil pump gears, 407
Oil pump pickup
modeling clay to measure, 408
screen clogged, 214
Oil pump pickup to oil pan clearance, 408
Oil pump rotor, measuring, 104
Oil pumps, positive displacement pumps, 212–213
Oil recycling companies, 205
Oil return (drain) line, clogged, 235
Oil return holes, 285
Oil seals
materials, 385
purpose and function, 385
rear main seal, 385
Oil service reminder light, resetting, 642
Oil sump, 5
Oil temperature, 212
run-to-run comparisons, 411
Oil, used, 50–51
Oil/vapor separator, 942–943
Oil/water separator, 942–943
OL (over limit or overload)
digital meter displays, 448
reading display, 451
Oldsmobile, 2
Olds, Ransom E., 1
On-board diagnosis (OBD), 958
Onboard diagnosis second generation. *See* OBD-II
On-board diagnostics, 5
On-Board Diagnostics (OBDs), 958
Onboard refueling vapor recovery (ORVR), 861, 931
reduced-size fill tube, 861
Once per trip monitors, 960
One-filament stop/turn bulbs. *See also* Single-filament bulb
turn signals, 610
One-speed and two-speed idle test, 921
"One to three" clearance, 395
One-way clutches, 1575–1576
checking, 1605
installation, 1576
roller clutch, 1575
sprag clutch, 1575–1576
One-way roller clutch, 1555, 1575
installation, 1606
One-way sprag clutch, 1575
One-way valve, 1576
One-wire oxygen sensor, 848
On-off solenoids, 1581
OnStar
aggressive driving, 697
diagnosis and service, 640
location of three-button control, 639
monitoring location, 639
parts and operation, 639–640
On-the-job (OTJ) training
apprentice programs, 17
first day on the job, 27
lube technician, 10
On-the-vehicle lathes
step-by-step, 1190–1194
wheel removal, 1175
On-vehicle rotor machining, 1175, 1190–1194
Opacity, 174
test, 174
Op-amps (operational amplifiers), 519
Open circuit, 429–430
common causes, 429
current flow behavior, 429
definition, 486
procedure to locate, 487
schematic, 429
series circuit, 434
Open circuit battery voltage test, 546–547
Open circuit voltage, 546
Open differential, 1519–1520
Open-end wrenches, 68
tire repair, 1282
Open-loop operation, 849
Open loop operation, 849
Operational amplifiers (op-amps), 519
Opposite-phase steering, 1375
Opposite the whitewall, 1251
Optical distributors, 786
cutaway view, 786
light shield installation, 787
one-degree slits, 786
Optical headlight aiming, 622–623
Optical sensors, 785
testing, 799
visual inspection, 799
Orange conduit, 478
Orbital steer, 1382
Organic acid technology (OAT), 176–177
Orifice-controlled PCV systems, 943
Orifices, separator plate, 1577
Orifice tube system, 716
accumulator, 722–723
assortment shown, 743
clogged orifice shown, 742
clogged orifice tube test, 742
examples of colors and sizes (chart), 751
fixed-orifice tubes, 725
orifice tube location, 727
receiver-drier shown, 723
service, 753
touch, feel test, 743
typical, 718
Orifice tube system diagnosis, touch, feel test, 743
Orifice tube system service, 753
Original equipment (OE) parts, 29, 136
O-rings, 163
location on Ford PowerStroke diesel engine, 163
symptoms of trouble, 163
O-ring seal, 747
O-rings shown, 748
replacement, 747–748
O-ring valve stem seal, 308–309
installation, 309
ORVR (onboard refueling vapor recovery), 861, 931
reduced-size fill tube, 861
OS (oversize) stems, 290–291
Oscilloscopes. *See also* Digital oscilloscope; Digital storage oscilloscope (DSO)
ABS, 1228
COP system, 811
definition, 461
display grid, 461
fuel injector testing, 907–908
MAP sensor testing, 838
number of channels, 464
optical sensor testing, 799
setup and adjustments, 462
test leads, 465
TP sensor testing, 830
triggers, 464–465
types of, 461
using, 465
waste-spark system, 811
OSHA (Occupational Health and Safety Act), 48, 49–50
OSHA-approved air nozzles, 82
Otto four-stroke cycle machine, 1
Otto, Nicholas, 1, 149
0 "Ought" gauge, 469
Outer cups, 1072
Outer rings, 1072
Outer wheel bearings, 1072
Out-of-round drums, 1160
Output, 1343
Output drivers, 817
Output member, 1541
automatic transmission, 1559
Output shaft, 1476
Output test, MAF sensor, 843
Outside air temperature (OAT) sensor, 732
Outside folding mirrors, 670–671
electric mirror control, 671
in folded position, 671
haunted mirror story, 671
Overcenter adjustment, 1367
Overcharging batteries, 542, 550
Overdrive, 117
Overdrive (OD), 1474
automatic transmission, 1558
Overdrive first, 1582
Overdrive fourth, 1583–1584
Overdrive second, 1582–1583
Overdrive third, 1583
Overhang, 302
Overhauling the engine
major, 262
minor, 262
Overhead camshaft (OHC) design, 4
camshaft bearings, 379–380
camshaft installation, 400–401
camshaft location, 315
engine disassembly, 265, 285
lip seal installation, 394–395
noisy, 328
oil passage check valve, 409
oil passages, 216
terminology, 323
valve lash adjusting shims, 401
valve train assembly, 404–405
Overhead camshaft (OHC) engine disassembly, 265, 285
bearings layouts, 285
loosening bearing caps, 286
valve seats and guides, 281
Overhead valve (OHV), 150, 315
cutaway of V-8 engine, 151
design, 4
lubricating oil, 285
lubrication, 328–329
stud-mounted rocker arms, 321
valve stem seals, 308
Overheating
air dam broken, 746
common causes of, 194
coolant overflow container boiling, 194
engine failure and, 182
at highway speeds, 194, 197
quick and easy diagnosis, 197
thermostat removal precautions, 185
Overlap, 229
Overlay, 375
Overrunning alternator dampener (OAD)
exploded view, 244
low or no alternator output, 590
special tool, 580
Overrunning clutch, 563
operational diagram, 563
Oversize (OS) stems, 290–291
Oversteer, 1233, 1274
Over-travel springs, 1097
Overvoltage protection for hybrid electric vehicles, 454
Owner manuals, 71, 120
free downloads, 72, 120
key to proper operation, 120
proper operation, 72
Oxides of nitrogen (Nox)
burning or watery eyes, 925
catalytic converter role, 951
clogged EGR passages, 940
EGR control of, 936
emissions, 5
excessive, causes of, 926
exhaust analysis, 923–924
high, causes and correction, 926
specifications, 926
testing for, 926
Oxygen (O2)
exhaust analysis, 923
measuring, 925
Oxygenated fuels, 760
storage life, 771
Oxygen level test, 953
Oxygen sensor (O2S), 846
bias voltage, 848
closed loop and open loop, 849
computer input sensor, 816
construction and operation, 846
diagnosis, 850–853
different designs, 846
DTCs, 859
DTC troubleshooting, 859
exhaust system back pressure, 248
false rich indication, 851
front and rear connector switched, 848
fuel trim, 849–850
heater circuits, 848
high O2S readings, 851
how voltage is generated (view), 846
IAT-type coolant replacement, 194
location, 846
low O2S readings, 851
with low pulse width, 926
narrow band, 846
numbering and location, 849
pending monitor, 963
poor ground connection, 850
pulse width, 878
purpose and function, 846
room temperature vulcanization (RTV) sealers, 853
stoichiometric air-fuel ratio response, 848
visual inspection, 850
volts per division (*V/div*), 462
wide-band, 854
Oxygen sensor (O2S) testing
false rich signal, 851
KOEO, 851
KOEO test, 851
post catalytic converter oxygen sensor, 853
propane oxygen sensor test, 853

using a digital voltmeter, 850–851
using a scan tool, 851–852
using a scope, 852–853
using MIN/MAX method, 851
Oxygen sensor waveform analysis, 853, 854
frequency, 851–852
good reading, 854
rapid switching, 851–852, 853
Oxygen sensor wires, 851
Oxygen storage capacity (OSC), 950
Ozone, 925
depletion process shown, 719
refrigerants, 718, 719

P

P0128 diagnostic trouble code (DTC), 182
P0521 diagnostic trouble code (DTC), wrong oil viscosity, 200
Pacific fuse element, 471
Pads
brake, 1118–1122
bedding-in, 1136–1137
reaction, 1134
shoe support, 1089
Pad wear indicators, 1119
PAG oil, 720
Painting the engine, 409
Palladium, 949
Pal nuts, 63
Pancake engine design, 149
Panhard rod, 1310, 1337
Pan removal, 1594–1595
PAO, 1137
Paper test, 242
Paper towel test, 138
Parallel circuits
calculation examples, 440–441
capacitors in, 496–497
current flow (amperes), 439
definition, 438
determining total resistance, 438–440
electronic calculators, 439
laws, 438
total resistance, 440–441
voltage drop, 440–441
Parallel flow coolant system, 190
Parallel hybrid, 986
Parallelism, 1167, 1380
Parallelogram linkage, 1372, 1373
replacement, 1382–1384
Parameter identification (PID), 964
Parasitic load test, 552–553
Parasitic load tool, 553
Parking brake
before parking pawl, 1581
disc brake performance, 1118
ratchet mechanism, 1145, 1146
rear disc brake caliper, 1118
typical cable system, 1145
typical hand-operated, 1146
Parking brake cables, 1148, 1149
adjustment, 1153, 1155, 1155–1156
lubricating precautions, 145
removal, 1156
Parking brake click test, 1155
Parking brake linkages, 1094, 1147–1149
Parking brake operation, diagnosis, and service, 1145–1156
caliper-actuated disc parking brakes, 1150–1153
drum parking brakes, 1149–1150
electric parking brakes, 1156
front and rear entry parking brake cables, 1149
parking brake cable adjustment, 1153, 1155–1156
parking brake linkages, 1147–1149
parking brake standards, 1145
parking brake warning lamps, 1147
pedals, levers, and handles, 1145–1147
Parking brake pedals, 1146–1147
typical assembly, 1146
Parking brake release, 1147
Parking brakes
apply system and, 1017
drum brakes, 1089
FMVSS 135 brake test, 1020
rear disc, 1126–1127
red brake dash warning lamp and, 1043
standards, 1145
as term, 1145
Parking brake trick, 1160
Parking brake warning lamps, 1147
Parking lamps, bulb trade numbers, 606
Park position, automatic transmission, 1557
Partially nonhunting gear sets, 1519
Particulate matter (PM), 168
relative size, 168
standards, 168
Partitions, battery, 539–540
Parts
aftermarket, 29–30
major brand gasket company, 309
off the floor, 31–32
original boxes for, 29
original equipment (OE), 29
rebuilt, 30
remanufactured, 30
renewal, 29–32
used, 30
Parts and time guides, 28, 122
definition, 76
exploded engine view, 73, 121
Parts counter person, 13
Parts manager, 13
Parts replacement, 29–30
Parts washer, 275
Part-time employment, 17
Part-time four-wheel drive, 1534
transfer case, 1539
Pascal's law, 1028–1031, 1388
"Pass-by" noise limits, 1247
Passenger presence system (PPS), 695–696
Passenger seat sensor, 693
PASS fire extinguisher procedure, 45
Passivation, 181
Path of least resistance, 438
Pawl, 1097
Pax run-flat tires, 1252–1253
unique components shown, 1253
PCI (programmable controller interface), 530
PCMs. *See* Powertrain control modules
PCM sensor
defective, signs, 1594
fast learn, 1608–1609
PCV (positive crankcase ventilation), 5
plugged, and gasket failure, 384
testing, 943
PCV (positive crankcase ventilation) system diagnosis
3 X 5 card test, 944
crankcase vacuum test, 944
DTCs, 945
PCV monitor, 945
rattle test, 944
snap-back test, 944
symptoms, 943
system performance check, 944
PCV (positive crankcase ventilation) systems, 942
checking oil leaks, 944
PCV (pressure control valve), 882
PCV hose, 137
PCV monitor, 945
PCV valve with fastener, 945
PCV system performance check, 944
PCV system testing, 947
PCV valves, 5
airflows, 943
backfire operation shown, 943
crankcase ventilation, 943
ice blockage prevention, 945
spring-operated plunger, 943
whistling engine noise, 944
wires at, 945
Peak-and-hold injector drive circuit, 908
typical waveforms, 908
Peak inverse voltage (PIV), 513
Peak power, 706
Peak reverse voltage (PRV), 513
Pedal ratio, 110, 1024
Pedals. *See* Brake pedals
Pedestal-mounted grinders, 84
Pedestal-mounted rocker arms, 321
valve lash, 321
Peen, 73
PE-HD plastic, 112, 113
Peltier effect, 425
heated and cooled seats, 669
Peltier, Jean Charles Athanese, 425, 669
Pending, 963
Pending codes, 963
Penetrating oil, 64, 76
Penetration test, 143
Pentroof combustion chamber, 283
Pentroof design, 282
four valves shown, 283
operation, 283
Percentage, 115
Perforated steel core gaskets, 381
with nonstick coating, 383
typical, 382
Performance
aftermarket air filter, 226
EVAP system problems, 932
racing manifolds, 222
seat duration related, 330
Performance. *See also* High-performance; V-type engines
smaller diameter pulley, 231
smaller torque converter for, 1557
Performance problems
cracked exhaust manifold, 225
Toyota, 792
valve seat recession, 298
Perform ride mode, 1352
Perimeter frame, 1289
Peripheral pump, 866
Permanent magnet (PM) motors, 560, 664
power antenna, 701–702
power seat, 666–668
power windows, 664–665
Permanent magnet (PM) sensors, 635–636
Permanent magnet fields, 561
Permeability, 499
Personal protective equipment (PPE), 41–42
hazardous materials, 48
service work, 131
Pet-friendly antifreeze, 177
Petrodiesel, 780
Petroleum, 754
PFE sensor, 938
PH, 273
PH coolant testing, 180
meter for measuring, 180
Phenolic caliper pistons, 1130–1131
inspection, 1132
Phillips, Henry F., 72
Phillips screwdrivers, 72
PHOAT (phosphate hybrid organic acid technology), 177
Phosphor, 633
Photocell, 1343
Photochemical smog formation, 925
Photodiodes, 514, 732
construction, 514
purpose and function, 514
schematic symbol, 514
Photoelectricity, 426
Photons, 514
Photoresistors, 514–515
schematic symbol, 515
Phototransistor, 518, 1343
PH scale, 111–112
Physical vapor deposition (PVD), 345
Physics, laws of, 1023, 1210
Picket fencing, 700
Pickle forks, 1383
ball joint removal, 1320
steering service, 1382
tie rod ends, 1510
Picks for releasing terminal from connector, 475
Pick trick for oil filters, 206
Pickup coil, 446, 784
AC voltage output, 798
magnetic sensor testing, 796–798
showing how waveform created, 798
tachometer trick, 785
waveforms and speed related, 798
PID (parameter identification), 964
Piece of paper demonstration, 402
Piezoelectricity, 426
Piezoresistivity, definition, 834
Pigs in pipelines, 755
Pike's Peak brake inspection, 1054
Pillars, 3
Pilot bearing, 415, 1455, 1460–1461
replacement, packing, 1461
squealing noise, 1462
Pilot bushing, 1460–1461
Piloting surfaces, 346
Pilot operated absolute (POA) valve, 718
Pin bushings, 1507
Pinch bolt, 1510
Pinch bolt ball joints, 1321
Pinch weld seams, 92
Ping, 758
knock sensors, 791–792
octane rating related, 760
Ping modules, 534
Pinion bearing preload, 1370
Pinion depth shim, 1528
Pinion flange, 1522
shown, 1528
Pinion gear, 1473
during operation, 1517–1518
ring and pinion gear set, 1526–1528
rotation, 1473
shown, 1528
Pinion gear preload, 1528–1529
Pinion gears, starter overhaul, 574
Pinion gear thrust washers, 1524
Pinion seal replacement, 1531
Pinion shaft, 1517
Pinion shaft bearing, replacement, 1526
Pinion shaft shim thickness tool kit, 1529
Pinion torque, 1369
Pins, 63
Pin-slider calipers, 1124
Pintle valve, 723
valve seat slot, 725
Pipelines, 755
Piping, damaged or defective, 248
Piston adjuster, 1154
Piston and rod assembly
full-floating rods, 349
interference fit rods, 348–349
Piston assemblies, 1038
Piston construction
cam ground pistons, 339
cast pistons, 338
forged pistons, 338
hypereutectic pistons, 338
piston finish, 339
piston head designs, 338–339
piston head size, 339
piston ring grooves, 337
piston strut inserts, 340
slipper skirt pistons, 339
Piston finish, 339
General Motors, 339
Piston head size, 339
skirt diameter compared, 340
Piston installation tool, 1154
Piston markings, 398
Piston pin, 337
bores, 340
fit, 341
interference fit, 342
piston pin offset, 340–341
retaining methods, 341–342
terminology, 340
Piston pin fit, 341
Piston pin knock, 240
Piston pin offset, 340–341
major thrust surface diagram, 340
Piston pin retaining methods, 341–342
Piston ring, 337
checking before installation, 397–398
classifications, 343
compression rings, 343
conducting heat, 342
construction, 344–345
dirty engine oil, 202
friction and engine speed, 154
oil control rings, 343
purpose and function, 342
ring gap, 343
Piston ring compressor, 399
styles shown, 399
Piston ring construction materials, 344–345
Piston ring expander tool
compression ring installation, 350
typical, 350
Piston ring grinder, 350
hand-operated, 350
Piston ring grooves, 337
Piston ring service, steps, 349–350
Pistons
acceleration rate, 337
bore and stroke shown, 153
cast pistons, 338
construction, 338–340
finish, 339
installation, 398–399
markings, 398
measuring, diameter, 338
notching facing toward front, 398
operation, 337
oversize bore calculation, 360
parts involved, 337
phenolic caliper, 1130–1131
piston pin retaining methods, 341–342
piston pins, 340–342
piston rings, 342–344
purpose and function, 337
removal, 266
removing from rods, 347
rotating back into caliper, 1134–1135
seals combustion chamber, 337
share the same parts, 337
steel caliper, 1131–1132
weight for replacements, 338
Piston seal, caliper overhaul, 1133
Piston size
application force and, 1029–1030
hydraulic pressure and, 1029
piston travel *versus*, 1030
Piston slap, 240
Piston stops, 1090
Piston stroke
compression stroke, 149, 150
definition, 149
exhaust stroke, 149, 150
intake stroke, 149, 150
power stroke, 149, 150
Piston strut inserts, 340
cylinder wall clearance, 340
Piston top designs, 890
Piston travel, 1030
Pitch, 58
Pitman arm, 1363
removal, 1383, 1384
steering linkage, 1372
Pitman shaft, 1363
PIV (peak inverse voltage), 513
Plain bearing, 374
Planar design, 855
dual cell, 855–856
Planar design zirconia oxygen sensor, schematic, 855
Planetary gear set, 1559
automatic transmissions, 1558–1559
compound, 1559–1560
simple, 1559
torque flow, 1558–1559
transfer cases, 1540–1541
cutaway view, 1540
typical, 1540
Planetary ring gear, 574–576

Planet carrier, 1540
automatic transmission, 1558
Planet pinions, 1540
Plantinum electrodes, conventional oxygen sensor, 846
Plasma, 791
Plasma method, 345
Plasma rings, 345
Plastic (nylon) retainers, 1507
Plastic intake manifolds, 222
construction, 222
Plastic optical fiber (POF), 534
Plastic/rubber gaskets, 384
Plastics, 112–113
identification, 112–113
Plastigage® (gauging plastic), 394
step by step, 413–414
Plateau honing, 360
cylinder surface shown, 360
Platform, 1290
Platforms, 1091
Platinum, 949
Platinum electrodes, zirconia oxygen sensor, 855
Platinum spark plugs, 802
Plenum, 223
shown, 254
Pliers, 73–75
Plunge joints, 1500
cross-groove, 1501
double-offset ball-type, 1501
Plunger lever, 564
Ply steer, 1247
tire shown, 1249
PM (particulate matter), 168
relative size, 168
standards, 168
PM (permanent magnet) generator, soldering gun trick, 635
PM (permanent magnet) motors, 560
power seats, 666–668
power windows, 664, 664–665
PM (permanent magnet) sensors, 635–636
PM (powdered metal) connecting rods, 346–347
fractured parting line, 347
replacement, 348
PM2.5, 168
PM10, 168
PM generator, 635–636
PM starters, 560
P-N junction, 513
PNP transistor, 516
POA valve, 718
POF (plastic optical fiber), 534
Points, 495
Point-type distributor, 495
Point-type ignition system, 495
Poisoning, chemical, 51
Polarity, direction of induced voltage, 504
Pole
magnetism, 499
north (N) and south (S), 499
Pole piece, 784
Poles, 484
Pole shoes, 560
diagram, 559, 561
Police radar frequencies, 662
Polishing, crankshaft, 374
Polyacrylate steam seal material, 309
Polyalkaline glycol (PAG) oil, 720
Polyalphaolefin (PAO), 1137
Polyglycol, 133, 1050
Polymethyl methacrylate, 617
Polyolefin, 476
Polyurethane gloves, 41
Poly V (serpentine) belts, 139–140
belt routing guide, 140
belt tension measurement, 139–140
water spray trick, 140
Pontiac, remote keyless programming, 673, 674, 677
Pontiac Grand Am
brake problems, 1132
speedometer repair, 636
Pontiac Vibe, cruise control below 25 mph, 72, 120
Poppet valve, 294, 1405
Pop rivet, 63
Pop tester, 173
typical, 173
Pop-ups on piston heads, 338–339
Porous lead, 539
Porsche, high-performance brakes, 1165
Portable crane and chain hoist, 85–86
Portable exhaust analyzer, 926
Port-fuel injection systems, 878–879
Port fuel-injection systems, 878–879
advantages, 878
air cleaner housing, 220
checking fuel-injector resistance, 904
cylinder head ports, 303
diagnosis, 902–903
diagram, 885
fuel-pressure regulator shown, 880
gasoline direct-injection compared, 889
grouped double-fire, 878
intake and exhaust ports, 284
Port- fuel injection systems, location of various components, 879
Port fuel-injection systems
manifold runners, 879
nozzle assembly, 879
plastic intake manifolds, 222
pressure regulator diagnosis, 900
sequential fuel injection (SFI), 878, 878–879
simultaneous double-fire, 878
terminology, 222
two injectors per cylinder, 879
upper and lower intake manifolds, 222–223
variable intakes, 222
Porting (relieving), 284
Ports, 283–284
Position sensor, 1344
cruise control, 659
Positive backpressure, 936
Positive caster, 1417
Positive crankcase ventilation (PCV), 5
hose, 137
Positive crankcase ventilation (PCV) systems, 942
plugged, 235
Positive crankcase ventilation (PCV) valve
checking, 901
clogged, 901
Positive displacement, 230
Positive displacement fuel pump, 865–866
detail shown, 865
Positive-displacement piston compressors, 726–727
Positive displacement pumps, 212–213
Positive engagement starters, 564
Positive offset, wheel, 1254
Positive rotator, 300–301
ball-type, 300–301
spring-type, 300
Positive rotators, 300–301
Positive slip, 1236
Positive slope, 464–465
Positive switching of high- and low-beams, 619
Positive temperature coefficient (PTC), 426
Positive temperature coefficient (PTC) thermistor, 736
Positive terminal
batteries, 480
female connector, 481
Positive twist ring, 344
Positive valve stem seal
installation, 309
Teflon® wiping ring, 309
Post catalytic converter oxygen sensor analysis, 853
Post-catalytic converter sensor testing, 853
Postinjection pulses, 170
Potato chip problem, 287
Potential energy, 106
Potentiometer, 427
described, 828
memory seats, 667, 668
schematic symbol, 813
throttle position signal voltage, 828
TP sensors, 895
typical mount, 828
voltage path, 813
Pot joint, 1359
exploded view, 1360
Pounding tool recommendations, 44
Pour point, 198
Pour point for diesel fuel, 777
Powdered metal (PM) connecting rods, 346–347
fractured parting line, 347
replacement, 348
Power, 107
defined, 425
definition, 157
fused jumper wire for, 445
symbol for, 425
Power adder, 235
Power antenna
ground wires, 508
testing and service, 701–702
typical assembly, 702
Power-assisted steering operation and service diagnosis, 1402–1408
electric, 1399–1401
electrohydraulic power steering, 1402
fluid cooler, 1392
hoses, 1392
hydraulic systems, 1388
integral, 1392–1396
pressures and volume, 1406
PSP, 1391
pump and reservoir, 1388–1391
service items, 1402–1403
steering rack service, 1409–1411
vane-type pump, 1390, 1391
VES, 1396–1399
Power assist mode, 989
Power balance test, 245
procedure, 245
Power bleeding, 1066–1067
Power brake unit operation, diagnosis, and service, 1195–1207
brake assist system, 1201
charcoal filters, 1198
drive cycle data points, 961
dual (tandem-) diaphragm vacuum boosters, 1201
hydraulic system leak test, 1202
Hydro-Boost hydraulic brake boosters, 1203–1207
Hydro-Boost symptom-based guide, 1207
need for power brake assist, 1196
principles of vacuum, 1196–1197
pushrod clearance adjustment, 1202–1203
vacuum booster disassembly and service, 1203
vacuum booster leak test, 1202
vacuum booster theory, 1197–1198
vacuum brake booster operation, 1199–1201
vacuum check valves, 1199
Power chamber, 1197–1198
Power distribution centers, fusible links and mega fuses, 473
Power door locks, 671
circuit breakers, 472
Powered mast antenna, 701
Powerline capacitor, 705
connected in parallel, 705
installation, 706
precharged procedure, 706
usage guide, 705
wiring diagram, 706
Power path, 429
Power seats
circuit breakers, 472
circuit diagram, 667
easy exit seat programming, 667
lumbar, 667
memory seat, 667
motor(s), 666–668
motor layout, 667
parts and operation, 666
service access, 668
symptom guide, 683
troubleshooting, 667–668
what every driver should know, 668
Power source, 429
common, 486–487
supplemental, capacitor for, 495
Power steering, diagnosis and troubleshooting, 1402
Power steering analyzer, 1406
Power steering control module (PCSM), 1400
Power steering fluid, 1403–1404
all-vehicle type, precautions, 139
bleeding air out of system, 1404–1405
checking, 139
cold climate fluid, 1404
color of leak, 230
filler cap/dipstick, 139
flushing, 1404
low or contaminated, 1403
types, 139
Power steering fluid cooler, 1392
Power steering hoses, 1392
Power steering pressure switch, air conditioning, 730
Power steering pressure tester, 1405–1406
Power steering pump pulley service, 1406
Powerstroke, troubleshooting chart, 172
Power tools, 82–84
Power train, arrangement, 1495
Powertrain control modules (PCMs), 5–6, 1402
air-fuel ratio sensing, 804
alternator control, 585
analog-to-digital signals, 813
Chevrolet pickup location, 815
Chrysler location, 815
coil-over-plug-type ignition systems, 790
computer controls, 816
cooling fans, 191
cruise control, 659
DC to DC converter, 521
determination of faults chart, 963
differential “delta” pressure, 169
E85 fuel system requirements, 769
EGR valve, 168
EGT 1 and EGT 2 use, 169
EGT sensor signals, 169
fuel trim, 849–850
functions, 812–813
glow plugs, 165
General Motors exception, 771
GM trucks, 693
HEUI system, 163
inputs and outputs, 1580–1581
MAP sensor uses, 835–837
push-button start systems, 557–558
SAE terminology, 812
signal from knock sensors, 791
spring test, 894
TP sensor uses, 829
transmission fluid temperature signal, 826
uses of oxygen sensor, 849–850
in virtual flexible fuel vehicle, 771
wheel diameter, 693
Power washing, 43–44
safe use, 44
Power window motors, 664–666
Power windows
auto down/up features, 665
circuit using PM motors, 665
power window motors, 664–666
programming auto down, 666
switches and controls, 664
symptom guide, 683
troubleshooting, 665–666
PPE (personal protective equipment), 41–42
hazardous materials, 48
service work, 131
PPO, 780
PPS (passenger presence system), 695–696
Prealignment checks, 1428–1429
Precision arbor, 357
Precision insert-type bearing shells, 375
shown, 376
Precollision system
operation, 662
purpose and function, 662
terminology, 662
Preconverter, 950
Preinstallation checklist, 415
Preload, 1366
Preloaded clutches, 1520–1521
cone-type, 1521
Eaton locker differential, 1521
viscous coupled limited-slip units, 1521
Prelubricating the engine, 409
Press-in ball joint removal, 1321
Pressure, 1388
Pressure (electronic) sensor, 1346
Pressure bleeding, 1066–1067
Pressure cap
collapsed radiator hose story, 189
functions, 187
location, 196
metric radiator caps, 187
operation, 187
precautions with removal, 136
pressure testing diagram, 193
removal precautions, 194, 196
replacement, 196
vacuum valve, 187
Pressure control, 1570
PCM outputs, 1580
Pressure control solenoids, 1570
diagram, 1571
Pressure control valve, 1569–1570
Pressure control valve (PCV), 882
Pressure decay stage, 1215
Pressure differential, 833, 1196
switches, 1041–1042
Pressure differential switch, 626, 628
Pressure-drop balance test, 905–906
Pressure dump stage, 1215
Pressure feedback EGR (PFE) sensor, 938
Pressure gauge
testing back pressure, 248
testing back pressure with, 952
Pressure holding stage, 1215
Pressure, hydraulic, 1029
Pressure increase stage, 1215
Pressure jet washer, 274
Pressure measurements, metric, 98
Pressure plate, 1454, 1573
designs of, 1458–1459
purpose, 1458
Pressure reduction stage, 1215
Pressure regulating valve, 213
Pressure regulator
diagnosis, 900
gasoline in vacuum hose, 900
Pressure regulator valve, 1569–1570
Pressure release stage, 1215
Pressure-relief mode, 1397
Pressure-relief valve, 1391
Pressure sensors, principles of, 833–834
Pressure switches, 1197, 1216
Pressure switches, air conditioning, 729–730
Pressure-temperature relationships, 714
Pressure tester, hand-operated, 137
Pressure testing, 1139
blocks, 276
bubbles from crack, 277
cooling system, 193
crack detection, 276
cylinder heads, 276
fluid leaks, 1593
hand-operated tester, 193
location (taps) for connecting gauge, 1593

Pressure testing (*Continued*)
for power steering, 1405–1406
precautions, 193
soapy water, 277
testing for leaks, 276
Pressure transducer, 900
Pressure-type Karman Vortex sensor, 842
Pressure-vacuum filler cap, 861
Pressure valve operation, 188
Pressure vent valve (PVV), 881
Pretensioners, 687
Prevailing torque nuts, 60
Preventative maintenance (PM), 130. *See also* Service procedures, routine
items requiring maintenance, 130
Priestly, Joseph, 235
Primary brake shoes, 1091–1092, 1096, 1149
Primary coil windings, 505
Primary ignition circuit, 784–785
diagram, 784
operation, 784–785
Primary vibration, 371
four-cylinder engines, 372
Primary winding, 504, 783
connections, 783
location, 783
Primary windings, waveform showing primary current flow, 797
Primary wire, 468
Priming pump, 164
Princeton University P-series fuel, 774
Principal end, 152
"Prindle" gear selector, 1557
Processing, computer systems, 813
Professionalism
grooming, 24, 30
housekeeping duties, 31–32
self-management, 32
Programmable controller interface (PCI), 530
Programmable read-only memory (PROM), 813
Programming auto down, on power windows, 665
Progressive rate springs, 299
PROM (programmable read-only memory), 813
replacing the computer, 813
Propagation, 112
Propane, 772
Propane oxygen sensor test, 853
fuel rich reading, 853
shut off reading, 853
Propeller shaft, 5, 1495
Proportioning valves, 1043–1046
Propylene glycol (PG) antifreeze, 177
Protection, for circuits, 429
Protocol, 528
Protons, 421
PRV (peak reverse voltage), 513
PSCM (power steering control module), 1400
motor, 1401
steering shaft torque sensor, 1401
steering wheel position sensor, 1401
P-series fuels, 774
composition of, 774
PSP (power steering pressure), 1391
Psychrometer, 714
sling style shown, 714
PT (preventative maintenance), 130
PTC (positive temperature coefficient), 426
circuit protectors, 472–473
normal operation, 472
PTC circuit protectors, 472–473
PTC thermistor, 736
P-type material, 509, 510
diodes, 511
Pull, 1413
toe, 1418–1420
Puller, vibration damper removal, 267
Pull-in winding, 564
Pulls, 1048, 1110
disc brakes, 1117, 1138–1139
Pulsating brake pedals, 1110, 1139
Pulse train, 463–464
definition, 463
frequency, 463
Pulse width, 354, 1349
definition, 464
described, 450–451
injector on-time shown, 907
sensors affecting, 878
Pulse-width-modulated sensors, 1266
Pulse-width modulated type of injector drive circuit, 908
Pulse-width modulation, 1349
Pulse-width modulation (PWM), 464
computer controls, 817–818
cooling fan speed control, 818
duty cycle, 817
solenoids, 520
Pulse-width modulation, suspension control, 1352
Pulse wipers, 648
Pulse wipe systems, 652
Pulsing circuit breaker, 490
Pump, power steering, service, 1406–1408
Pump cavitation, 187
Pump cell, 855
Pump motors, hydraulic modulator assembly, 1215–1216
Pumps, 1569–1571
checking assembly, 1601
electronic pressure regulation, 1570
gear type, 1570
gerotor type, 1570
parts and operation, 1569
pressure regulation, 1569–1570
purpose and function, 1569
typical pressures, 1570–1571
vane-type, 1570
variable displacement, 1570
Pump-up, 327
Punches, 75
Pup converter, 950
Pure plant oil (PPO), 780
Purge valve, 930
problems after refueling, 931
Push-button start system, 557–558
Pushrod
bent, 322
engine assembly, 391
GM lengths, 406
hardened, 322
hollow pushrod dirt, 322
purpose and function, 322
rotating pushrod test, 329
scratch test, 322
types, 322–323
Pushrod clearance adjustment, 1202–1203
typical adjustable pushrod, 1202
Pushrod end, 1035
Pushrod engines, 150
cam bearing location, 379
cam location, 316
camshaft bearing journals, 316
overhead valve engines, 322
pushrod shown, 322
Pushrod guide plates, 321
Putty knife, 272
PVD (physical vapor deposition), 345
PVV (pressure vent valve), 881
PWM, 464
computer controls, 817–818
cooling fan speed control, 818
duty cycle, 817
PWM (pulse-width modulated) signal, throttle plate motor, 894
PWM, solenoids, 520
Pyrolytic (high-temperature) oven, 274–275
airless blaster, 275
Pyrometer, heater trouble testing, 738
Pyrometer (infrared thermometer), 953
Pyrometer, measuring high-side pressure, 741
Pyrotechnic devices, 54
PZEV (partially-zero-emission vehicle), 127
PZEV (partial zero-emission vehicle), 919

Q

Quadrasteer, 1375–1376
"goofy mode," 1379
Quadricycle, 1, 2
Quench area, 281
Quick and easy automatic transmission/transaxle diagnosis, 1587
Quick and easy backlash test, 1525
Quick and easy ECT test, 825
Quick and easy fuel volume test, 872
Quick-disconnect valves, 748
Quick take-up master cylinders, 1036
Quiet mode, 990
Quill, 1455, 1476
Quill shaft, 1461

R

R & I (remove and inspect), 29
R & R procedures, 28
parts replacement, 29
Ra (arithmetic average roughness height), 1168
R-12 (Freon), 718
Schrader valves, 748
service cap O-ring, 749
R-134a, 718
O-ring seal replacement, 747–748
pressure-temperature average readings, 741
service cap O-ring, 749
RABS (Rear Antilock Braking System), 1211
Race vehicle
cross-drilled crankshaft, 368
piston pin offset to minor thrust, 341
valve spring compressor, 310
Race vehicle alignment, 1443
Racing manifolds, 222
Rack-and-pinion power steering, 1393
Rack-and-pinion steering
adjustments, 1369–1370
gears, 1367–1369
inner tie rod ends, 1373–1374
integral power steering, 1393, 1395, 1396
steering wheel precautions, 691
wear items, 1380
Rack-and-pinion steering gear, 1357
Rack support, 1369
Radar cruise control
parts and operation, 661
purpose and function, 659
radar detector impact, 661
terminology, 661
Radar detectors, 661
Radar frequencies, 661
Radial clearance, 1071
Radial force variation, 1277
Radial loads, 1071
Radial-ply tires, 1241
rotation, 1275, 1277
size for older vehicles, 1246
Radial pull, 142, 1247
Radial runout, 1276–1277
Radial tire pull, 1247
Radial tires, 142
Radiation, 110
Radiator, 5
cleaning exterior of, 197
clogged and overheating, 182
collapsed radiator hose story, 189
coolant level check precautions, 238
corrosion from overheating, 193
cutaway showing automatic transmission cooler, 1569
hand test, 739
how they work, 187
lower air dam, 187
pressure caps, 187–188
tubes and fins diagram, 186
types, 186–187
cross-flow, 187
down-flow, 187
Radiator cap, 187–188
metric, 187
testing ECT sensor, 820
Radiator hoses, 137
cut-and-peel trick, 138
heater diagnosis, 738
Radio
battery access point, 555
battery replacement issues, 555
E & C (entertainment and comfort) communication, 528
lightning damage, 710
"LOC" on display, 710
no-start story, 535
security code to unlock, 554, 710
security lock problem, 710
technician use, 30
Radioactive materials, 48
Radio and heater (R&H), 6
Radio choke, 709
diagram, 709
Radio core support, horn mounts on, 647
Radio frequency (RF), 699
AM waves, 700
FM waves, 700
Radio-frequency interference (RFI), 506, 700
braided ground wire, 709
capacitors to reduce, 496
capacitor usage, 708–709
definition, 708
noise, 700
radio choke, 709
Radio interference. *See* Radio-frequency interference (RFI)
Radio "pop" trick, 728
Radios and receivers, 700
Radio security lock problem, 710
Radius rods, 1312
bushing noise, 1312
Rain sense module (RSM), 653–654
location, 654
Rain sense wipers, 653–654
diagnosis and service, 654
diagram, 654
parts and operation, 653–654
RAM (random-access memory), 814
Ramp, 327
drive-on, 94
Random-access memory (RAM), 814
Random roadside testing, 922–923
Range, for digital meters, 447
Range charts, 1593
typical shown, 1593
Range shift, 1539
Rapid combustion phase, 161
Raster (stacked) position of ignition oscilloscopes, 808
Ratchets, 69, 70–71
Ratchet-type automatic adjusters, 1099
Rationality testing, MAP and MAF sensors, 829
Rationality tests, 959
enabling monitor, 963
Rattle noise, 241, 1322
Rattle test, 944
Ravigneau gear set, 1560
shown, 1561
RBS (rubber-bonded socket), 1373
RBWL (red brake warning lamps), 1017–1018, 1043, 1147, 1221
RWAL diagnosis, 1224
Rc60, 316
RCM gaskets, 384
RCRA (Resource Conservation and Recovery Act), 49
Reaction member, 1541, 1577
automatic transmission, 1559
transmission bands, 1571–1572
Reaction pads, 1134
Reaction rod, 1313
Reaction shaft, 1554
Reactive materials, 48
Reactor, 1551
Read-only memory (ROM), 813
Ready light, HEVs, 256
Real-time dampening (RTD), 1345, 1352
components, 1352
Real wheel steering, rear steer, 1375
Rear air-conditioning system, 735
location of ducts, 736
Rear Antilock Braking System (RABS), 1211
Rear axle bearing and seal replacement, 1080–1081
Rear axle bearing service, 1085–1086
Rear camber, 1438
Rear camber, adjusting, 1438–1439
Rear coil spring, replacement, 1341
Rear crankshaft oil seal, 395
Rear disc auxiliary drum parking brakes, 1150
disc brake rotor shown, 1150
typical assembly, 1151
Rear disc brake service, 1153
Rear disc parking brakes, 1126–1127
exploded view, 1126
Rear drive axle classifications, 1079
Rear electronic level systems, 1356–1357
Rear end, 1517. *See also* Differentials
Rear end noise diagnosis, 1525
Rear entry parking brake cables, 1149
Rear leaf springs, replacement, 1341–1342
Rear main seal, 385
Rear mount caliper, 1130
Rear park assist (RPA), 641
diagnosis, 641
Rear parking brake adjustment, 1155
Rear steer, 1375
Rear suspension
IRS, 1338–1339
leaf spring, 1336–1337
live axle, 1336
rear leaf springs, 1341–1342
rear shock replacement, 1341–1342
semi-independent, 1339–1340
semi-trailing arm, 1338
service, 1340
solid rear axles, 1335–1336
trailing arm, 1337
troubleshooting electronic leveling systems, 1356–1357
Rear toe adjustment, 1439
Rearview cameras, 640
Rear Wheel Antilock (RWAL), 1211
Rear wheel drive
definition, 125
differential, 1503
differential fluid check, 144
engine installation, 417
power train, 5–6
removal of engine, 263–264
Rear wheel drive (RWD), wheel bearing adjustment, 1078
Rear wheel drive, tire rotation, 141
Rear wheel steering
control module, 1376–1378
mode switch, 1377–1378
motor assembly, 1377
position sensor, 1377–1378
steerable rear axle, 1378
SWPS sensor, 1377
Rear window defoggers, 662–663
corrosion or junction faults, 682
grid antenna, 701
symptom guide, 683
Reboring cylinders, procedure, 359
Rebound clips, 1296
Rebuilding, 262
Rebuilt alternators, 597
Rebuilt parts, 30
Recalls, 78, 123
Receiver/drier, 721–722
service, 752–753
Recertification, 40
Recirculating ball steering gear, 1364–1366
Recirculation operation, 735
Recombinant battery, 542
Reconditioning, 1175
complete (major overhaul), 262

Rectifier, 581
six diodes, 581
Rectifier bridges, 515–516
alternator, 581
replaceable assembly, 596
Rectifier testing, 596
assembly, 596
meter setup, 596
results, 596
testing procedure, 596
Red assembly lube, avoid for automatic transmissions, 1606
Red brake fault warning light, troubleshooting, 636
Red brake warning lamps (RBWL), 1017–1018, 1043, 1147, 1221
RWAL diagnosis, 1224
Red lightning bolt warning lamp, 896, 897
Red meter lead
position, 447
reading digital meters, 452
Red oil light, 249
Red Seal program, 40
"Reduced power" warning light, 896
Reed valve, 727–728
Reference, 855
Reference electrodes, Nernst cell and pump cell, 856
References, 19
Reference voltage, 521
Refining
cracking, 754
crude oil types, 754
distillation, 754
major steps and processes, 754–755
shipping, 755
Refinishing, 1175
Reflashing, 813
Reformulated gasoline (RFG), 761–762
Refractometer, 179
coolant testing, 136
diagram of use, 179
procedures, 176
Refrigerant, 718–719
contamination with another, 741
environment and, 719
identification, 747
leak detectors, 744
leak repair, 746
lines and hoses, 723, 724
noncondensable gases, 748–749
oils, 720
overcharge readings, 742
precautions handling, 748
recovery procedures, 746–747
recycling, 749
undercharge readings, 742, 743
underhood sticker for, 750
using specified amount, 751
Refrigerant identification, 747
Refrigerant identification machine, 740
shown, 740
Refrigerant identifier, 749
Refrigerant leak detectors, 744
Refrigerant lines and hoses, 723
shown, 724
Refrigerant oil, 720
recycling, 749
retrieval shown, 747
Refrigerant recovery procedures, 746–748
identification, 474
leak repair, 746
line connections, 747–748
recovery, 746
repairs or replacement of components, 474
Schrader valves, 748
service valves, 748
Refrigerant recovery unit, 746
typical units shown, 747
vacuum on system, 747
Refrigerant recycling, 749
Refrigerant testing
black light, 744
dye, 744
soap solution, 744
Refueling, problems after, 931
Regeneration, 169
diesel particulate filter, 169
process, 169
types of DPF, 170
Registration fee, 37
Reid vapor pressure (RVP), 755
Relative humidity, 714
Relative motion, 504
Relay, 485
accessory installation, 488
armature, 485
diagnosing, 485
diodes in, 511
electromagnetic switch, 502–503
four-terminal, 485
ISO identification, 485
operation, 485–486
schematic of wiring, 485, 486
solenoid compared (chart), 502
solenoid compared, 487
on starter, 503
testing, 485–486
transistor compared, 516
uses of electromagnetism, 502–503
voltage spike control, 486
Relay coil, computer controls, 816
Relearn (reset) procedures, 1263, 1268
Relearn onboard computer, after fuel-injector service, 910
Release bearing, 1454, 1461
construction, 1461
diaphragm striping, 1461, 1462
installation, 1461–1462
lubrication, 1462
shown, 1461
types of, 1462
Released position, 1034, 1200
Release solenoids, 1215
Relief valve, 213
Relieving, 284
Reluctance, 499–500
Reluctor wheel, 500
damaged, 798, 799
Remanufactured engine, 262–263
Remanufactured parts, 30
Remote reservoir (power steering), 1389
Remote reservoir shock absorbers, 1304
Remote sensing, 922
Remote starting, 558
Remote vehicle start (RVS), 558
Removal and reinstallation (R & R) procedures, 28
Removal of engine
check service information first, 263
cleaning area, 263
front-wheel-drive vehicle, 264
oil gallery plug removal before cleaning, 268
photos/videos of engine, 263
rear-wheel-drive vehicle, 263–264
step by step, 269–270
tag and bag, 264
two ways, 263
usual procedures, 263–264
Remove and inspect (R & I), 29
Remove and replace (R & R), 29
Removers, 76–77
Renewal parts, 29–30
Repair estimating, 28
nondealership time guides, 28
Repair options, 262–263
Repair order (RO), 27
Replacement brake part performance, 1020
Replacement parts, failures, 511
Replacement wheels, 1281
Replenishing ports, 1032
Reserve capacity, 543
battery drain and, 553–554
charge time, 550
Reservoir diaphragms, master cylinder, 1031–1032
Reservoirs, master cylinder, 1031–1032
Residual (rest) pressure, 865
Residual check valves, 1041
Residual magnetism, 499
Resistance
causes of high resistance, 431
conductors and, 426–427
copper wire and NTC thermistor compared, 515
definition, 425
digital meter usage, 457
ECT sensor measurement, 821
ECT testing with multimeter, 820
examples, 437
measuring with ohmmeter, 447–448
multiple use, in electrical circuits, 439
ohm measurement, 425
path of least resistance, 438
pickup coils, 798
reading digital meter displays, 453
as sum (addition) of all resistances, 434–435
voltage drop test for determining, 436
Resistance measurement, 1227
Resistance suppression, 507
Resistors
color-code interpretation, 427
fixed, 427
schematic symbol, 483
spike protection, 513
spike protection resistors, 513
spike reduction method, 486
terminating, 534
typical carbon, 427
variable, 427
Resistor spark plugs, 802
Resistor-type occupant detection sensors, 696
Resonance tube, 221
Resonate, 369
Resonators, 226
Resource Conservation and Recovery Act (RCRA), 49
Respirator, 48
Rest pressure test, 871
Restricted exhaust, 247–248
Resume preparation
educational information, 18
experience and skills, 18
personal information, 18
references, 19
sample, 18
Resurfacing, 1175
Retainer, 294
Retainer clip, 1126
Retainer plate (flange type), 1080
Retainer-type rear axles, 1080
Retaining bolts, caliper, 1131
Retaining nut, tightening, 406
Retaining pin, 1123
Retirement savings plans, 21
Returnability, 1417
Return path (ground), for circuits, 429
Return rings, inspection, 1604
Return springs, 1093, 1105
Reverse bias, 511
Reverse cooling, 189
Reversed-flow cooling systems, 284
Reverse-flow mufflers, exhaust valve cracking, 295
Reverse gear, 1482
automatic transmission, 1557
GM typical torque flow, 1584–1585
sliding reverse gear, 1482
Reverse twist ring, 344
Reversing cameras, 640
Revolutions per minute (RPM), frequency, 463
RFI (radio-frequency interference), 506
noise, 700
RHD (right-hand dipstick), 354
Rheostat, 427
interior dash lights, 612
schematic symbol, 483
Rhodium, 949
Ribbon-type airbag crash sensor, 690
schematic, 690
Rich exhaust, 856
lambda less than 1.00, 857
negative current, 856
Rich indicator, 924
Ride height, 1428
measuring points, 1429
Ridge reamer, 266
Right-hand dipstick (RHD), 354
Right-hand rule, 500
Right-side courtesy light, 486–487
Right-to-know laws, 49
Rigid fuel lines, 862
Rim size, 1272
Rim width and tire size, 1249–1250
rim size rule-of-thumb, 1249
Ring and pinion gear set, 1526–1528
Ring compressor, 399
Ring gap, 343
bore in inches (chart), 398
checking, 349
clearances to expect, 398
location, 399
measuring with feeler gauge, 350
Ring gear, 1517, 1540
automatic transmission, 1558
differential, 1517
drive pinion relationship shown, 1518
during operation, 1517–1518
Ring gear bolt replacement, 1529
Ring gear runout, 1525
Ring gear to pinion gear ratio, 563
Ring groove
checking side clearance, 349
service, 349
Ring link networks, 525
Ring/star hybrid networks, 525
Ripple voltage, 463
Riveted linings, 1092, 1120
Riveted or pinned tie rod ends, 1374
Riveting, 1092
Rivets, 63
RMS (root mean square), 287, 453, 1169
amplifier, 706
RMS power, 706
RMS power at 2 ohms, 706
RO (repair order), 27
Road crown, 1413
Road sensing suspension (RSS), 1352
Road test, automatic transmission repair, 1608–1609
Robertson screwdrivers, 72
Rochester Multec fuel injectors, 883
Rocker arm
aluminum high-performance, 320
assemblies, 217
high-performance aftermarket, 391
HLA in, 323
pedestal-mounted, 321
prelubricating the engine, 409
purpose and function, 320–321
ratio, 320
shaft inspection, 328
shaft-mounted, 321
stud-mounted, 321
trial assembly, 391
worn, 328
zero lash, 406
Rocker arm covers, removal during engine disassembly, 264
Rocker arm shafts
sticking valves, 322
V-6, 321
Rocker cover gaskets, checking for leaks, 239
Rocking couple, 372
Rockwell "c" hardness, 316
Rod alignment fixture, 348
Rod bearing
loads, 376
noise, 240
Plastigage® step by step, 413–414
tightening tip, 400
Rod bearing bores, wear, 348
Rod bearing journals, 365–366
crankpin centerline, 366
Rod bolts, 399
Role model, 31
Roller bearings, 1071–1072
Roller cell (vane) fuel pump, 865
Roller chain drive, 318
Roller hydraulic lifters, 405
Roller lifters
hydraulic roller lifter, 327
retainer plate, 326
Rolling acceleration test, 174
Rolling code reset procedure, 672
Rollover leakage protection, 862
check valve, 862
inertia switch, 862
ROM (read-only memory), 813
Room-temperature vulcanization (RTV), 385–386
Room temperature vulcanization (RTV) sealers, 853
Rooster comb, 1577
Root, 1518
Root cause, 105
Root mean square (RMS), 287, 1169
surface finish, 287–288
Roots, Philander and Francis, 230
Roots supercharger, 230
blower and intercooler, 231
two lobes, 230
Rope seal installation, 396
staggering parting lines, 396
Rosin-core solder, 475
Rotary control valve, 1392–1393
Rotary engine, 152
Rotary flow, 1554
Rotary vane fuel pump, 865–866
action shown, 865
Rotating assembly, 147
V-8 engine, 147
Rotating engine assembly removal
block inspection, 267
camshaft removal, 267
crankshaft and main bearing removal, 267
harmonic balancer removal, 267
Rotating pushrod test, 329
Rotation direction, 152
Rotation speed, 154
Rotor, cleaning after machining and sanding, 1174
Rotor balancing, 1280
Rotor current, 581
Rotor damper, 1170
Rotor gap voltage, 810
Rotor lateral run out, 1166
Rotors, 579–580. *See also* Disc brake rotors; Machining brake drums and rotors
adapters for hubbed and hubless types, 1171
brake, 1122
construction, 579–580
damage, 1158–1159
definition, 579
how they create magnetic fields, 580
induced current, 583
machining step-by-step, 1182–1189
mark before removing, 1161
rotor assembly cutaway view, 580
rotor current, 580
storing, 1160
styles, 1164
surface finish, 1168–1169, 1172–1173
when to machine, 1167–1168
Rotor type oil pump, 213
operation, 213
Rough cut, 1172
Rough idle
check the vacuum, 1198
screen on control valve, 354
Rough idle story, 1591
Roughing stone, 304
RPA (rear park assist), 641
RPM (engine speed), traction control, 1236
RPM (revolutions per minute), frequency, 463
RPO code, 1352
RSM (rain sense module), 653–654

RSS (road-sensing suspension), components, 1352
RTV (room-temperature vulcanization), 385–386
RTV (room temperature vulcanization) sealers, 853
RTV sealants, 385–386
  application, 407
  gasket substitute on nonmachined surfaces, 386
  precautions, 386
  timing covers, 407
Rubber and contact cement, gasket installation, 384
Rubber-coated metal (RCM) gaskets, 384
  avoiding sealer with, 386
Rubber-coated steel gaskets, 384
Rubber compatibility chart, 1055
Rubber coupling, 666
Rubber mallet trick, 870
Rubber tire valve stems, 1264
Rubber types, 1054
Rule measurements, 98–99
Run-flat tires, 1252–1253
Run-in, 589
Running (dynamic) compression test, 244
  procedure, 244
Rusty air impact wrenches, 83
RVP (Reid vapor pressure), 755
RVS (remote vehicle start), 558
RWAL (Rear Wheel Antilock), 1211
  diagnosis, 1224
Rzeppa joint, 1498
  cage, 1512

S

Saab
  remote keyless programming, 673, 674, 678
  throttle switch, 729
Saddles, 356
SAE (National Institute for Automotive Service Excellence)
  certification tests, 34–40
  contact info, 35
  eight tests, 6–7
  steel numbering designations, 113
  test registration booklet, 7
SAE (Society of Automotive Engineers), 199, 526, 578, 961
  camshaft duration, 324
  engine oil ratings, 199
  PCM terminology, 812
SAE 5W-30, 199
SAE 10W-30, 199
SAE certification, 32
  service areas, 34
Safety, 42–46
  air compressor, 82
  air hose, 45, 82
  alternative fuels, 776
  antilock brake systems, 1231
  areas around exits and fire extinguishers, 32
  chisel, 76
  cooling fan, 191
  creeper, 92
  cutter, 75
  engine stands, 86
  EP lubricants, 1484
  file, 75
  floor jack, 91–92
  grease, 1074
  hacksaw, 77
  hammer, 73
  hand, 42, 421
  hand tools, 80
  job shadowing, 16
  lifting vehicles, 92–94
  mallet, 73
  plier, 74
  portable crane, 86
  power steering service, 1408
  pressure testing, 193
  punch, 76
  ratchet, 70–71
  screwdriver, 73
  shop cloth disposal, 43
  smoking and grease, 1074
  socket, 70–71
  sodium-filled valves, 295
  wrenches, 68–69
Safety belts, 687
  belt retractors, 687
  how they work (diagram), 687
  inertia-type mechanism, 688
  lights and chimes, 687
  pretensioner, 687
  warning light, 688
Safety glasses, 41
  cylinder head work, 268
  valve and seat reconditioning, 301
Safety inspection, service, 131
Safety stands, 91
  tall, 93
SAI (secondary air-injection) system
  air distribution manifolds and nozzles, 946
  belt-driven air pumps, 946
  diagnosis, 947
  electric motor-driven air pumps, 946–947
  exhaust check valves, 946
  hose, 137
  operation chart, 947
  parts and operation, 945–946
  purpose and function, 945
  typical components, 945–946
  visual inspection, 947
SAI (steering axis inclination), 1421
  diagnosing, 1435
  measuring, 1433
SAI pump, 945
  electric motor-driven, 947
Sales manager, 14
Salespersons, 14
Salvage yards, 30
Same-phase steering, 1375
Sampling rates, 461
SAPS (in ACEA oil), 201
SAR (supplemental air restraints), 688
SAS (self-aligning spacer), 1162
Satellite Digital Audio Radio Services (SDARS), 707–708
Satellite radio
  antenna, 708
  diagnosis and service, 708
  ESNs and subscriptions, 709
  parts and operation, 707
  reception, 708
  Sirius/XM radio, 707
Saturated switch-type injector-driven circuit, 907
Saturation, 907
Saturn
  battery sizes, 543
  drive train removal, 1484
  hydraulic clutch replacement, 1466
  nonplanetary gear set, 1561
  remote keyless programming, 673, 674, 677
  transmission repair, 1599
  waste-spark ignition system, 788
SBA (supplemental brake assist), 1203
Scan data
  transmission problem diagnosis, 1589
  typical automatic transmission/transaxle values, 1589
Scan testing, charging circuit, 588
Scan tool data (PID), 857
Scan tool method, 185
  engine coolant temperature, 185
Scan tools, 5
  ABS bleeding, 1068–1069
  ABS diagnosis, 1229–1230
  for accessories, 653
  ATF levels, 138
  bidirectional, 653
  bidirectional control of automatic transmission/transaxle, 1588
  charging system problems, 588
  drive cycle, 961
  dual cell diagnosis, 856–857
  ECT sensor testing, 823
  engine testing procedure, 851–852
  erasing DTCs, 962
  ETC readings, 898
  EVAP system, 929
  Ford SCP BUS, 530
  fuel-system diagnostics, 912
  fuel trim values, 857
  global OBD-II, 964
  GM Tech 2 scan tool, 534
  Honda, 534
  Honda/Toyota communications, 533
  IAC count checking, 912
  IAC counts, 902
  ignition inputs, 635
  MAP sensor testing, 838
  OBD-II generic or factory, 857
  oxygen sensor testing, 851–852
  ping modules, 534
  power windows, 666
  single cell wide-band oxygen sensor, 859
  TP sensor testing, 830, 831
  troubleshooting speedometer/odometer, 637
  vacuum leak diagnosis, 902
  warning lights, 625
Scan tool testing, ABS, 1228
Scan tool values, 972
Scavenging, 325
Schematic symbols, 481–482
  battery, 481–482
  boxed components, 483
  BUS systems, 527
  capacitor, 483
  Chevrolet Equinox with GMLAN BUS and UART, 537
  color-code as key, 484
  computer data line circuit schematic, 536
  electrical components, 483
  electric heated unit, 483
  electric motors, 483
  memory saver, 554
  momentary switch, 484
  operational amplifier, 519
  photodiode, 514
  photoresistor, 515
  phototransistor, 518
  resistors, 483
  SCR, 515
  separable replaceable part, 483
  side marker lights, 612
  thermistor, 515
  transistor, 516
  wiring, 481–482
Schmitt trigger, 785
School bus garage, 10
Schrader valve, 1257
  fuel pressure gauge with, 902–903
  fuel pump pressure, 870
  location in GM v-6, 870
Schrader valves, 748
  depressor pin shown, 750
SCI (serial communications interface), 530
Scientific method, 105–106
  example, 105–106
Scientific notation, 115
Scion, remote keyless programming, 677
Scopes, scope testing. *See* Digital oscilloscope; Digital storage oscilloscope (DSO); Oscilloscopes
Score resistance, 377
Scoring, 1158
Scotch Brite® pad, 273
SCP (standard corporate protocol), 529
SCR (selective catalytic reduction), 170–171
  advantages/disadvantages, 171
SCR (silicon-controlled rectifier), 515
Scraper ring, 344
  oil control, 344
Scraping, 272
Scratch cut, 1162–1163
Scratch test, 322
Screwdrivers, 72–73
  tightening, 72
Screwdriver trick, 1138
Screw jack assembly, 666
Screw, nut, and cone actuation, 1152–1153
  typical GM rear disc brake, 1152
Screw-type puller, 394
Scroll, 189
Scrub radius, 1422–1424
SDARS (Satellite Digital Audio Radio Services), 707–708
  satellites and repeater stations, 708
Seal, lip seal installation, 394–395
Sealants, need for, 381
Seal cut gap, 343
Seal drivers, 79
Sealed beam headlights, 613
  four-headlight system, 613
Sealed bearing replacement, 1078
Sealed-front-wheel-drive bearings, 1072
Sealed Housing for Evaporative Determination (SHED) test, 921
Sealed lead-acid (SLA) battery, 542
Sealed valve regulated (SVR) battery, 542
Sealer, cup soft plugs, 393
Seal puller, shown, 1075
Seal pullers, 79
Seals
  dynamic, 1074
  grease, 1078
  labyrinth, 1089
  static, 1074
  wheel bearings and service, 1074
Seasoned engine, new engine compared, 357
Seat airbags, 696–697
Seat belt fastened switch, 693
Seat belt pretensioner assemblies, 687
Seat duration, 330
  valve timing and lift effects on performance, 330
Seat filter, 669
Seat sensors, airbag, 695–696
Seat track position (STP) sensor, 696
Secondary air-injection (SAI) system
  air distribution manifolds and nozzles, 946
  belt-driven air pumps, 946
  diagnosis, 947
  DTCs, 947
  electric motor-driven air pumps, 946–947
  exhaust check valves, 946
  hose, 137
  operation chart, 947
  parts and operation, 945–946
  purpose and function, 945
  typical components, 945–946
  visual inspection, 947
Secondary brake shoes, 1091–1092, 1096
Secondary ignition circuit, 783
Secondary vibration, 371
Secondary winding, 504
Second-class lever, 109
Second-class levers, 1023
Second gear, 1481
Second position, automatic transmission, 1558
Section 609 (Clean Air Act), 719
Sector gear, 1363, 1366
Sector shaft, 1363
  bushings shown, 1366
Sector shaft endplay, 1367
Sediment chamber, 538
Seebeck, Thomas Johann, 425
Selectable Ride (SR), 1347
  mode select switch, 1350
Selection availability (SA), 637
Selective catalytic reduction (SCR), 170–171
  advantages/disadvantages, 171
Select low principle, 1211
Self-aligning spacer (SAS), 1162
  setup shown, 1163
Self-energizing action, 1087, 1089, 1094
Self-induced voltage, 504
Self-leveling shocks, 1354
Self-parking system, 1401
Self-powered test lights, 445–446
Self-propelled vehicles, 1
Self-tapping inserts, 65
Self-tapping screws, 62
Semiconductors, 423, 509
  construction, 509
  examples, 509
  N-type material, 509
  P-type material, 509
  summary of fundamentals, 510
Semi-floating axles, 1079
Semi-independent rear suspension, 1339–1340
Semimetallic friction material, 1121
Semimets, 1121
Semi-trailing arm rear suspension, 1338
Sensing and diagnostic module (SDM), 690
  interior view, 690
Sensor air gap, 1213
Sensorless Flex-Fuel systems, 771
Sensors
  active, 1213
  brake pedal position (BPP), 1403
  brake pedal travel, 1217
  computer input, 816
  delta pressure method, 1267
  digital wheel speed, 1213–1214
  electronic stability control systems, 1234–1236
  ESC, 1234–1236
  hand-wheel position, 1234
  height sensor, 1343
  installation, 1266
  lateral acceleration, 1235
  magnetically-triggered-type, 1266
  modes of operation, 1265
  operation, 1265
  pressure, 1264–1265
  pulse-width-modulated, 1266
Sensors. *See also* Wheel speed sensors (WSS)
  self-parking systems, 1401
  steering shaft torque, 1401
  steering wheel position, 1234
  storage mode, 1266
  throttle position, 1236
  TPMS service tools, 1268–1269
  transmitter ID, 1267
  types of, 1264–1265
  valve stem-mounted, 1265
  vehicle speed (VS), 1234
  wheel, 1432–1433
  wheel speed, 1236
  yaw rate, 1235–1236
Sensors, electronic (suspension), 1343–1345
  air suspension, 1345
  ECBM, 1346
  handwheel position, 1345–1346
  lateral accelerometer, 1346
  linear Hall-effect, 1345
  pressure, 1346
  rear wheel position, 1377–1378
  steering wheel position, 1345–1346, 1377, 1401
  vehicle speed (VS), 1346
  yaw rate, 1346–1347
Sensors, TPMS
  activations, 1267–1268
  banded, 1265
  battery life, 1268
  checking, 1265
  hand held testers, 406
  installation, 1272
  stop leak in tires, 1280
Separate battery trick, 709
Separator PCV systems, 943
Separator plate, 1576
  typical, 1601
Separators, battery, 539
Sequential fuel injection (SFI), 878, 878–879
  color of wires, 878
Sequential gasoline blending, 761

Serial communications interface (SCI), 530
Serial data
  BUS communication, 524
  radios and receivers, 700
Series circuit laws, 436–437
Series circuits, 434
  capacitors in, 497
  examples, 437
  Ohm's law, 434–435
  path of least resistance, 438
  resistance calculation, 434–435
  total resistance, 434–435
Series flow coolant system, 190
Series hybrid, 985–986
Series-parallel circuits, 441–442
  definition, 441
  faults, 442
  solving calculation problems, 442–443
  types of faults, 442
Series-parallel flow coolant system, 191
Series-parallel hybrid, 987
Series starter motors, 559
  counter electromotive force (CEMF), 559
  wiring diagram, 560
Series-wound field, 649
Serpentine (Poly V) belts, 139–140
  noisy camshaft, 329
  tension range chart, 140
  water spray trick, 140
Serpentine belts, 1403
Service
  disconnect battery first, 1463
  eight areas, 6–7
  increasing age of vehicles, 9
  need for, 8–9
  three Cs, 27
  warranties, 8–9
Service advisor, 12
  duties, 12
Service bay, 27, 47
Service brakes, 1016, 1202
Service caps, 748
  O-rings shown, 749
Service consultant, 12
Service description method (tires), 1245
Service engine soon light, 5
Service/flash programming, 978
Service information (SI), 71–78, 120, 120–121
  advantages/disadvantages of hard copy versus electronic, 74, 122
  aftermarket supplies guides and catalogs, 78, 124
  BUS circuit faults, 536
  computer data line circuit schematic, 537
  electronic service information, 77–78, 122–123
  factory, 71–73, 120–121
  following recommended procedures, 28
  Google for, 26
  hotline services, 78, 124
  lubrication guides, 71, 120
  network communication protocol to use, 535
  owner manuals, 71, 120
  print it out, 73, 121
  reading and writing instructions, 26
  service manuals, 71–73, 120–121
  specialty repair manuals, 78, 124
  types of, 74–75, 120–121
  vehicle service history records, 71, 120
Service manager, 12–13
  typical duties, 12–13
Service manuals, 71–73, 120–121
  component location section, 76
  how pages are numbered, 76
  how to use hard copy versions, 76
  sections in hard copy versions, 120–121
  table of contents, 77
Service procedures, routine
  accessory drive belt inspection, 139–140
  air filters, 132–133
  automatic transmission fluid check, 138–139
  brake fluid inspection, 133
  cabin filter replacement, 132
  chassis lubrication, 143
  cooling system inspection, 136–138
  differential fluid check, 144
  do no harm, 131
  engine oil inspection, 134–135
  getting ready for service, 130–131
  manual transmission check, 144
  power steering fluid, 139
  pre-service inspection, 130
  protect the technician, 130–131
  protect vehicle, 130
  safety inspection, 131
Service procedures, routine. *See also* Preventative maintenance (PT)
  tire and wheel service, 140–143
  transaxle lubricant check, 144
  under-vehicle inspection, 145
  windshield washer fluid, 132
  windshield wiper service, 131
Service stall, 27
Service technician, duties, 27–29
Service technician. *See also* Automotive technician (tech)
Service terms, regulations in some states, 27
Service valves, 748
  before evacuating the system, 753
Service writer, 12
Servo action, 1087, 1089, 1096
  disc brakes, 1117
Servo brake starwheel automatic adjusters, 1097–1098
Servo linkages, 1572
Servomotor, 894
Setback, 1424–1425
Setting toe, 1442–1444
720-degree cycle, 149
77 mm transmission, 1476
Severe service times, 74, 122
SFI (Specialty Equipment Manufacturers Association Foundation, Incorporated), 1256
Shackles, 1296
Shaft-mounted rocker arms, 321
  inspection, 328
  rocker shafts shown, 321
SHED test, 921
Sheet metal screws, 62
Shielding, for EMI suppression, 507
Shift control solenoids, PCM or TCM controls, 1580
Shifter fork, 1478
Shifter paddles, 1564
Shift forks, 1477
  inspection, 1484
  transfer case, 1543, 1544
  typical mechanism, 1477
  worn shift fork mystery, 1486
Shift modes
  automatic transmission, 1557–1558
  quick and easy diagnosis, 1587
  test drive, 1587
  use while diagnosing, 1587
Shift sequence
  described, 1478
  diagram, 1479
  transfer case service, 1543
Shift solenoids, 1581
  computer controls, 816
Shift valves, 1579–1580
Shim chart, 1442
Shimmy, 1277
  wheel alignment, 1414
Shims, 571–572
  determining thickness, 116
  front camber, 1442
  rear camber, 1440
  shim chart, 1442
  typical alignment chart, 1444
Shim-type head gaskets, sealers, 386
Shipping of gasoline, 755
Shock absorbers, 1302–1306
  air shocks/struts, 1304–1305
  air springs, 1306
  coil-over, 1306
  diagnosis, 1323–1324
  double-tube, 1307, 1308
  front shock replacement, 1324
  gas-charged, 1304
  operation, 1303–1304
  rear shock replacement, 1341
  remote reservoir, 1304
  self-leveling, 1354
  shock stud trick, 1323
Shock loading, 1084
Shock sensor, 678–679
Shock stud trick, 1323
Shoe anchors, 1090
Shoe click noise, 1110
Shoe contact areas, 1089
Shoe rims, 1091
Shoes
  brake, 1091
  drum brake, 1091–1093, 1107
  leading, 1094
  primary, 1091–1092, 1096, 1149
  secondary, 1091–1092, 1096
  trailing, 1095
Shoes, steel-toed, 41
  shown, 42
Shoe support pads, 1089
Shoe webs, 1091
Shop cloth disposal, 43
  in metal container, 43
Shop equipment, care and maintenance, 86
Shop foreman, 12
Shop management software, 28
Shop owner, becoming, 22–23
Short block, 262
  disassembly, 266
  final assembly, 392–397
  preparation for assembly, 388–390
  trial assembly, 391–392
Short block final assembly
  block preparation, 392
  cam bearings, 393–394
  correcting bearing clearance, 394
  crankshaft installation, 396
  crankshaft rotating torque, 397
  installing cups and plugs, 393
  lip seal installation, 394–395
  main bearing tightening procedure, 396
  measuring main bearing clearance, 394
  rope seal installation, 396
  thrust bearing clearance, 396
Short block preparation
  checking surfaces before assembly, 389
  items to check, 388–389
  preparing block for studs, 389–390
  preparing threaded holes, 390
  surface finish, 389
Short circuit
  common causes summarized, 491
  definition, 489
  locating, 489–491
Shorted (circuit), 430
Shorting bars, 694
Short/long-arm suspensions, 1313–1314
Short-range radar (SRR), 661
Short-to-ground
  definition, 430
  testing with tone generator, 490, 491
Short-to-ground, checking for, 1227–1228
Short-to-voltage
  blown fuses, 489
  case study, 430
  definition, 430
Shot peening, 374
Shrink ratios, 476
Shrouding, 281
Shunt field, 649
Shunt motors, 560
  wiring diagram, 560
Shunts, 438. *See also* Legs
Shut-off tool for batteries, 553
Shutoff valves
  fuel system procedure, 903
  shown, 903
Siamese cylinder bores, 354
  engine blocks, 354
Siamese ports, 283
Side airbags, 696–697
Sideband frequencies, 700
Side bearing adjuster tool, 1530
Side bearing preload, 1530–1531
Side bearing preload adjustment, 1523
Side bearings, 1523
  shown, 1523
Side-channel pump, 866
Side clearance, 343
  compression ring seals, 343
Side curtain airbag deployment, 689, 697
Side-cut pliers, release drum from shoes, 1103
Side cuts, 74
Side gears, close-up, 1519
Side marker lights
  alternate flashing by, 612
  bulb trade numbers, 607
  headlight switch, 605
  schematic, 612
  series-parallel circuit, 441
Side post battery adaptors, 550
Side terminal battery adaptors, 550
Sidewalls, 1241
  "e" symbols, 1247
  typical markings (chart), 1248
SIDI (Spark Ignition Direct Injection), 887
Sight glass, 740
Signal electrode, 846
Signal-to-noise ratio, 706
Silent chain type, 317
  sprockets and, 317
Silicon, 338
  described, 509
  forward voltage, 513
Silicon-controlled rectifier (SCR)
  construction, 515
  symbol and terminal identification, 515
  uses, 515
Silicon diaphragm strain gauge map sensor, 834
Silicone brake fluid, 133–134, 1052
Silicone coupling fan drive, 191
Silicone grease, 1137
Silicone sealers, on valve cover gaskets, 853
Silicon spray, precautions with, 853
Simple planetary gear set, 1559
Simpson gear set, 1559–1560
Sine wave
  alternator, 582
  voltage curve diagram, 582
Sine with dwell (SWD) test, 1233–1234
Single cell wide-band oxygen sensors
  construction, 857–858
  four wires shown, 858
  testing with millimeter, 858
  testing with scan tool, 859
Single-channel ABS systems, 1211
Single-channel scope, 464
Single-cut files, 75
Single-filament bulb
  digital multimeter testing, 608
  electrical problems, 430
Single overhead (SOHC) design, 150
Single overhead camshaft (SOHC), 315
  design, 4
Single-pole, double-throw (SPDT) switches, 484
Single-pole, single-throw (SPST) switches, 484
Single stroke bleeding method, 1063–1064
Single-wire CAN (SWCAN), 529
Sinking brake pedals, 1038, 1053
Sintered metal, 1121
Sintering, 1121
Sinusoidal, 453
SIP (State Implementation Plan), 920
SIR (supplemental inflatable restraints), 688
Sirius radio, 707
SISS (smart idle stop system), 891
6T70 transaxle disassembly and assembly, 1612–1615
Six-cylinder engines
  cubic inch displacement chart, 155
  maximum amperage draw, 569
Six-speed manual transmission, cutaway view, 1476
Sizing hone, 360
  cylinder surface, 360
Skewed, 253, 830
Skill levels and severe service, 29
Skin effect, 468–469
  speakers, 703
Skirt diameter, 338
SLA (sealed lead-acid) battery, 542
SLA-type suspension, 1313–1314
  adjusting front camber/caster, 1442
Sleep mode, tire-pressure sensors, 1265
Sleeve, 99
  micrometer shown, 99
Sleeve bearing, 374
Sleeving, 359
Sleeving the cylinder, 359
  dry cylinder sleeve, 359
SLI batteries, 6, 539
Slide hammers, 1602
Sliding calipers, 1122, 1126
  exploded view, 1126
  machined ways shown, 1126
Sliding conductor, 691
Sliding friction, 202
Sliding reverse gear, 1482
Sliding sleeve, 1477
Sling, 417
Sling psychrometer, 714
Slip angle, 1249
  shown, 1250
Slip-joint pliers, 73
Slipper skirt pistons, 339
Slipping clutch
  checking for, 1462
  flywheel failure, 1459
  possible causes, 1467
Slip ring, torque converter, 1553
Slip-ring-end (SRE) housing, 578
Slip rings, 595
Slope, 1044
Slot antenna, 700
Slotting, 1165
Small-hole gauge, 100
  measuring valve guide, 290
Smart airbag systems
  dual-stage, 691
  sensor use, 693
Smart idle stop system (SISS), 891
Smog, photochemical formation, 925
Smog pump, 945
Smoke machine testing, 968
  leak detection, 932
  leaks in exhaust system, 925
  unit shown, 932
Smoking and grease, 1074
Snake trick, 940
Snap acceleration test, 174
Snap-back test, 944
Snap-ring pliers, 75
Snap rings
  correct installation, 1543
  location, 1485
  removal, 1603
  snap-ring pliers in reassembly, 1544
Snap rings and clips, 62–64
Sniffer construction, 709
Sniff test, alternator, 594
Sniff test for gasoline, 763
Snips, 75
Soap, 111
Social Security taxes, 21

Society of Automotive Engineers (SAE), 199, 961
alternator/generator, 578
communication, classes of, 526–527
distributor ignition (DI), 782
electronic ignition, 782
engine oil ratings, 199
on PCMs, 812
Socket adapters, 71
precautions with, 71
Sockets, 69, 71
Sodium azide pellets, 689
Sodium-filled valves, 295
hollow stem, 295
safety, 295
Soft core plugs, 393
Soft skills, 17
SOH (state of health), 534
SOHC (single overhead camshaft), 315
additional components, 162
design, 4, 150
Solder, 475
wire repair methods summarized, 477
Soldering guns, 79–80
wire repair, 475, 477
Soldering gun trick, 635
Soldering procedure, 476
Solenoid
checking resistance, 570
as electromagnetic switch, 503
pulse-width modulated, 520
relay compared, 487
relay compared (chart), 502
Solenoid-controlled damper, 1352
Solenoid ohmmeter check, 570
Solenoid-operated starters, 564–565
exploded view, 570
operation, 564–565
solenoid windings, 564
wiring diagram, 564
Solenoids, actuator, 1348–1349
Solenoid-type cranking circuit, voltmeter hookups, 567
Solenoid valves, 1210–1211
Solid, 713
Solid axle, 1335–1336
Solid brake rotors, 1122
Solid-bushing inserts, 65–66
Solid fuel inflators, 689
Solid lifters, 298
adjustment, 406
cutaway view, 327
ramp, 327
Solid rear axles, 1335–1336
Solid rotors, 1122, 1164
Solid-state flashers, 611
Solid valve lifter, 327
Solvent-based cleaning, 273
Solvents, 51–52, 52
hazardous ingredients, 52
used, 52
Solvent spray, 51
Soot, 168
in DPF passages, 169
very small particles, 168
Sound, 112
Sound systems, capacitors for, 496. *See also* Audio system; Radio
Space frame, 1290
Space-frame construction, 4
Spalling, 1076, 1082
Spanner wrench, 1154
Spare tire, wheel speed fault code and, 1229
Spare tires, 1251
size designations, 1245
temporary mobility kits, 1270
Spark
how it is created, 506–507
intermittent, 794
Spark Ignition Direct Injection (SIDI), 887
Spark knock, 758, 791–792
clogged EGR passages, 940
octane rating related, 760
Spark line, 808
firing line relationship, 810
slope, 809–810
Spark line length, guidelines, 809
Spark lines
length of, 809
reading, 809–810
upward-sloping, 809–810
Spark output (SPOUT), 792
Spark plug boot, 801
Spark plugs, 802
best placement, 281
carbon fouling, 803
clipped side (ground) electrode, 803
construction, 801
heat range, 801, 802
heat transfer diagram, 802
inspecting for wear, 803
installation, 802
installation (hose trick), 243
misfire, 851
misfire and oxygen sensor, 851
normal wear shown, 802
operation, 149
overtightening, 804
parts diagram, 802
platinum, 802
polarity, 787–788
reach, 801
removal procedure, 802
resistor type, 802
seat type, 801
service, 802–804
typical installation torque (chart), 804
typical wear shown, 803
Spark plug thread chaser, 802
Spark plug wire boot pliers, 801
Spark plug wire pliers, 800
Spark plug wires
high voltage problem, 805
inspection, 799–801
maximum allowable resistance, 801
original wiring brackets, 805
precautions with disconnecting, 790, 806
reading digital meter displays, 452
testing, 799
track, 800
visual inspection, 800–801
water spray bottle for testing, 801
Spark tester
with alligator clip, 794
always use, 796
diagnosis, 794
recessed center close-up, 796
SPDT (single-pole, double-throw) switches, 484
Speaker outputs, 700
Speakers, 702
impedance matching, 702–703
midrange, 704
purpose and function, 702
skin effect, 704
sound levels, 704
speaker frequency response, 704
subwoofer, 704
tweeter, 704
two-terminal, 703
types, 704
wiring, 703–704
Speaker wire, 704
skin effect, 704
Specialty repair manuals, 78, 124
Specialty service facilities, 9
Specific gravity
battery testing, 547
charge indicators, 541–542
definition, 540–541
diesel fuel testing, 778
Specific gravity test, 547
Speed control. *See* Cruise (speed) control
Speed density, 840
Speed-density fuel-injection system, 835, 876–877
central port injection, 883–884
demand delivery system, 881–882
fuel injectors, 883
idle control, 885
MAP sensor values, 837
stepper motor operation, 885
Speed-density fuel-injection system modes of operation, 884–885
Speed gears, 1477
Speed nuts, 1102
Speedometer
calibration and tire diameter, 642
electronic, 635–636
Lincoln Town Car, 635
memory chip, 814
operation, 635–636
previous repairs, 636
service, 637
tire size related, 1245
Speed ratings of tires, 1246
chart, 1247
Speed sensitive steering (SSS), 1398
Speed sensor
defective, signs, 1594
troubleshooting, 637
Speed sensors, PCM inputs, 1580
Spider, 1496
Spider gears, 1517
close-up, 1519
Spider, of wheel, 1254
Spike protection, 512–513
Spike protection resistors, 513
Spike suppression, capacitors for, 495
Spindle, 99
Spin-on oil filter, cutaway view, 205
Spiral bronze alloy bushing, 291
installed view, 292
Spiral bronze alloy sleeve bushing, 291
Spiral lock rings, 342
Spit holes, 346
Splash gasoline blending, 761
Splash shields, 1118
Splay angle, 369
Splice pack (SP), 525
Splices
how to read symbols, 482
location schematics, 482
schematic symbol, 482
Spline bind, 1506
Spline phaser system, 332
assembly, 332
operation, 332
Split-ball gauge, 100
Split-loom tubing, 104
Split point, 1044
Split-type (half-shell) bearing, 379
Spoke angle, 1443
Sponge lead, 539
Spongy brake pedals, 1037, 1109
Spontaneous combustion, 43
Spool rear end, 1531
Spool valve, 1398, 1578
SPOUT (spark output), 792
Sprags, 1575
Spray-guided combustion, 890
diagram, 890
Spray washing, 274
pressure jet washer, 274
Spread, 378
Spreader tool, reinstallation of exhaust manifold, 225
Spreading jacks, 225
Spring compressing tool, 1328
Spring deflection, 1291
Spring deflection rate, 1292
Spring frequency, 1293
Spring insulators, 1329
Spring load, 1293
Spring-lock connectors, 864
quick-connect shown, 865
tool for disassembly, 864
Spring-lock coupling
Ford, 748
tool needed, 748
as variation on O-ring seal, 748
Spring pocket, 1294
Spring rate, 1291, 1292–1293
age of vehicle, 1293
Springs
coatings, 1295
coil, 1291–1295
fiberglass, 1296–1297
leaf, 1295–1297
suspension, 1291
Springs, synchronizer, 1477
“Spring test,” 894
Spring-type positive rotator, 301
Sprinter, troubleshooting chart, 172
Sprue, 338
Sprung weight, 1290
SPS, 1401
SPST (single-pole, single-throw) switches, 484
Spun bearing, 378
Spur gear, 1472
helical gear compared, 1473
teeth shown, 1472
“Square wave,” 816
Squeaking noise, 1504
drum brakes, 1110
Squeal, disc brake, 1137–1138
Squealing noise, pilot bearing, 1462
Squib, 689
removal from housing, 689
Squirrel cage blower motor, 654
Squish area, 280
SRE housing, 578
SRS (supplemental restraint system), 688
SSS (speed sensitive steering), 1398
Stabilitrak, 1352
Stabilizer bar link and bushing service, 1326–1327
Stabilizer bars, 1301–1302
replacement, 1327
Stabilizer links, 1302
Stainless steel valves, 294
Staked tie rod ends, 1374
Stall, service bay, 27
Stall acceleration test, 174
Stall speed, 1555
checking in reverse, 1591
procedure, 1591
Standadyne assembly, 162
Standard 135, 1145
Standard corporate protocol (SCP), 529
Starburst symbol, 200
Star link networks, 525
Star pattern, lug nut, 1273–1274
Start clutch, 1564
location, 1564
Start clutch calibration, 1564–1565
Starter, 503
Starter amperage test, 569
excessive current draw, 569
lower amperage draw, 569
reason for, 569
specifications, 569
tester diagram, 569
test preparation, 569
Starter armature, 467
service, 570
Starter brushes, 561
inspection, 571
replacement, 571
Starter drives, 562–564
cranking circuit, 557
cutaway view, 563
failure mode, 563–564
gear ratio, 563
operation, 563
purpose and function, 562
Starter drive-to-flywheel clearance, 571–572
procedure for proper clearance, 572
shims needed, 571–572
symptoms of clearance problems, 572
Starter motor
avoid hitting, 562
battery condition, 555
brushes, 561
compound motors, 560
cranking circuit, 556
cutaway view, 562
field coils, 570
gear-reduction starters, 562–564
how they work, 560–561
installation, 571
operation, 558–560
overhaul procedure, 573–576
permanent magnet motors, 560
positive engagement starters, 564
principles, 558–559
series motors, 559
service, 570–571
shunt motors, 560
solenoid-operated starters, 564–565
troubleshooting procedure, 566–568
troubleshooting symptom guide, 572
“whining” noise, 563
Starter motor operation
parts involved, 560–561
permanent magnet fields, 561
starter brushes, 561
Starter motor service, 570–571
disassembly procedure, 570
inspection and testing, 570–571
purpose, 570
Starter removal, 569–570
Starter ring gear, 152
Starters
with attached solenoid, 503
removal, 569–570
small size, 565
Starter solenoid (relay), 564–565
“clicking” sound, 566
cranking circuit, 557
source of battery drain, 555
Starter solenoid battery terminals, fusible links and mega fuses, 473
Starting, lighting, and ignition (SLI) batteries, 6, 539
Starting systems
computer-controlled, 557–558
overhaul, 573–576
Starting systems. *See also* Starter motors
symptom guide, 572
troubleshooting procedure, 566–568
Star washer, 62
Starwheel adjuster, 1107
pre-assembly, 1108
State Implementation Plan (SIP), 920
State inspection EVAP tests, 932
State of charge, battery, 546–547
State of health (SOH), 534
State tax, 21
Static balance, 1278
Static electricity
definition, 425
from door handles, 492
Static electricity, from tire friction, 1243
Static friction, 1025
Static load, 1293
Static seals, 1074
Stationary stator windings, 580
Stator, 580, 1551
construction, 580
delta-connected, 583
induced current, 582
one-way roller clutch, 1555
shorted, 595
“STA” label, 582–583
testing, 595
visual inspection, 599
wye-connected, 582
Stator coils, 1349
Stator hub, 1555
Stator support, 1554
Steam
blown cylinder head gasket, 238
excessive exhaust head gasket failure, 248
possible causes, 238
Steam cleaning, 274
Steam slits, 191
Steel, 113
SAE designations, 113
Steel caliper pistons, 1131–1132
Steel camshaft, 316
Steel disc inspection, 1603
Steel shot, 44
Steel spacers (shims) tool, 1531
Steel-toed shoes, 41
shown, 42
Steel wheels, 1256

Steerable rear axle, 1378
Steering columns, 1358–1363
collapsible, 1360–1361
column cover, 1360
construction, 1361–1363
flexible coupling, 1360
hammer use, 1361
steering shaft, 1359
telescoping, 1361
tilt mechanisms, 1361
universal joint (U-joint), 1359–1360
Steering dampener, 1372
caster, 1418
Steering gear ratio, 1364
Steering gears
adjustments, 1366–1367
constant-ratio, 1364
conventional, 1363–1364
rack-and-pinion, 1367–1369
ratio, 1364
recirculating ball, 1364–1366
sector gear, 1363
variable-ratio, 1364
Steering knuckles, 1299
ball joints, 1328–1329
diagnosis and replacement, 1328–1329
front suspension, 1312
suspension, 1299
Steering linkage, 1372–1373
common wear items, 1380
four-wheel, 1375–1378
inspection, 1380–1382
jounce/rebound test, 1380
killer Bs, 1382
lubrication, 1378
replacement, 1382–1384
service, 1382–1385
tie rod ends, 1373
Steering offset, 1422–1424
Steering rack removal and installation, 1409–1411
Steering shaft, 1369
Steering shaft bearing, 1363
Steering shaft torque sensor, 1401
Steering stops, 1378
Steering wheel controls
E & C communication, 528
photodiodes, 514
Steering wheel position sensor, 1345–1346
signals analyzed, 1377
Steering wheel position sensors, 1234
electric power steering, 1401
Steering wheels
air bags, 1358
alignment, 1439
centering, 1444
horn, 1358
removal, 1444–1446
Stellite®, 294
hard seat stones, 304
Step-bore master cylinders, 1036
Step/courtesy light, bulb trade numbers, 607
Stepped ECT circuits, 819
transition temperature, 821
Stepper motor, 629
Stepper motor operation, 885
schematic, 886
Stepper motors, disadvantage for ETC, 894
Step-up transformer, 505. *See also* Ignition coils
Stereo broadcasts, 700
Stereo equipment, potentiometer, 427
Stethoscope fuel-injection test, 901
fuel returning, 901
lack of sound, 901
Stethoscope fuel-pressure test, 871
STF (synchromesh transmission fluid), 144
Stick-on wheel weights, 1279
Stiffening capacitor, 705
Stitching tools, 1282
Stock clutch disc, 1457
Stoichiometric air-fuel ratio, 757–758, 856
CNG, 102
Stone wheels, 84
Stop drilling, 277
Stop lamps
bulb trade numbers, 606
schematic, 610
two-filament bulbs, 610
Stop-leak
in tires, 1279
TPMS sensors, 1280
Stop ring, 1478
Stops with engine off, 1020
Storage, computer, 813–814
Storage mode, 1266
Straddle-mounted pinion, 1522
Straight blade screwdrivers, 72
Straight cut aviation snips, 75
Straight cut tin snips, 75
Straightedge, 103
with feeler gauge, 103, 286
precision ground, 286
Straight front axle, 1312
Straight roller bearings/rear axles, 1523
Straight time, 21
Straight vegetable oil (SVO) as fuel, 780
Stratified catalyst heating mode, 890
Stratified mode, 889
Stress relief procedures, 374
Stress riser, 1295
Strike-out bumpers, 1308
Stroke, 154
how it is determined, 154
Strokes, number of, 149
Strong hybrid, 990
Strut, servo, 1572
Strut-quadrant ratchet automatic adjusters, 1099
Strut rod bushing service, 1327
Strut rods, 1301
bushings, 1327
longitudinal support, 1299, 1303
nut removal, 1325
short/long-arm suspension, 1313–1314
Struts, 1306, 1308
camber adjustment, 1440
Chapman, 1339
checking for bent, 1434
MacPherson, 1306, 1314–1315
modified, 1308, 1315
pistons, 340
replacement procedure, 1331–1334
shown, 1310
strut spring compressor, 1325
upper strut mounting bolts, 1324
Struts, piston inserts, 340
piston pin area, 340
Strut suspension, 1314–1315
Stub shaft, 1361
Stub-type frame, 1289
Stuck-open thermostat, 253
Stud-mounted rocker arms, 321
typical, 321
Stud removal tool, 76
Stud remover, 76
Studs, 58
preparing block for, 389–390
Subaru
intercooler, 233
remote keyless programming, 678
Sublet repairs, 29
Subwoofer, 704
Suction stroke, 727
SULEV (super-ultra-low-emission vehicle), 127
SULEV (super ultra low emission vehicle), 919
Sulfated, 545
Sump, 217
Sun gear, 1540
automatic transmission, 1558
Sunload sensor, 732
Supercharged engines, MAP sensor calibration, 834
Supercharger, 151, 230
boost control, 230, 232–234
centrifugal, 230
Ford cutaway view, 231
Ford V-8, 228
pressurizing air, 229
roots type, 230
service, 230
types of, 230
volumetric efficiency, 228
Supercharger boost control, 230, 248–249
boost control factors, 248
bypass valve, 230
purpose and function, 232
relief valves, 248–249
wastegate, 248
Superheat, 724–725
Superimposed position of ignition oscilloscopes, 808
Supplemental air restraints (SAR), 688
Supplemental brake assist (SBA), 1203
Supplemental inflatable restraints (SIR), 688
Supplemental restraint system (SRS), 688
Supplies guides and catalogs, 78, 124
Suppression capacitors, 497
for EMI suppression, 507
Suppression diodes, 512–513
Surface charge, 546
Surface finish, 287–288, 366, 1024, 1168–1169, 1172–1173
block and cylinder head chart, 389
correct final, 1174
gasket sealing, 389
honing tool, 362
measured in microinches, 389
Surface finish machine, electronic, 1170
Surface grinder, 287
cast-iron cylinder head, 287
cylinder heads, 287
Surfaces, checking before engine assembly, 389
Surface-to-volume ratio, 281
Surge dampers, 299
Surge tank, 188
location diagram, 189
Suspension
overview, 2
RSS, 1345
Suspension and steering, ASE test task list, 38
Suspension bumpers, 1310
Suspension height, system actuator, 814
Suspension, modified, 1234
Suspension position sensor, 1344
Suspension principles, 1298–1299
anti-dive, 1299
anti-squat, 1299
lateral links, 1298
Suspension system
ball joints, 1300
ball joints diagnosis, 1318
bump stops, 1308
coil springs, 1291–1295
control arms, 1299–1300
conventional versus electronic, 1343
dry park test, 1317
frame construction, 1289–1290
front suspension types, 1312
Hooke's Law, 1291
independent, 1290
leaf springs, 1295–1297
platforms, 1290
problem symptom chart, 1316
purpose of, 1257
road test diagnosis, 1316–1317
servicing, 1315
shock absorbers, 1302–1306
spindle, 1298
springs, 1291
stabilizer bars, 1301–1302
steering knuckles, 1299
strut rods, 1301
struts, 1306, 1308
torsion bars, 1297–1298
unsprung weight, 1290
visual inspection, 1317–1318
SVO fuel, 780
SVR (sealed valve regulated) battery, 542
Swash plate, 728
location, 729
SWCAN (single-wire CAN), 529
Sweet smell, 239
Swept area, 1115
Swirl combustion, 890
diagram, 890
Switched output, computer controls, 816
Switches
brake fluid level sensor, 1043
brake light, 1048–1049
brake pedal travel, 1217
brake warning, 1041–1042
electronic stability control, 1233
independent, 664
lockout, 664
master control, 664
momentary switch, 484
normally open (N.O.)/normally closed (N.C.), 484
normal position in schematics, 484
open, 487
pressure-differential, 1041–1042
schematic symbol, 484
traction deactivation, 1237–1238
transmission range, 1236
Switchgrass, 768
Switching, ignition system, 783–784
Swollen parking cable, 1148
SWPS, 1377
Symmetrical camshaft, 320
Symptom information charts, 76, 123
hesitation chart, 77, 123
Synchromesh transmission, 1477
Synchromesh transmission fluid (STF), 144, 1487
Synchronized throttle-body fuel-injection, 877
Synchronizer assembly, 1477
construction, 1477–1478
Dodge/Plymouth Neon, 1483
operation, 1478
three-piece, 1480
three stages of shift, 1478
typical, 1478
Synchronizer keys, 1478
shown, 1479
what they do, 1479
Synchronizer parts and operation, 1477–1480
Synchronizer ring, 1477
Synchronizer sleeve, worn, 1486
Synchronizer springs, 1477
Synchronizer struts, 1478
Syncrude, 776
Syn-gas (synthesis gas), 772
Synthetic brake grease, 1137
Synthetic engine oil, 202–203
advantages/disadvantages, 203
API groups, 202–203
fluid at low temperatures, 203
lawn and garden equipment, 203
Mobil 1, 203
superchargers, 248
switching to regular oil, 135
synthetic blends, 203
Synthetic fuels, 774–776
coal to liquid (CTL), 775–776
Fischer-Tropsch, 775
future of, 776
methanol-to-gasoline (MTG), 776
Synthetic retainers, 1507
Synthetic rubber gaskets, 383

T

TAC (Throttle Actuator Control) module, 893
Tachometer trick, 785
Tach reference (purple/white) wire, 792
Tag number, 1599
Taillights
bulb replacement procedure, 621
bulb trade numbers, 606
headlight switch, 605
LEDs, 514
schematic, 609
series-parallel circuit, 442
troubleshooting, 488
Tailpipe outlet exhaust, precautions, 170
Take-home pay, 21
Tandem-diaphragm vacuum boosters, 1201
exploded view, 1204
Tang, 378
Tank and vapor cleaning
cold tank cleaning, 275
vapor cleaning, 275
Tap, 60
thread chaser compared, 61
Tape measure, 98–99
Taper breaker, 1320
Tapered pilots, 303
Tapered piston ring gap, 343
Tapered reamer, 278
Tapered roller bearings, 1071–1072, 1526
Tapered roller bearings/rear axles, 1523
Tapered valve guide pilots, 303
Taper face ring, 344
oil control, 344
Taper taps, 60
Tappets (lifters)
hydraulic lifters, 327
purpose and function, 326
solid lifters, 327
valve lash, 327
Tap test, 844, 1159
Target idle speed, TP sensor, 829
Target upstream fuel trim, 853
Task manager, 958
enabling criteria, 960
Taylor Automotive Tech-Line, 124
TBT (throttle-body temperature), 824
TC. *See* Traction control (TC)
TCC, 1556
friction material, 1557
PWM, 1557
TCM (transmission control module), 1565
TCM sensor
defective, signs, 1594
fast learn, 1608–1609
TDC (top dead center), 149
TDMA (time division multiple access) protocol, 534
Teacher, 30
Team building, 31
Team leader, 12
Teamwork, 31
Tech 2 scan tool
battery drain test, 554
bypass mode, 535
DTC P0336, 799
pinging, 534
shift solenoid current, 1589
zero RPM while engine running, 798
Technical knowledge, 16
Technical service bulletins (TSBs), 78, 122, 1449
flat-rate time included, 122
HVAC diagnosis, 737
transmission problem diagnosis, 1590
Technician (tech)
housekeeping duties, 31–32
job classifications, 10–13
need for, 8
protection during service procedures, 130–131
work sites, 9–10
Technician A and Technician B questions, 36
Technician certification, 34–40
Technician team leader, 12
TED (thermoelectric device), 669
Teflon® seals
dry installation, 395
gasket, 385
precaution with using oil on, 385
Teflon® tape, precautions, 393
Telephone communications, 25–26
pen and paper handy, 25
smile while talking, 26
Telescope, 1361
Telescopic gauge, 100
camshaft bearing measurement, 101
main bearing bores, 357
Telescoping steering columns, 1361

Telltale light, 1233
dash warning symbols, 625
Temperature, 110–111
conversion chart, 111
and heat, 713
high-side pressure in air conditioning, 740–741
normal operating temperature, 418
volume and pressure of a vapor, 713
Temperature sensor bulb, air conditioning, 717
Temperature sensors
DTCs, 827
electrically heated seats, 668–669
fuel delivery, 877
Temporary mobility kits, 1270
Tensile strength, 59
Tensioner, OHC timing drives, 405
Tensioner marks, 140
Terminal
crimping, 476
definition, 474, 480
removing from a connector, 474
schematic symbol, 482
Terminal 30, 485
Terminal cleaning, batteries, 545
Terminals, loose, 431
Terminating resistors, 534
Tertiary-amyl methyl ether (TAME), 760
Tertiary butyl alcohol (TBA), 760
Test drive, 418
shift modes, 1587
transmission problem diagnosis, 1587
Testers, diodes and transistors, 520
Test identification (TID), 964
Testing mass airflow (MAF) sensor, 842
Test lights, 79, 445–446
12 volt, 445
continuity, 445
defective fusible link, 589
high-impedance, 445
LED, 445
locating a short circuit, 489
nonpowered, 445
self-powered, 445–446
Test strips
brake fluid, 134
coolant, 136
shown, 137
Test strip testing, 180
Tetraethyl lead (TEL), 758
TEV (thermostatic expansion valve), 716
Teves Mark IV, 1225
TFE (two-flow electronic) steering, 1397–1398
TFT (transmission fluid temperature) sensor, 825–826
THD (total harmonic distortion), 706
Theft deterrent indicator lamp, as fault indicator, 566
Thermactor pump, 945
Thermal (bimetal) flashers, 611
Thermal blanket for battery, 469
Thermal cleaning, 44
advantages, 274
microbial cleaning, 274
pyrolytic oven, 274–275
temperatures involved, 274
Thermal ovens, 44
safe use, 44
Thermal shock, 296
Thermal vacuum valve, leaking, symptoms, 249
Thermistors, 515, 585
symbols, 515
temperature compensation, 584–585
uses, 515
Thermocouple, 425
Thermodynamics, 111
Thermoelectric device (TED), 669
Thermoelectricity, 425
Thermoplastic, 112
Thermoset plastic, 112
Thermostat, 5
bypass, 184
coolant temperature, 148
diagnosis, 738
excessive temperature rise, 185
exploded view, 118
location on Chrysler and GM, 183
normal operating temperatures, 823
operation, 183–184
placement location, 118
positioning, 186
purpose and function, 183
reasons not to remove, 185
replacement, 185–186, 746
structure, 186
stuck in open position, 184, 253
testing, 185
wax-actuated (cross section), 184
Thermostatic control, 716–718
Thermostatic cooling fan, 191–192
Thermostatic expansion valve (TEV or TXV), 716
diagram, 724
how it operates, 723–725
sensing bulb, 724, 725
Thermostatic spring cooling fan, 191–192
view of typical, 192
Thermostat replacement, 185–186
failure patterns, 253
procedure, 253
Thermostat testing
hot water method, 185
infrared pyrometer method, 185
scan tool method, 185
Thermo switch, 718
Thickness gauges, 102
Thickness variation (TV), 1167
Thimble, 99
Thimble design for oxygen sensor, 846
Thin-walled bronze alloy sleeve bushing, 291
Third brake light, 659
Third-class lever, 109–110
Third-class levers, 1023
Third gear, 1481
Third position, automatic transmission, 1558
Thread chasers, 61, 390
Thread depth, 141
Threaded adjuster, 1530
Threaded fasteners, 58
Threaded inserts, 65
Threaded rod for dial indicator, 103
Thread locker
strength, 386
on studs, 390
Thread lubricant, 402
Thread pitch gauge, 61
Thread repair inserts, 64–67
3 × 5 card test, 944
Three-angle valve job, 302
Three-channel ABS systems, 1211
Three Cs (concern, cause, correction), 27
Three-cylinder engine, crankshafts, 368
Three-minute charge test, 548
Three-position actuators, 732
Three-quarter-floating axles, 1079
Three-wire oxygen sensor, 848
Threshold voltage, 517
Throating angle, 302
Throating the valve seat, 305
Throttle Actuator Control (TAC) module, 893
Throttle body, removal for cleaning, 911
Throttle body assembly, 894
cleaning procedure, 898
electronic throttle body motor, 894
precautions with, 898
throttle plate and spring, 894
Throttle-body fuel-injection systems, 877–878
Chevrolet V-6, 876
fuel pressure regulator shown, 877
nonsynchronized, 877
synchronized, 877
Throttle-body injection
intake manifolds, intake air speeds, 221–222
terminology, 221
unit on GM V-6, 222
Throttle-body injector, purpose, 221
Throttle body relearn procedure, 898–899
Throttle-body temperature (TBT), 824
Throttle control assembly, corrosion shown, 897
Throttle plate motor
H-bridge circuit, 894
shown, 895
Throttle plates, 894
cleaning, 911
default position shown, 895
fail safe position, 894
neutral position, 894
normal and abnormal operation, 897
staying where it is moved, 897
Throttle position (TP) sensors, 893, 895–896
5-volt reference, 831
5 volt V-ref interface, 521
backing up other sensors, 829
computer controls, 816
computer input functions, 829
computer input sensor, 816
cruise control, 659
DTCs, 831
fuel delivery, 877–878
Hall-effect, 895
location, 893
opposite voltage signals, 896
PCM inputs, 1580
PCM uses for, 829
potentiometers, 427, 828
pulse width, 878
skewed, 830
testing, 830–831
three-wire potentiometer, 895
three wires, 828
traction control, 1236
voltage at idle, 828
waveform, 462
Throttle position (TP) sensor testing, 830–831
using Min/Max function, 831
using scan tool, 831
Throttle switch, 729
Throttle valve, 1578
cable on 4T-60, 1578
diesel engine, 160
Throttling losses, 159
Through bolts, 560
installation, 576
removal, 573
Throwout bearing, 1454
Throws, 484
Thrust angle, 1425
Thrust bearing, 365
ground surface, 366
Thrust bearing clearance, 396
dial indicator, 396
Thrust bearing insert, 396
Thrust line, 1436
Thrust plate, 319
Thumping noise, 1110
Ticking noise, worn cam lobe, 328
TID (test identification), 964
Tier 1 emission standards, 127, 919
Tier 2 emission standards, 127–128, 919
Tie rod adjusting tools, 1445
Tie rod ends, 1373
greasing, 1378
locking pliers for, 1446
rack-and-pinion inner, 1373–1374
replacement, 1383, 1384
Tie rods, 1372
setting toe, 1443
steering linkage, 1373
Tightening fasteners, 64
Tightening torque precautions, 389
Tilt steering column, 1361
Time base, 462
Time division multiple access (TDMA) protocol, 534
Time guides, 28, 29
severe service times, 74, 122
Time per division, 462
Timer circuits, capacitor for, 495–496
Timer relay, 662
Timesert® kit, 66
Timing belt
failure, 318
oil leak failure, 318
Timing belt replacement
guidelines, 255
need for, 255
single overhead camshaft engine, 255
Timing chain
Chevrolet replacement, 320
failure in Mercedes-Benz, 319
and gear installation, 405
hydraulic sensor, 317
installation, 405
noise, 240
plated links, 404
replacement, 262
standards, 318
soaking, 405
Timing cover installation, 407
sequence, 407
Timing gear, GM V-6, 267
Timing sprocket, worn, 262
Tinnerman nuts, 1102, 1162
Tin snips, 75
TIR (total indicator runout), 304, 329
Tire, cross-sectional view with terms, 1245
Tire and wheel service, 140–143
Tire balancer, shown, 1280
Tire balancing, 1278–1280
dynamic, 1278
liquid in tires, 1279
prebalance checks, 1278–1279
static, 1278
weight recommendations, 1280
wheel weights, 1279
Tire chirp noise, 1209
Tire diameter, speedometer calibration related, 642
Tire disposal, 54
Tire gauges, digital *versus* mechanical, 1268
Tire inflation
nitrogen inflation, 1270
reasons to check, 1270
underinflation impact, 1271
Tire lug nut torque, 142
Tire mounting, 1272–1273
age of tires, 1277
break-in period, 1272
checking rim size, 1272
lubricants, 1272
match mounting, 1272
procedure, 1283–1285
Tire noise, 1074
Tire pressure
changes with temperature, 1243, 1262
checking, 140–141
cold placard inflation pressure, 1262
digital gauge, 1268
fine-tune handling, 1274
indirect TPMS, 1262–1263
inflation levels, 1270
inspection, 141
low pressure effects, 1262
need for monitoring, 1261–1262
seasonal changes, 141
spare tires, 1251
specified pressure, 141
spec locations, 141
traction, 1246–1247
two quick checks, 141
warning lamp, 1263, 1263–1264
where to locate sticker, 1262
Tire pressure gauge, 141
Tire pressure monitoring system (TPMS), 627, 1217
Tire repair, 1281–1282
procedure, 1286–1287
Tire rotation, 141–142, 1274, 1274–1275
modified X method, 142, 1275
tech tips, 1273
when to rotate, 142
Tire runout gauge, 1276
Tires
ABS and, 1208–1209
age, 1277
all-season, 1250–1251
all-wheel concerns, 1275
bead, 1241
belts, 1242
bias-ply, 1241
braking vibration and, 1167
caster angle wear, 1418
“chirp” noise, 1209
conicity and ply steer, 1247, 1249
disposal, 1282
DOT code, 1251
feathered wear, 1421
grooves, 1240
high-flotation, 1245
inspection, 1259–1260, 1276
LRR, 1253
load index, 1246
M & S, 1250
materials, 1241
metric designations, 1243
molding, 1242
outside diameter, calculating, 1244
parts, 1240–1242
“pass-by” noise limits, 1247
pulling and, 1117
purchasing considerations, 1253–1254
purpose and function, 1240
radial-ply, 1241
rim width and tire size, 1249–1250
rotation, 1274–1275
run-flat, 1252–1253
service description method, 1245
sidewall, 1241, 1247
size, 1117
slip angle and handling, 1249
space saver spare, 1229
speed rating, 1246
static electricity buildup, 1243
stock, 1217
temperature pyrometer, 1448
temperature resistance, 1250
toe, 1418–1421
TPMS, 1261
traction, 1208–1209, 1240, 1250
unsprung weight, 1257
UTQGS, 1250
valves, 1257
wear chart, 1428
Tire selection, considerations, 1253–1254
Tire service
how to check pressure, 141
inflation pressure, 140–141
inspection, 141
rotation, 141–142
specified pressure, 141
two quick checks, 141
Tire size
for older vehicles, 1246
Pax tires, 1252–1253
recommendation, 1245
recommendations, 1243
rim width and, 1249–1250
unsprung weight, 1257
Tire slip, 1209
braking distance, 1209
graph, 1210
non ABS, 1211
vehicle stability, 1209
Tire surface contact area, 1249
Tire tread depth gauge, 1240
Tire tread wear chart, 1428
Tire valve core torque wrenches, 1268
Titania, 848
Titania (titanium oxide) oxygen sensor, 848

Titanium, 294
TLEV (transitional low-emission vehicle), 127
TLEV (transitional low emission vehicle), 919
Toe, 1418–1421, 1518
measuring, 1433
pull, 1418–1420
rear toe, 1439
setting, 1442–1444
TOOT (toe-out on turns), 1424, 1433
unit conversions, 1443
Toe-control rod, 1339
Toe in, 1417
Toe out, 1417
Toe plate, 1361–1362
Tolerance adjustment, 1447
Tone generator tester, 490
Tone ring, 1212
Tools
borrowing and using others', 27, 30
tool box housekeeping, 31
which to purchase, 28
Tool sets and accessories, 78
TOOT (toe-out on turns), 1424, 1433
Tooth contact pattern chart, 1527
Tooth contact pattern test, 1526
Top dead center (TDC), 149
Topping angle, 302
Topping the valve seat, 304–305
Top-tier gasoline, 763
Torch, setup and lighting procedure, 87–88
Torque, 106, 157
checking specifications, 71
corrected torque, 411
defined, 1475
ft-lb or lb-ft, 157
graph showing horsepower and, 117
as measured value, 410
speed related, 1475
transmission needs, 1472
typical (GM) flow, 1582–1584
unit for, 71
work compared, 107
Torque angle, measuring, 404
Torque arm, 1337
Torque converter, 1551
clutch engagement and release, 829
engine noise diagnosis, 240
installation, 416
internal splines, 416
Torque converter clutch (TCC), 1556
cutaway view, 1601
diagnosis, 1592–1593
drop in fuel economy, 1592
friction material, 1557
PCM or TCM controls, 1581
PWM, 1557
shown, 1556
Torque converter clutch (TCC) solenoid
computer controls, 816
shown, 1590
Torque converters, 1551–1556
ATF routed, 1569
checks, 1600
coupling phase, 1555
cutaway view, 1554
diameter, 1555–1556
drives the pump, 1553–1554
expanded view, 1556
flexplate, 1553
hub flat sections, 1554
installation, 1608
internal splines, 1554
normal operation, 1555
operation, 1552–1553, 1554
precautions with dropping, 1609
replacement, 1601
stall speed, 1555
stall testing, 1591
torque multiplication phase, 1554–1555
transmission input shaft, 1554
vibration test, 1592
Torque dampener plate, 1552
Torque flow through standard open differential, 1519–1520
Torque-limiting adapter, 1274
Torque multiplication, 1475
flows shown, 1555
Torque multiplication phase, 1554–1555
Torque plate, 360
cylinder honing, 361
Torque prevailing nuts, 1510
Torque rating, 1560
Torque sensitive vibration, 1498
Torque steer, 1430–1431
Torque sticks, 142
shown, 142
Torque-to-yield method, 403–404
bolt construction, 403
procedure, 404
steps, 404
Torque-turn method, 404
Torque wheel method, 1020
Torque wrench, 70
calibration checker, 71
care with cylinders, 383
how to apply, 404
reading, 195, 590
second click story, 143
tire lug nut torque, 142
Torsen differentials, 1521
shown, 1522
Torsional dampers, 1457
Torsional twist rings, 344
Torsional vibration damper (harmonic balancer), 369, 370
importance of correct size, 370
Torsional vibration damper, vibration damage, 369
Torsion bars
adjustment, 1329
service, 1329
SLA suspension, 1313
Torx bolt, loosening, 1438
Torx driver, 573
Total base number (TBN), 201–202
Total circuit resistance (RT), 439
Total harmonic distortion (THD), 706
Total indicator runout (TIR), 304, 329, 1166
Total resistance
in parallel circuits, 440–441
series-parallel circuit examples, 442–443
Total suspended particulate (TSP), 168
Total toe, 1433
Touch screens on navigation systems, 638
Touring ride mode, 1352
Toxic materials, 48, 52
Toyota
airflow sensors, 844
battery replacement issues, 554
battery sizes, 543
BUS communications, 532
combination spark plug system, 790
cruise (speed) control, 72, 120
cruise control, 658
direct fuel injection, 887
EGR temperature sensor, 826
failed emission test, 844, 926
fuel cap, tightening, 934
hybrid vehicles, 127
immobilizer or vehicle theft deterrent key learn procedures, 682
lane monitoring system (LMS), 641
low engine power problem, 792
minimum speed with cruise control, 658
precollision system, 662
radar cruise control, 661
remote keyless programming, 677, 678
scan tools compared for air-fuel ratio, 857
turbocharger, 228
variable camshaft timing, 330
Toyota Camry
high idle, 897
smog emissions label, 920
Toyota HEV
closed loop operation, 855
heating and cooling, 736
ready light, 256
Toyota hybrid (FCHV), C02 refrigerant, 719
Toyota Prius, bin number, 127
Toyota truck, electrical problems, 636
Toyota T-TEN training, 17
TP (throttle position) sensors
backing up other sensors, 829
computer input functions, 829
fuel delivery, 877–878
PCM uses for, 829
potentiometers, 828
pulse width, 878
testing, 830–831
traction control, 1236
TPC tire rating, 1253
TPMS (tire pressure monitoring system), 1217, 1261
diagnostic tools, 1267
identifying vehicle with, 1264
indirect, 1262–1263
installing a new sensor, 1266–1267
pressure sensors, 1264–1265
receiver, 1266
relearn procedure, 1268
replacement tires, 1265
rubber tire valve stems, 1264
TREAD Act, 1263
warning lights, 1266
TPMS relearn, 1268
Track
definition, 800
diagram, 800
Tracking, 1425–1426
Track of a vehicle, 1290
Track rod, 1310, 1337
Trac-loc limited slip differential, 1520
Traction, ABS, 1208–1209
Traction active lamps, 1236–1237
Traction control (TC), 1236–1238
brake-actuated, 1537
diagnosis, 1238
typical system, 1237
Traction control or low traction light, 1237
Traction control system, 627
Traction deactivation switch, 1237–1238
Traction, tire, 1208–1209, 1240, 1250
Trade number, 605
Trade show training, 78, 124
Trailer hitch, braking problems related, 1132
Trailer icon lights, 661
Trailer tow mode, 660
Trailing arm rear suspension, 1337
Trailing shoes, 1095
Trainee, 30
Training, 10, 11
cooperative education programs, 17
working with a mentor, 30–31
Training conferences, 78, 124
Tramp, 1276, 1414
Transaxle, 6
ASE task list, 38
automatic, 1561
checking wiring, 1596
disassembly, 1484–1485
factory service manuals, 72–73, 121
removal, 1482–1483
shown, 1483
transmission compared, 1472
use of term, 1454
Transaxle diagnosis, quick and easy, 1587
Transaxle disassembly
clutch packs, 1603
clutch piston inspection, 1604
clutch piston removal and inspection, 1603
friction disc inspection, 1603
hubs, drums, shells, and planetaries, 1604
mount to holding fixture, 1600
pump assembly, 1601
return spring inspection, 1604
steel disc inspection, 1603
torque converter checks, 1600
unit disassembly step by step, 1601–1603
valve body, 1601
Transaxle lubricant check, 144
Transaxle removal, step by step, 1610–1611
Transaxle repair
6T70 disassembly and assembly, 1612–1615
dynamometer testing, 1608
reinstalling, 1608
removal, step by step, 1610–1611
road test, 1608–1609
verifying need for repair, 1598–1599
Transaxle service, NV-350 transaxle service, 1491–1493
Transducers, 411, 1593
Transfer cables, 1148
Transfer case, 5, 1534, 1537
chain-drive, 1543
cutaway showing drive chain, 1543
exploded view of New Venture 241, 1538
gear-to-gear, 1539–1540
mode shift, 1539
NV-242 transfer case service, 1546–1549
planetary gear set, 1540–1541
purpose and function, 1537, 1539
range shift, 1539
service and problem diagnosis, 1543–1544, 1545
typical, 1537
Transfer case bearings, 1543
Transistor, 784
Transistor gates, 518–519
construction, 518
operation, 518–519
purpose and function, 518
Transistors, 516–517
basic operation, 516–517
bipolar, 516
blown, 518
construction, 516
Darlington pair, 517
definition, 516
field-effect transistors (FETs), 517
with gate circuit, 518
how they amplify, 517
how they work, 516–517
phototransistor, 518
purpose and function, 516
relays compared, 516
symbols, 516
testing, 520–521
Transmission, 5
disassembly, 1484–1485
gear ratios, 1473–1475
gear types, 1472–1473
need for, 1472
removal, 1482–1483
shown, 1483
speed gears, 1477
synchronizer parts and operation, 1477–1480
torque, speed, and power, 1475
transaxle compared, 1472
use of term, 1454
Transmission bands, 1571–1572
adjustment, 1596–1597
Transmission bearings, 1460
Transmission case, 1476
Transmission control module (TCM), 1565
Transmission cooler installation, 1609
Transmission dummy shaft, 1486
Transmission filler cap, tight installation, 1586
Transmission filler plug, tight installation, 1586
Transmission fluid heater, 1569
Transmission fluid leak, location, 1592
Transmission fluid temperature (TFT) sensor, 825–826
PCM inputs, 1580
Transmission identification number, 1599
Transmission input shaft, 1460, 1554
Transmission installation
automatic, 416
manual, 415–416
Transmission oil temperature (TOT) sensor, 825–826
Transmission problem diagnosis, 1586–1591
commanding shifts, 1587–1588
DTCs, 1588–1589
fluid check, 1591–1592
scan data, 1589
stall testing the torque converter, 1591
technical service bulletins, 1590
test drive, 1587
transmission/transaxle identification, 1590–1591
verify customer concern, 1591
Transmission range switch, 1236, 1580
checking procedure, 641
Transmission shifting, computer controls, 816
Transmission trailer towing mode, 660
Transmission/transaxle identification, 1590–1591
Transmitter ID, for TPMS sensors, 1267
Transverse mounting, 149, 151
Tread, 1240–1241
feathered wear, 1421
TREAD Act, 1263
tire inflation, 1270
Tread chaser, 363
Tread depth, 1240
Tread featheredging, 1420
Tread rubber, 1240
Tread wear, 1250
Trial assembly
check angle between heads, 392
short block, 391–392
valve train, 391
Triangulation, 1313
Tri-fuel vehicles, 774
Trigger level, 464
Triggers, 464–465, 784
Trigger slope, 464–465
Trimetal bearings, 375
Trip, definition, 960
Tripod fixed joint, 1501
Tripod plunge joint, 1501
Tri-state dampers, 1351–1352
Trouble codes
charging system, 586
storage in RAM, 814
U codes, 530
Trouble lights, 84
Troubleshooting
battery testing, 555
blower motor, 656
cruise (speed) control, 636
cruise control, 659
electrical, guide for, 491–492
electronic dash instruments, 642
heated rear window defogger, 663
horn system, 647, 656
intermittent electrical problems, 491
keyless entry, 672
navigation system, 639
power seats, 667–668
power windows, 665–666
red brake fault warning light, 636
starting system, 572
step-by-step procedure, 492
windshield washers, 656
windshield wipers, 652, 656
WOW dash display, 642
Troubleshooting plan, 31
Troxler effect, 619
Truing, 300
Trunk light, 607

Trunnions, 1496
TSB (technical service bulletins), 1449
TSBs (technical service bulletins), 78, 122
  flat-rate time included, 122
TSP (total suspended particulate), 168
Tube-nut wrenches, 68
Tuftriding, 366
Tumble combustion, 890
  diagram, 890
Turbine, 1551
Turbine fuel pump, 866
  cutaway view, 867
Turbine wheel, 231
  diagram, 231
  expanding exhaust gases, 231
Turbocharged diesels, 166
  variable, 167
Turbocharged engines, MAP sensor calibration, 834
Turbocharger, 151, 230–232
  air filters, 220
  failures, 234–235
  heat energy use, 231
  liquid-cooled, 232
  operation, 231–232
  pressurizing air, 229
  size and response time, 232
  Toyota, 228
  turbine wheel and impeller wheel, 231–232
  two are better, 234
  volumetric efficiency, 228
Turbocharger failures
  preventing, 235
  symptoms, 234–235
Turbochargers, separator systems, 943
Turbo lag, 232
Turning, 1175
Turning radius, 1424
Turning torque, 1529
Turn signals, 610–611
  bulb trade numbers, 606
  combination turn signal and hazard warning flasher, 611
  one-filament stop/turn bulbs, 610
  operation, 610
  schematic, 610
  switch cutaway view, 610
Turns ratio, 505, 783
TV (thickness variation), 1167
Tweeters, 704
Twin I-beams, 1299
  checking, 1435
  front suspension, 1312
Twist, 286
  connecting rods, 347–348
  cylinder head, 286
  positive/reverse torsional, 344
Twisted pair, 469
  BUS communication, 524
  reducing interference, 529
Two-channel scope, 464
Two-filament stop/turn bulbs, 610
Two-finger trick, 804
Two-flow electronic (TFE) steering, 1397–1398
Two-lobed epitrochoid, 152
Two-material valves, 295
Two-stage airbags, 691
Two-step sensor (narrow band), 848
Two-wire oxygen sensor, 848
TXV (thermostatic expansion valve), 716

U

UART (universal asynchronous receive and transmit), 527–528
UART-based protocol (UBP), 530
UBP module communications, 530
UCO fuel, 780
U diagnostic trouble codes, 530
U-joints (universal joints), 5, 6, 70, 1496–1497
  1350 series, 1498
  diagnosis, 1508–1509
  inclinometer, 1508
  inspection, 1504–1505
  “relieving,” 1507
  replacement, 1506–1507
  retaining methods, 1505
  snap ring, 1506
  steering column, 1358–1363
  stub shaft, 1361
  synthetic retainer removal, 1507
  working angles, 1497–1498, 1508
ULEV (ULEV I, ultra-low-emission vehicle), 127
ULEV (ultra low emission vehicle), 919
ULEV II (ultra-low-emission vehicle), 127
ULEV II (ultra low emission vehicle), 919
ULSD, 778–779
Ultra-low-sulfur diesel (ULSD) fuel, 778–779
  pump decal for, 780
Ultrasonic cleaning, 275
  fuel injectors, 275
Ultrasonic Karman Vortex air flow sensors, 842
Ultrasonic sensors in bumper
  location, 641
  three wires, 641
Umbrella valve stem seal, 308
  installation, 309
UNC (Unified National Coarse), 58
Underground coal gasification (UCG), 776
Underground storage tanks (UST), 51
Underhood light
  bulb trade numbers, 607
  checking for common power source/ground, 487–488
Understeer, 1233, 1274
Under-the-dash courtesy lights, 617
Under-vehicle visual inspection, 145, 1380
UNF (Unified National Fine), 58
Unibody, 3, 1290
Unified National Coarse (UNC), 58
Unified National Fine (UNF), 58
Unison ring, 167
Unit-body (unibody), 1290
Unit-body construction, 3
Unitized bodies, 92
Universal coolant, 177
Universal drive cycle, 961
Universal joints. *See* U-joints (universal joints)
Universal joints (U-joints), 6, 70
Unplug it test, 844
Unshrouding, 284
  intake valve, 284
Unsprung weight, 1257, 1290
Up and down vibration, 1276
Up-integrated ignition, 793
Upper and lower intake manifolds, 222–223
Urea, 171
  injection, 171
Used cooking oil (UCO) as fuel, 780
Used oil, 50–51
Used parts, 30
Used vehicles sales person, 14
UST (underground storage tanks), 51
Utility knives, 75
UTQGS (Uniform Tire Quality Grading System), 1250

V

V-6 engine
  60-degree crankshafts, 369
  90-degree crankshafts, 369
  90-degree engine balance shafts, 372
  90-degree splayed crankshaft design, 369
  burning oil, 944
  false rich signal, 849
  grouped fuel injectors, 905
  major thrust side, 341
  waste-spark ignition wiring diagram, 789
V-8 engine
  coolant flow, 189
  crankshaft types, 367
  cubic inch displacement chart, 155
  main bearing studs, 390
  major thrust side, 341
  oil pump problems, 408
Vacuum, 1196
  air pressure related, 833
  diagram of process, 833
  MAP sensor DTC, 838
  measuring, 1196–1197
  principles of, 1196–1197
Vacuum-biased fuel-pressure regulator, 880–881
Vacuum bleeding, 1064–1065
Vacuum booster disassembly and service, 1203
Vacuum booster leak test, 1202
Vacuum booster operation test, 1202
Vacuum booster theory, 1197–1198
Vacuum brake booster
  principle of pressure differential, 1198
  typical assembly, 1196
Vacuum brake booster operation, 1199–1201
Vacuum brake booster pushrod gauging tool, 1203
Vacuum check valves, 1199
Vacuum control circuits, 733
  diagram, 734
Vacuum failure mode, 1200–1201
Vacuum gauge
  MAP sensor as, 836
  micron, 749, 750
  testing back pressure, 248
  testing back pressure with, 952–953
Vacuum hose
  checking, 838
  pressure levels, 900
Vacuum leaks, ETC system, 897
Vacuum lock, fuel tanking venting, 862
Vacuum modulator valve, 1578
  defective, signs, 1594, 1596
  testing, 1596
Vacuum pump
  diesel engine-driven, 166
  electrically powered, 1197
  hand operated, 838
  for pressure regulator diagnosis, 900
Vacuum-referenced fuel-system regulator, 871
Vacuum servo, 1147
Vacuum solenoids, duty cycle, 817
Vacuum system diagrams, in service manuals, 74, 75
Vacuum tests, 245–247
  cranking vacuum test, 246
  fluctuating vacuum, 246
  idle vacuum test, 246
  low and steady vacuum, 246
Vacuum tube fluorescent (VTF), 633
Valance ring, 509
Valence ring, 422
Valve (camshaft) overlap, 324
  calculating, 324–325
Valve adjustment step by step, 257–260
Valve body, 1576–1577
  being tested, 1607
  cardboard trick, 1601
  checks, 1601, 1606–1607
Valve cam phaser (VCP), 332
Valve clearance (lash), 296
  adjusting, 298
  adjustments (installation), 401
  HLA, 323
  pedestal-mounted rocker arms, 321
  valve opening at zero, 323
  valve seat recession, 298
Valve clearance, specification calculations, 115
Valve cover gaskets, RCM gaskets, 384
Valve duration, 282
Valve face, 294
  resurfacing angle, 302
Valve face angle, 301
Valve face grinding
  margin, 301
  purpose and function, 300–301
Valve fault diagnosis
  carbon deposits, 296
  excessive temperatures, 296
  high-velocity seating, 297
  poor valve seating, 296
  valve seat erosion, 297
Valve float, 298
  hydraulic lifter, 327
Valve grinders
  operation, 301
  procedure, 301
  resurfacing face, 301
  tip square with stem, 320
Valve grinding compound trick, 79
Valve guide, 289–291, 294
  cutaway view, 102
  integral, 289
  measuring, 290
  measuring instruments, 290
  measuring valve guides, 290
  oversize valve stems, 290–291
  replacement, 291
  types, 289
  valve-to-stem guide clearance, 290
  wear on, 289
Valve guide knurling, 290
  sectional view, 291
Valve guide pilots, types, 303
Valve guide replacement
  purpose, 291
  recommended procedure, 291
  spiral bronze insert bushings, 292
  valve guide inserts, 291
  valve guide sizes, 291
Valve job, 262
  grinding for more power, 301
Valve keepers (locks), 294, 299
Valve lash (valve train clearance), 327
  adjusting shims, 401
  adjustment, 406
Valve leakage, repair options, 262
Valve lifter, removal procedure, 329
Valve location design, 4–5
Valve materials, alloys, 294–295
Valve noise diagnosis, 328
Valve opening designs, 323
Valve overlap, 282
Valve pockets, 339
Valve reconditioning procedure, 300
Valve regulated lead-acid battery (VRLA), 542
Valve reliefs
  newer engines, 339
  recesses for valve clearance, 339
  view, 339
Valve removal procedure, 294
Valve rotators, 299–300
Valves
  adjustable, 321
  bent, 319
  bleeder, 1061
    loosening, 1062–1063
  clicking, 240
  combination, 1048
  control, 1210–1211
  distance around (formula), 282
  dropping a valve, 297
  flow-control, 1390, 1393–1396, 1396
  height-sensing proportioning, 1045–1046
  impact breakage, 297
  measuring open space, 282
  metering, 1046–1048, 1066–1067
  nonadjustable, 321
  opening areas, 283
  parts identified, 294
  pressure-relief, 1391
  proportioning, 1043–1046
  pulling and, 1048
  reconditioning procedure, 300
  residual check, 1041
  rotary control, 1392–1393
  safety, 320
  seats and guides, 281
  solenoid, 1210–1211
  spool, 1398
  sucking a valve, 297
  swallowing a valve, 297
  vacuum check, 1199
  valve stem height, 307
Valve seal materials, 309
Valve seat, 294
  acceptable widths, 305
  angles and width, 301–302
  excessive wear, 297
  insert seats, 296
  installation step by step, 311–313
  integral seats, 296
  poor, 296
  recession, 298
  removal methods, 306
  replacement, 306–307
  testing, 305–306
  types, 306
  typical wear, 296
Valve seat concentricity, 304
Valve seat cutters, 305
  grinding stone compared, 305
  rotation clockwise, 305
Valve seat erosion, 297
Valve seat grinding stones
  dressing, 304
  grinding procedure, 304
  types, 304
  valve seat cutters compared, 305
Valve seating
  excessive wear, 297
  poor, 296
  typical wear, 296
Valve seat inserts, 289, 305
  aluminum cylinder heads, 289
Valve seat installation step by step, 311–313
Valve seat recession, 296
  performance, 298
  symptoms, 298
  valve clearance (lash), 298
Valve seat reconditioning, 301–303
  angles, 301–302
  interference angle, 302
  purpose and function, 301
  three-angle valve job, 302
  width, 302
Valve seat replacement
  insert seal removal methods, 306
  integral valve seats, 306–307
  purpose, 305
  types of valve seats, 306
Valve seat testing
  methods, 305–306
  purpose, 305
Valve shrouding, 281
  intake mixture, 282
Valve size relationships, intake valves, 294
Valve spring, 294
  Chevrolet V-8 rebuilt, 391
  held in place, 298
  operation, 298
  purpose and function, 297
  spring materials and design, 298
  squareness checks, 299
  types, 298
  typical related components, 294
  valve spring inspection, 299
  variable rate springs, 299
Valve spring bind (coil bind), 320
Valve spring compressor, 268
  installing the valves, 310

Valve spring inserts (VSI), 307
corrected installed height, 307–308
Valve spring keeper, 297
Valve spring scale, 299
Valve spring seat, aluminum cylinder heads, 310
Valve spring surge, 299
Valve spring tester, 299
for same tension, 391
Valve stem height, 307
measuring, 307
Valve stem seals
engine vacuum, 308
materials, 309
overhead valve (OHV), 308
parts from known manufacturer, 309
purpose and function, 308
types, 388–389
VSI (valve spring inserts), 307
Valve stem-to-guide clearance, 289
aluminum cylinder heads, 289
dial indicator, 290
oil consumption excessive, 289
Valve timing, diagram, 326
Valve train assembly
bleeding hydraulic lifters, 405
disassembly, 285–286
hydraulic lifter adjustment, 406
hydraulic valve lift installation, 405
lubrication, 328–329
OHV engine lifter and pushrod installation, 405–406
solid lifter adjustment, 406
timing chains and gear installation, 405
timing drives for OHC, 404–405
trial assembly, 391
Valve train clearance (valve lash), 327
Valve train disassembly, 285–286
labeling pushrods, 286
Valve train friction, 326
Valve train geometry, 405
Valve train lubrication, 216–217
Valve train problem diagnosis
symptoms, 328
symptoms for valve seat recession, 298
valve noise diagnosis, 328
Vane airflow (VAF) sensor, 840
with cover removed, 840
cutaway view, 840
DTCs, 844
Vane phaser system, 332
magnetically controlled vane phaser, 332–333
moving camshaft, 333
OHC engines, 332
Vane pump, power steering, 1390
Van Karman, Theodore, 841
Vapor, 713
temperature, pressure, and volume, 713
Vapor cleaning, 275
Vapor lock, 757
fuel lines, 862
fuel tank layout, 864
Vapor purging, 928
Vapor vent lines, 863
Variable, 117
Variable brake proportioning system, 1020
Variable-cam timing, 330–334
reasons for varying (chart), 331
Variable-delay wipers, 649
Variable displacement (air conditioning) compressor, 728
V-5, 729
Variable displacement pump, 1570
positions shown, 1571
Variable-effort steering (VES), 1396–1399
Variable force solenoids (VFS), 1570
Variable fuel sensor, 768
location of, 769
Variable orifice, 1391
Variable pitch springs, 299
Variable-position actuators, 732
Variable-rate air springs, 1350–1351
Variable rate springs, 299
Variable ratio, 1364
Variable-ratio steering gear, 1364
Variable resistors, 427
Variable speed fuel pumps, 868–869
Variable turbocharger, 167
Variable valve timing, 330–334
cam-in-block engine cam phaser, 334
magnetically controlled vane phaser, 332–333
OHV, 331–332
operation, 330–331
spline phaser system, 332
operation, 332
vane phaser system, 332
Variable valve timing (VVT), 331
varying positions, 331
Variable valve timing and lift electronic control (VTEC), 334
Honda mockup, 334
VATS security system, 679
V-belts, 139
tension range chart, 140
water spray trick, 140
V-blocks, checking starter drive, 570–571
VCP (valve cam phaser), 332
VECI (vehicle emissions control information), 126
label, 121
Vegetable oil, as fuel, 780
"Vehicle," as preferable term, 28
Vehicle communication interface module (VCIM), 640
Vehicle creep, 1555
Vehicle emissions control information (VECI), 126
label, 121
Vehicle hoists, 92–94, 95–96
Vehicle identification, 126
for Flex Fuel vehicles, 769
Vehicle identification number (VIN), 11, 126
how to read, 771
ordering engine parts, 385
Vehicles
front and rear of, 125
left and right side, 125
Vehicle safety certification label, 126
Vehicle service history records, 71, 120
Vehicle speed (VS) sensor
computer input sensor, 816
cruise control, 659
GPS system, 639
smart airbags, 693
Vehicle speed (VS) sensors, 1234, 1346
Vehicle stability, 1209
Vehicle stability control (VSC) system, 627
Vehicle stability enhancement system (VSES), 1346, 1352
Vented brake rotors, 1122
directional vane, 1165
Vented rotors, 1164
Ventilation system, typical settings, 732
Venting, 1035
Vent ports, 1032
Vent valve, 234
Vernier dial caliper, 102
diagram, 102
VES (variable-effort steering), 1396–1399
V-FFV (virtual flexible fuel vehicle), 771
VI (viscosity index), 198
Vibration, 1167
diagnosis, 1592
power brakes, 1207
primary and secondary, 371
up and down, 1276
Vibration damage, counterweights, 369
Vibration damper, 267
installation, 407
removal with puller, 267
Vibration problem, engine mounts design and location, 368
Vibratory cleaning, 275
VIN (vehicle identification number), 11, 126
ordering engine parts, 385
Vinyl gloves, 41
Virtual flexible fuel vehicle (V-FFV), 771
Viscosity, oil pump capacity and leakage, 214
Viscosity index (VI), 198
SAE rating on oil filler cap, 199
wrong oil viscosity, 200
Viscosity index (VI) improver, 201
polymer view, 201
Viscous coupling, 1521
cutaway view, 1536
FWD, 1536
interior shown, 1536
location, 1542
Vise, bench vises, 85
Vise Grips, 1446
Vise Grips®, 74
Visual inspection
ABS, 1221–1222
accessory drive belt, 589
A/C leak detection, 744
backing plates, 1104
backup camera, 640
battery, 545
battery cables, 545
block inspection, 267
brake fluid, 1052
brake springs, 1105
coolant, 136, 179
coolant level and condition, 239–240
cooling system testing, 192–193
crack detection, 276
crankshaft service, 372
disc brake calipers, 1132
disc brakes, 1128–1129
drive belts, 589
driveshaft, 1504–1505
drum brake linings, 1104
drum brake shoes, 1107
EGR testing, 940
electronic fuel-injection problems, 900–901
engine condition diagnosis, 238–240
flood or deep water signs, 1227
fluid leak diagnosis, 1591
front and rear brakes, 1045
front suspension, 1317–1318
fuses, 487
heater hoses, 746
heater problems, 738–739
hose, 1405
HVAC diagnosis, 737
intermittent "check engine" light, 909
leaking intake manifold gasket, 254
light bulbs, 608
locating an open circuit, 487
mass airflow sensors, 842–843
master cylinders, 1038–1039
oil leaks, 239–240
oil level and condition, 239–240
oil pump, 214
optical sensors, 799
oxygen sensor, 850
power steering, 1403
SAI systems, 947
spark plug wires, 799–801
starter brushes, 571
starting problems, 566
stator, 599
steering, 1380–1382
testing ECT sensor, 820
tires, 141, 1259–1260, 1276
U-joints, 1504–1505
under-vehicle, 145
wheel cylinders, 1105–1107
Visual tampering checks, 921
Viton valve stem seals, 309
VOC (volatile organic compound), fuel lines, 864
Voice commands
display, 707
icon on Cadillac, 707
Voice recognition, 706–707
Volatile organic compound (VOC), 864
Volatility
defined, 755
distillation curve, 756
Reid pressure vapor (RVP), 755
related problems, 757
seasonal blending, 756
Volkswagen
oil specifications, 204
rotating shafts, 388, 389
W-8 engine, 424
Volta, Alessandro, 424
Voltage
abbreviations and measurement, 424–425
BUS operation checks, 535
charging voltage test, 588
digital system, 816
electromagnetic induction, 504
locating an open circuit, 487
maximum, 504
producing from magnetism, 504
reading digital meter displays, 452
ripple voltage, 463
short-to-voltage, 430
Voltage conditions, color code for circuit patterns, 484
Voltage drop, 436, 566
as a testing method, 436
definition, 436, 566
determining, 436
diode, 513
ECT measurement with PCM, 820, 821
ECT testing with multimeter, 820
examples, 437
high versus low resistance, 567
Kirchhoff's voltage law, 435–436
parallel circuits, 440–441
proportional to resistance, 436
series-parallel circuit examples, 442–443
used in circuits, 436
Voltage-drop tester, 907
typical, 907
Voltage drop testing, 436, 566–568
battery cable connection, 567
charging system, 591–592
procedure, 591–592
purpose, 566
test procedure, 567–568
voltmeter hookups, 567
Voltage regulator, 583–584
battery as "true," 584
cutaway view, 584
Voltage signals, automotive computers, 813
Voltage spike, electronic component failure, 519–520
Voltage spike control, 486
Voltage stabilizer, 538
Volt, definition, 424
Voltmeters, 425
battery electrical drain test, 553
charging system voltage drop test, 592
described, 447
reading digital meter displays, 453
testing battery voltage, 547
Volts per division (*V/div*), 462
Volume measurements, metric, 98
Volumetric efficiency, 228
as calculated number, 411
turbochargers/superchargers, 228
Volvo, precollision system, 662
Vortex flow, 1554
VRLA (valve regulated lead-acid battery), 542
VSI (valve spring inserts), 307
valve stem seal, 308–309
VS sensor, 1345
VTEC (variable valve timing and lift electronic control), 334
engine oil pressure, 334
Honda mockup, 334
VTF (vacuum tube fluorescent), 633
V-type engine, 4
coolant flow diagram, 189
cylinder arrangement, 149
intake manifold gasket, 407
paired rod journals, 398
two turbochargers for, 234
V-type engines, exhaust gas control, 936

W

"Wait to start" lamp, 165
Wall-guided (swirl) combustion, 890
diagram, 890
Walnut shells, ground, 44
Wander, 1413
Wankel engine, 152
Wankel, Felix Heinrich, 152
Warehouse distributor, 29–30
Warm-up cycle, 960
Warning lamp
coolant temperature warning light, 194, 249
oil (engine) light, 249
oil change, 206
oil pressure, 242
Warning lights, TPMS, 1266
Warning lights on dash. *See* Dash warning lights
Warpage, 286
cylinder head, 265, 286
main bearing bores, 357
valve guide and seat misalignment, 296
Warranties, 8–9
expressed warranties, 8–9
flat-rate pay method, 21
Warranty claims, 16
Washcoat, 949
Washer pump
diagram, 653
installation, 653
service, 653
Washer pump switches, 652
Washers, 62
flat/lock, 62
Waste chart, 54–55
Wastegate, 233
computer-controlled valve, 233
operation, 233
Waste-spark ignition system, 782
Waste-spark ignition systems, 787
adjusting ignition timing, 805
compression-sensing, 788
corroded terminals, 800
dual trace scope pattern, 811
firing order, 805
odds fire straight, 788
operation, 787–788
schematic, 797
scope-testing, 811
typical engine, 788
V-6 wiring diagram, 789
Waste vegetable oil (WVO), 780
Water
as conductor, 423
in diesel fuel warning light, 625
introduction, 178
latent heat of vaporization, 713
phases or states, 712
precautions with lubricating diesel engine, 161
properties, 178
used with coolants, 178
water quality, 178
Water-based chemical cleaning, 274
Water fade, 1089, 1116
Water fire extinguishers, 45
Water-fuel separator, 161
Water jackets, 5

Water on carpet, causes, 738
Water pump, 5
auxiliary electric (HVAC), 715
bearing looseness check procedure, 190
bleed peep hole, 190
coolant movement, 189, 190
corrosion in, 190
cutaway view, 190
gasket removal cautions, 253
installation, 408–409
operation, 189–190
radiator cap, 188
replacement, 253
service, 190
Water pump gaskets, 384
Water pump pliers, 74
Water pump replacement, 253
guidelines, 253
need for, 253
Water spray trick, 140, 195
Waterwheel analogy, 432
Watt
brightness of light bulbs, 432
definition, 432
formula ("pie"), 432–433
Watt, James, 425, 432
Watt's law, 432–433
Watts linkage, 1338
Wavelength, 699
Waxing wheels, 1118
Wax method, 1063
Wax trick, 77, 268
Ways, 1126, 1134
Weak spark condition, ignition system symptom guide, 811
Wear bars, 1240
shown, 1241
Webs, 352
Web site help, 26
Wedge design, 282
Weight, 109
curb, 1290
GVW (gross vehicle weight), 1290
model, 1290
Weight bias, 1023
Weight measurements, metric, 98
Weight transfer, 1023
Welding
crack-welding aluminum, 278
crack-welding cast iron, 277
crankshaft, 374
new technique (flame), 277
Welding cable, 469
Welsh plugs, 393
Wet compression test, 243
Wet cylinder sleeves, 353
thickness, 353
Wet holes, 401
Wet sump, 217
Wet system (N20), 235
Wet weather, brakes, 1110
Wheel, 1254–1256
center section, 1254
JWL symbol, 1256, 1257
offset, 1254
Wheel alignment
adjusting rear camber, 1438–1439
aftermarket methods, 1447
camber, 1414–1416
caster, 1416–1418
centering the steering wheel, 1444
checking angles, 1431
electronic suspension, 1447
five-wheel, 1439
four-wheel, 1426, 1434, 1436–1437
frame, 1434
geometric centerline, 1434
hidden structural damage, 1449
included angle, 1421
maximum/minimum/preferred, 1431
modified vehicles, 1447–1448
plus or minus method, 1431
prealignment checks, 1428–1429
prealignment correction, 1427
procedure, 1450–1452
pull shown, 1413
pull to the right, 1446
questions about angles, 1437
race vehicles, 1443
SAI, 1421
sample specs and readings, 1437–1438
scrub radius, 1422–1424
setback, 1424–1425
setup, 1432–1433
specifications, 1431–1432
specifications vs. alignment readings, 1434
symptoms, 1413–1414
thrust angle, 1425
thrust line, 1436
toe, 1418–1421
tolerance adjustment, 1447
tracking, 1425–1426
troubleshooting list, 1449
turning radius, 1424
Wheel balancers, 1279–1280
Wheelbase, 1290
Wheel bearing adjustment nut, 1078
Wheel bearing looseness test, 1075
Wheel bearing race puller, 1077
Wheel bearings and service, 1070–1086
adjustment, 1078
anti-friction bearings, 1071–1072
bearing failure analysis, 1082–1084
bearing greases, 1072–1074
diagnosis, 1074–1075, 1083
inspection chart, 1076
packing, 1077
real drive axle classifications, 1079
rear axle bearing and seal replacement, 1079–1080
rear axle bearing service, 1085–1086
sealing bearing replacement, 1078
seals, 1074
service, 1075–1078
Wheel brakes, 1017
Wheel cylinder clip tool, 1106
Wheel cylinders, 1090, 1105–1107
exploded view, 1105
service, 1105–1106
Wheel lock key, 142
Wheel lug nuts, 142
second click story, 143
Wheel mounting torque, 142, 1273–1274
Wheel rate, 1294
Wheels
aluminum, 1256
back spacing, 1255
bolt circle measuring, 1256
dragging, 1110
hubcentric, 1281
lug nuts, 1257–1258
mag, 1256
measuring runout, 1276–1277, 1277
replacement, 1281
steel, 1256
stone, 84
waxing, 1118
wire brush, 84
Wheels and tires, overview, 2
Wheel sensor, 1432–1433
Wheel service, wheel mounting torque, 142
Wheel speed sensors (WSS), 451
ABS components, 1212
adjustment, 1228–1229
applications and precautions, 1213
checking gap, 1229
diagnosis, 1227–1228
input, 1210
location, 1213
measuring resistance of, 1228
operation, 1213
quick and easy diagnosis, 1221
schematic, 1213
sensor outputs shown, 1213
service, 1218–1219
tone ring readings, 1228
traction control, 1236
typical, 1228
Wheel studs, 142, 1175
torque chart, 1273
Wheel weight pliers, 1280
Wheel weights, 1279–1280
Whine
alternator, 708
possible causes, 241
Whine noise during cruise, rear end diagnosis, 1525
Whistle stop, 244
White exhaust smoke (steam), 171
blown cylinder head gasket, 238
possible causes, 238
White sidewall/lettered tires, 1241
WHMIS (Workplace Hazardous Materials Information Systems), 49
Wide-band oxygen sensors (O2S)
closed loop, 855
dual cell, 856–857
dual cell planar, 855–856
introduction, 854–855
pattern failures, 859
purpose and function, 855
single cell, 857–858
terminology, 853–854
Wide parting line, 346
Wide-range air-fuel (WRAF) sensor. *See* Wide-band oxygen sensors (O2S)
Wide-range oxygen sensor. *See* Wide-band oxygen sensors (O2S)
Wide-range oxygen sensors (O2S), 855
Windage tray, 217
preventing oil aeration, 217
Wind chill factor, 179
Window regulator, 664
electric motor assembly with, 645
Window tinting, GPS reception and, 638
Windshield washer fluid, 653
fluid reservoir cap, 132
methanol precautions, 132
recommended, 132
summer use, 132
Windshield washers
components, 648–649
diagnosis, 652–653
operation, 652
service, 653
troubleshooting, 656
Windshield wipers, 648
circuit diagram, 648
computer controlled, 648
depressed, 649
diagnosis, 649–650
hidden wipers, 649
interval wiper circuit diagram, 652
motors, 324
park position, 650
pulse wipe systems, 652
purpose and function, 648
rear wipers, 652
service, 131, 651–652
testing, 650–651
three-speed, wiring diagram, 650
troubleshooting, 652–653, 656
two-speed, wiring diagram, 650
variable-delay (pulse) wipers, 649
wiper blade insert replacement, 131, 132
wiper components, 648–649
Winter-blend gasolines, 756
Wiper blade insert replacement, 131, 132
Wiper motor
connector pin chart, 651
cowl panel location, 652
interior view, 649
location, 649
operation, 649
Wire brush wheels, 84
Wire color schematic symbol, 480, 482
Wire crimpers, 80
Wire gauge diameter table, 468
Wire movement, as cause of short circuit, 491
Wire repair, 475–477
methods summarized, 477
Wires
cut/broken, 486
intermittent electrical problems, 491
loose or broken, 487
Wire size, 480
schematic symbols, 480
Wire strippers, 80
Wiring
American wire gauge (AWG), 467
battery cables, 469
braided grounds straps, 468
center wire, 480
definition and terminology, 467
ground wires, 468–469
ignitions system, 149
jumper cables, 469
metric wire gauge, 467
primary wire, 468
routing direction, 500
twisted pair, 469
wiggle test for, 491
Wiring diagrams, in service manuals, 74, 75
Wiring guides, service manuals, 122
Wiring harness, high-voltage spikes, 520
Wiring schematics
center wire, 480
circuit information, 479–480
definition, 479
electrical and electronic symbols, 481
locating an open circuit, 487
meaning of arrows in, 480
in service manuals, 75
symbols, 481–482
terminology, 479
troubleshooting, where to start, 488
wire colors and abbreviations, 480
wire size, 480
Wood alcohol. *See* Methanol (methyl alcohol)
Wood alcohol (methanol), 771
Work, 106
Work (energy principles), 1022
Work, torque compared, 107
Work area marked off, 47
Work experience, for ASE tests, 35
Work habits
hints, 30
starting times and breaks, 31
Work hardened, 1256
Work hardened bearing material, 376
fatigue cracks shown, 377
Working conditions, 11
Work lights, 84
Work order, 11
"ask me about this," 27
checking vehicle for damage, 13
documenting, 28
first day on the job, 27
flagging, 29
reading, 27
typical, 13
work finished by another technician, 32
Workplace Hazardous Materials Information Systems (WHMIS), 49
Work sites, 9–10
World Wide Fuel Charter (WWFC), 763
Worm endplay, 1366
Worm gear, 1363, 1366
Worm holes, 1576
Worm tracks, 1576
Worn shift fork mystery, 1486
WOW dash display, 634
troubleshooting, 642
WRAF (wide-range air-fuel) sensor, 854
Wrenches, 68–69, 82–83
forged, 68
open-end, 1282
size of head, 60
spanner, 1154
tightening, 71
tire valve core torque wrenches, 1268
use of adjustable, 78
Wrench symbol warning lamp, 896
Wrist pins, 337, 340
Wrought alloys, 113
W-shaped crimp, 476
WSS. *See* Wheel speed sensors
WVO (waste vegetable oil), 780
WVO fuel, 780
WWFC (World Wide Fuel Charter), 763
Wye-connected stators, 582–583

X

Xenon headlights, 614–615
bi-xenon headlights, 614
compared to halogen bulbs, 614
XM radio, 707
aftermarket antenna, 708
shark-fin-type antenna, 708

Y

Yaw rate sensors, 1235–1236, 1346–1347
location and schematic, 1237
Yaw sensor, 639
Yellow conduit, 478
Yellow gas cap, 770

Z

ZDDP (zinc dialkyl dithiophosphate, or ZDP), 202
Zener diodes, 511–512
alternator voltage regulation, 584
construction, 511
despiking, 513
operation, 511–512
Zerk fittings, 143, 1372, 1373
Zero camber, 1415
Zero lash, 406
Zero ohms, 448
Zero pressure (ZP) tire, 1252–1253
Zero pressure tire (ZP), 1252
ZEV (zero emissions vehicle), 984
ZEV (zero-emission vehicle), 127
ZEV (zero emission vehicle), 919
ZF Fiedrichshafen AG, 1560
Zirconia oxygen sensors, 846, 847
conventional, reset limits, 854
cross-sectional view, 847
cup-type design, 846, 847
KOEO oxygen sensor test, 851
lean mixture, 847, 848
narrow band, 846
O2S voltage above 450 mV, 848
O2S voltage below 450 mV, 848
platinum electrodes, 846
reset limits, 854
rich mixture, 847, 848
typical view, 847
ZrO2 (zirconium dioxide), 846
Zyglo, 276